32nd International Conference on Digital Printing Technologies (NIP)

Printing for Fabrication 2016

Materials, Applications, and Processes

September 12 – 16, 2016 • Manchester, United Kingdom

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Brian Derby, University of Manchester

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2016 International Symposium on Technologies in Digital Photo Fulfillment
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TECHNICAL PROGRAM, ABSTRACTS, AND USB PROCEEDINGS

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7003 Kilworth Lane
Springfield, VA 22151 USA
703/642-9090; 703/642-9094 fax
info@imaging.org; www.imaging.org

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Table of Contents

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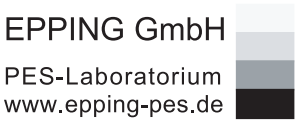

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Printing for Fabrication 2016 Week At-a-Glance

LOCATION LEGEND

- Renold C16
- Renold C2
- Renold C9
- Renold C15
- Renold D7
- Renold F Floor; room on ticket

SPECIAL EVENTS

Welcome Reception
Monday 18:00 – 19:15
Manchester Town Hall

Conference Exhibit
Tuesday 10:00 – 17:45
Wednesday 10:00 – 16:30
Renold C15

Colleague Connections—UK Innovation Landscape
Tuesday 15:20 – 16:30
Renold C9

Demonstration Session and Exhibit Time
Tuesday 16:30 – 17:45
Renold C15 and Enigma Café

Colleague Connections—Late Breaking News/Success Stories
Thursday 10:20 – 11:00
Renold C2

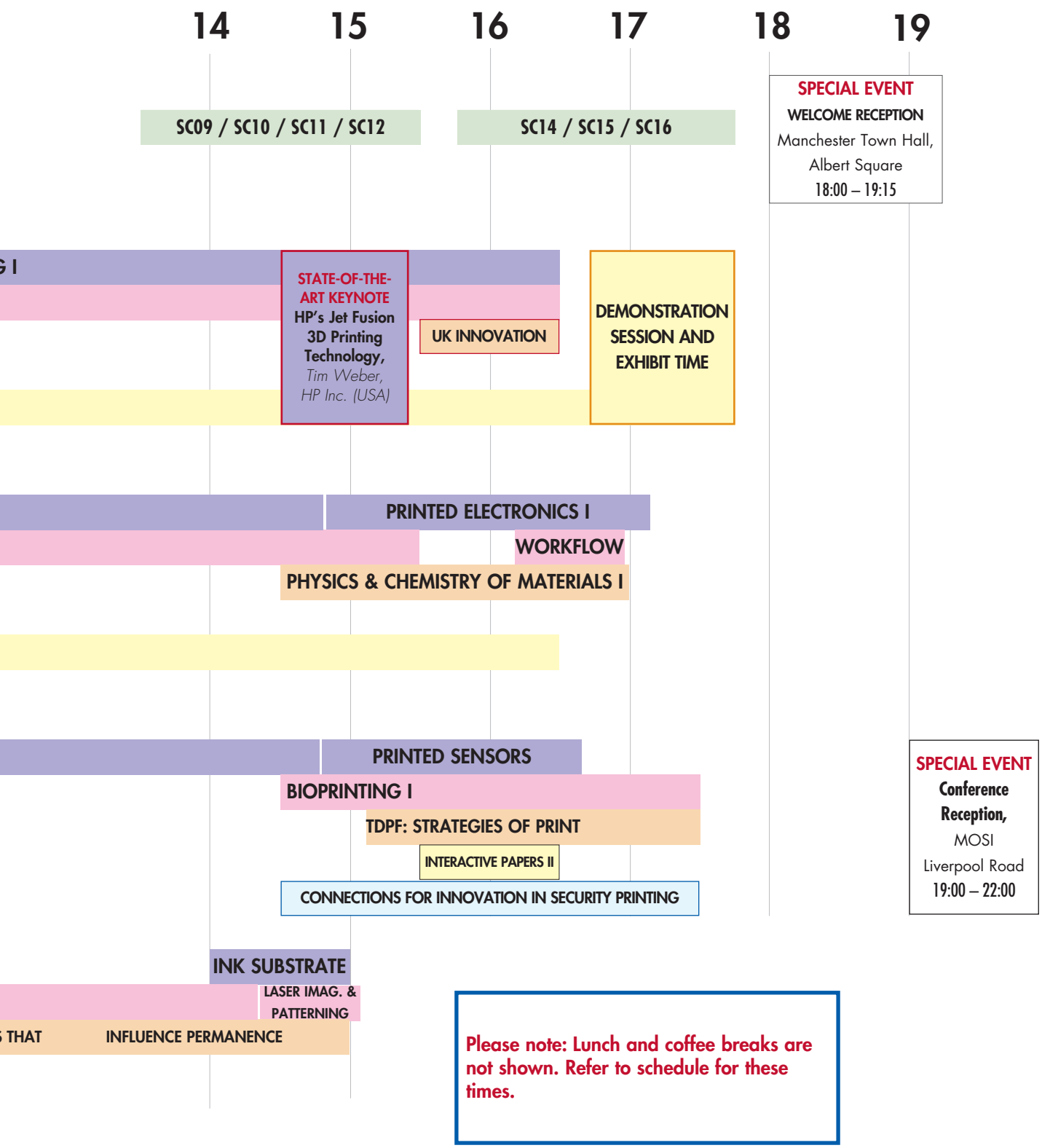
Annual Meeting of Members
Thursday 11:00 – 11:15
Renold D7

Interactive Paper Session I
Thursday 11:00 – 12:00
Renold C15

Colleague Connections—Connections for Innovation in Security Printing Workshop
Thursday 14:30 – 17:30
Renold D7

Interactive Paper Session II
Thursday 15:30 – 16:30
Renold C15

Conference Reception
Thursday 19:00 – 22:00
Museum of Science and Industry (MOSI)
Liverpool Road


14
15
16
17
18
19
SC09 / SC10 / SC11 / SC12
SC14 / SC15 / SC16
SPECIAL EVENT
WELCOME RECEPTION
Manchester Town Hall,
Albert Square
18:00 – 19:15
G I
STATE-OF-THE-ART KEYNOTE
HP's Jet Fusion 3D Printing Technology,
Tim Weber, HP Inc. (USA)
UK INNOVATION
DEMONSTRATION SESSION AND EXHIBIT TIME
PRINTED ELECTRONICS I
WORKFLOW
PHYSICS & CHEMISTRY OF MATERIALS I
PRINTED SENSORS
BIOPRINTING I
TDPF: STRATEGIES OF PRINT
INTERACTIVE PAPERS II
CONNECTIONS FOR INNOVATION IN SECURITY PRINTING
SPECIAL EVENT
Conference Reception,
MOSI
Liverpool Road
19:00 – 22:00
INK SUBSTRATE
LASER IMAG. & PATTERNING
S THAT
INFLUENCE PERMANENCE
Please note: Lunch and coffee breaks are not shown. Refer to schedule for these times.

Technical Papers Program: Schedule and Contents*

SPECIAL EVENT

WELCOME RECEPTION

Monday, September 12th
18:00 – 19:15
Manchester Town Hall
Albert Square

Kick off the conference by joining colleagues on Monday before heading to dinner

TUESDAY SEPTEMBER 13, 2016

KEYNOTE AND INVITED TALKS FOR ALL TRACKS ALL DAYS

Renold C16

TUESDAY, SEPTEMBER 13

Opening Ceremony and Keynote

Session Chair: Brian Derby, University of Manchester

9:00 – 10:10

9:00 **Materials in the Flatland,** *Kostya S. Novoselov, University of Manchester (UK)* 1

When one writes by a pencil, thin flakes of graphite are left on a surface. Some of them are only one atom thick and can be viewed as individual atomic planes cleaved away from the bulk. Such one atom thick crystals of graphite (dubbed graphene) turned out to be the strongest crystals available to us, the most conductive, most thermally conductive, most elastic, flexible, transparent material, etc, etc, etc. Its electronic properties are particularly exciting: its quasiparticles are governed by the Dirac equation so that charge carriers in graphene mimic relativistic particles with zero rest mass.

Still, probably the most important "property" of graphene is that it has opened a floodgate of experiments on many other 2D atomic crystals: BN, NbSe2, TaS2, MoS22, etc. The resulting pool of 2D crystals is huge, and they cover a massive range of properties: from the most insulating to the most conductive, from the strongest to the softest.

If 2D materials provide a large range of different properties, sandwich structures made up of 2, 3, 4 … different layers of such materials can offer even greater scope. Since these 2D-based heterostructures can be tailored with atomic precision and individual layers of very different character can be combined together, the properties of these structures can be tuned to study novel physical phenomena or to fit an enormous range of possible applications, with the functionality of heterostructure stacks is "embedded" in their design.

State-of-the-Art Invited Talk: 3D Printing

Session Chair: James Stasiak, HP Inc.

14:30 – 15:20

14:30 **HP's Jet Fusion 3D Printing Technology—Enabling the Next Industrial Revolution,**
Tim Weber, HP Inc. (USA) 2

In 2014 Hewlett-Packard announced the development and commercialization of an innovative 3D printing technology that promised to set new standards for performance, quality, reliability and low TCO. HP's Multi Jet Fusion™ (MJF) technology achieves its breakthrough performance by leveraging the company's 30+ year history of innovation and market leadership in imaging and digital printing. This presentation will provide an introduction to a new-to-the-world digital fabrication technology that makes it possible to design and print three-dimensional objects that possess both precise geometric and functional characteristics. The MJF technology will radically change the way engineers and designers prototype and produce functional parts and the blending of HP's MJF 3D printing technology with digital materials design creates a new fabrication paradigm – a paradigm that enables innovation in both form and function.

*Please note: Page numbers listed after paper titles refer to the page on which a paper is found in the full proceedings book found digitally on the USB stick that accompanies this book.

WEDNESDAY, SEPTEMBER 14

Wednesday Keynote

Session Chair: Brian Derby, University of Manchester

9:00 – 10:00

Over recent years there has been tremendous progress in developing low-temperature processible organic and oxide semiconductors that can be processed by solution-based printing techniques and provide high charge carrier mobilities for both n-type and p-type field-effect transistor operation, good operational stability and other functionalities such as efficient electroluminescence, sensing or memory functions. In this talk I will discuss the basic device and charge transport physics of organic and oxide transistors, review manufacturing approaches and assess their performance in light of a range of applications in displays and integrated systems.

THURSDAY, SEPTEMBER 15

Thursday Keynote and IS&T Awards

Session Chair:

9:00 – 10:10

Technology Research Association for Future Additive Manufacturing (TRAFAM) was established in 2014 to achieve the development of innovative additive manufacturing systems to meet the world's highest standards and the development of manufacturing technologies for high value-added products. In this presentation, the current status of the TRAFAM project is introduced.

FRIDAY, SEPTEMBER 16

Friday Keynote

Session Chair: James Stasiak, HP Inc.

9:00 – 10:00

Within tissue engineering and regenerative medicine, Biofabrication is a young and dynamically evolving field of research. It aims at the automated generation of hierarchical tissue-like structures from cells and materials through Bioprinting or Bioassembly. This approach has the potential to overcome a number of classical challenges relating to organization, personalized shape and mechanical integrity of generated constructs.

Although this has allowed achieving some remarkable successes, it has recently become evident that the lack of variety in printable hydrogel systems is one major drawback for the complete field. In order to be suitable for Biofabrication, hydrogels have to comply with a number of prerequisites with regards to rheological behavior and especially stabilization of the printed structure instantly after printing, while at the same time allowing the cells to proliferate. Also fabrication techniques are often not ideal and need to be optimized for the printing of anatomical structures.

This lecture will briefly introduce the field and the major printing techniques, as well as the most important demands on materials and fabrication techniques. It will then introduce a new method for the rational design of thermoplast fibre constructs by the combination of melt electrospinning with automated movement of the collector (Melt electrospinning writing). This technique allows for the generation of highly regular fibrous constructs with pore sizes in cellular dimensions and fibre diameters down to submicrometer. Printing of anatomical structures that would not be accessible otherwise will be demonstrated at one example. The lecture will then focus on printable hydrogels. Thiolene cross-linking of poly(glycidyl-co-allylglycidylether) based 3D plotted hydrogels will be introduced as alternative to the often used free radical polymerization to stabilize printed hydrogel structures with high resolution and reproducibility. Furthermore, a purely physically cross-linked system based on recombinant spider silk proteins will be introduced, in which beta-sheet interactions facilitate good printability and stability of the constructs.

SPECIAL EVENT

2016 EXHIBIT

Tuesday
10:00 – 17:45

Wednesday
10:00 – 16:00 PM

Renold C15

Visit this year's exhibitors, see page ii.

TUESDAY SEPTEMBER 13, 2016

DIGITAL FABRICATION AND 3D PRINTING TRACK

9:00 – 10:10 Opening Ceremony and Keynote, Renold C16, see page vi.

Exhibit Open: 10:00 – 17:45, Renold C15

Renold C16

3D Printing and Additive Manufacturing I

Session Chairs: Shinri Sakai, University of Tokyo; Adam Ellis, University of Sheffield; and Mike Regan, HP Inc.

10:20 – 16:30

10:20 **Material Jetting 3D Printing Process by Thermal Inkjet Head,** *Oh Hyun Baek, Keon Kuk, and Eun-Bong Han, Samsung Electronics Co., Ltd. (Korea)* 6

A new type of 3D printing process is introduced. The printing mechanism is based on material jetting process by inkjet-printing head to eject and deposit a photopolymer ink as the 3D object building material. The existing material jetting 3D printer adopted multi nozzle piezo-electrical print head. The piezo ink jet head requires complicated head structure, ink supply and maintenance system. The printing area should be large because of wide area of printing head and it causes that the 3D printing machine should be large and expensive for a commercial purpose only. In this study, Thermal ink jet head is applied to the print head for 3D printing process. The thermal head has low cost and compact printing mechanism but it is hard to apply photo polymer ink of material jetting process for jetting fluid because the thermal ink jet head fires the ink droplet by boiling mechanism. The specific building material for jetting in thermal head is applied and a 3D printing process is investigated for stable ejection and deposition on the substrate for building 3D object. The droplet volume of print head is under 20 pico-litters and ejection frequency is 2 kHz and the thickness of single layer deposited for building object is more than 10 micro-meters. The 3D printing system is fabricated and the hollow cylindrical object with high aspect ratio is successfully built and printing process is verified.

10:40 **Finishing Processes of Fused Deposition Modeling (FDM) 3D Printer,** *Kensuke Takagishi and Shinjiro Umezu, Waseda University (Japan)* 10

3D printer is expected to spread currently. This paper describes the processing method of modifying the FDM printed products. We get the characteristics of each of the processing by evaluation using the time and surface roughness.

11:00 **Three Dimensional Inkjet Fabrication of Nano-Composite Hydrogel,** *Yoshihiro Norikane, Hiroshi Iwata, Takashi Matsumura, Hiroyuki Naitoh, and Tatsuya Niimi, Ricoh Co., Ltd. (Japan)* . . . 14

We have developed the direct inkjet 3D fabrication system which can vary mechanical strength of nano-composite hydrogels on demand. The object body contains various parts which have gradual strength, colors and other physical properties. In addition, over-hanging and hollow structures were successfully obtained by using support material. It can be said that the hydrogel 3D fabrication system is able to construct a fine objects having partially controlled mechanical strength. Those objects have a potential of adding a unique value into the medical 3D model, and other applications.

The methodology of hydrogel fabrication and the properties of the hydrogel object are discussed, and the blood vessel model and the hollow vascular model were prepared for surgical training application.

11:20 – 11:50 Coffee Break — in the Exhibit Hall — Renold C15

11:50 **Newly Developed Printing Technologies for 3D Printed Electronics (Focal),** *Shizuo Tokito, Yasunori Yoshida, and Konami Izumi, Yamagata University (Japan)* 18

We report on two newly developed patterning methods for three-dimensional (3D) printed electronics applications, which are known as soft blanket gravure (SBG) and omnidirectional inkjet (OIJ) printing technologies. These technologies make it possible to print various inks directly onto non-flat or 3D object surfaces, and have a capability that could enable new electronic applications and markets.

12:20 **Inkjet Printing and the Steady State Macroscopic Mechanical Energy Balance (SSMMEB) Equation,** *Steven J. Simske, HP Inc. (USA)* 21

The author is a co-author on a Wiley book under preparation entitled the *"Handbook of Industrial Inkjet"* (chief editor Werner Zapka). One area of relevant new content in this book is in surface manufacturing, which refers to the customization of a finished product – usually a manufactured good – by using printing and/or printing-like processes. Surface manufacturing is a form of additive manufacturing in which there is a template in the form of a partially finished object upon which to use as a surface for the (usually product-finishing) custom manufacturing. There are four major types of inkjetting that can be considered for a role in surface manufacturing. After describing these,

we then consider their use in surface manufacturing in light of the Steady State Macroscopic Mechanical Energy Balance (SSMMEB) Equation. Some approaches to designing for variability are then discussed.

12:40 **Implementation of the Four-Flux Model for Spectral and Color Prediction of 2.5D Prints,** *Théo Phan Van Song,[1,2] Christine Andraud,[2] and Maria V. Ortiz Segovia[1]; [1]Oce Print Logic Technologies SA and [2]MNHN (France)* 26

Optical models to predict visual appearance of 2D prints are relatively well-known. Two-flux models, such as the Kubelka-Munk (KM) theory, are the most commonly used and offer good prediction rates. However, most two-flux models assume that the ink layer and the printing support have the same optical indices neglecting their wavelength dependency. An improvement of such constraint would be to include detailed optical indices of the inks in current models. In this paper we compute optical indices of our inks by printing ink stacks of different thicknesses on a transparent support for reflectance and transmittance measurements. Since KM-based models work under limited conditions, we input our computed indices into a more robust model. By taking additional fluxes into account, one can address the limitations of the two-flux approaches. For instance, the four-flux model considers two collimated and two diffuse fluxes propagating upward and downward the layer stack offering better reflectance and transmittance predictions especially when translucent materials are involved. Our four-flux theory including inks optical indices enables us to make spectral predictions of 2.5D prints without any preliminary measurements. The model is fairly accurate with primary colorants since the ΔE94 values do not exceed 1 unit.

13:00 – 14:30 Lunch Break (on own)

14:30 – 15:20 State-of-the-Art Invited Talk: 3D Printing
Renold C16, see page vi.

concurrent event

15:20 – 16:30 Colleague Connections: Overview of the UK Innovation Landscape
see details on page xv, Renold C9

15:30 **Development of Inks Suitable for the Manufacturing of Micro-Scale Polyurethane Foams,** *Fabian Schuster,[1,2] Tobia Goetz,[1,2] Thomas Hirth,[3] Achim Weber,[1,2] and Monika Bach[1,2]; [1]Institute of Interfacial Process Engineering and Plasma Technology, [2]Fraunhofer Institute for Interfacial Engineering and Biotechnology, and [3]Karlsruhe Institute of Technology (Germany)* 31

We herein present the development of inkjet inks that have the capability of producing micro-scale polyurethane foams. Inkjet technology can be used as an additive manufacturing tool using small amounts of liquids to form a desired structure. Furthermore, in situ chemical reactions can be carried out using this particular printing technique. In order to achieve suitable printing inks, viscosity properties were taken as the key limiting factor choosing the ink components. Poly(ethylene glycol) 200 was selected as the main polyol for the reactive inks. Glycerol ethoxylate, also known as star-PEG, was selected as the crosslinking agent due to its three primary hydroxyl groups as well as its good compatibility with PEG200. Variation in star-PEG content was investigated by means of rheometric and tensiometric measurements. For the reactive isocyanate compound, 1,6-hexamethylene diisocyanate (HDI) was chosen due to its high reactivity and low viscosity.

Polyurethane foams (PUF) were prepared in bulk to validate the foam recipe. Small droplets of the inks were then tested by manually placing two drops on top of each other. It was shown that in the absence of mechanical mixing the gelling and blowing reaction still take place. Furthermore, catalytic influences on the reactions were investigated using a central composite experimental design combined with FTIR-ATR spectroscopy. In order to evaluate the spectra, a deconvolution of the Amid I and Amid II area was conducted. The results were evaluated using an analysis of variance to gain models.

15:50 **On-Demand-Like FDM 3D Printhead Consideration,** *Hideo Taniguchi, Nobuhisa Ishida, and Jiro Oi, HIT Research Corporation (USA)* 37

HIT Research Corp, the research and development arm of HIT Devices Ltd., has been studying the feasibility of utilizing the patented on-demand and temperature-controllable heating device for various applications. One field identified and focused has been the fast growing three dimensional (3D) printing technology. There are several different methods of 3D printing, but the technology compatible with our device and also most widely used process is known as Fused Deposition Modelling (FDM).

An FDM 3D printer uses a thermoplastic filament, which is heated to its melting point by a heating device and then extruded through a small hole, layer by layer, to create a three dimensional object. The traditional 3D extruder (or printhead as we refer to) heating section has a discrete heating element and temperature sensor which makes it large and bulky. We integrated them on a single ceramic substrate so it will be more efficient, compact, lighter and easier to maneuver for the three dimensional head movement.

SPECIAL EVENT

DEMONSTRATION SESSION, EXHIBIT TIME, AND COFFEE BREAK

Tuesday, 16:30 – 17:45
Renold C15 and Enigma Café

Meet with authors display hardware, software, and objects related to their talks; talk with exhibitors abut their products and services, and connect with colleagues to wrap up the day.

Unlike many existing printheads which incorporate a substantial size cooling fan or some cooling devices in order to bleed off the excess heat which is not used for melting the material, the excess heat of the new heating head is minimal and cooling requirement is substantially reduced.

The most significant benefit for the new configuration is the ability to be made into a multi-nozzle line-type printhead due to the size and thermal efficiency. This will be left for the future report, the preliminary study indicates that there will be a serious impact on the process time when it becomes an actual product.

16:10 **3D High Viscosity Jetting of Functional Materials,** *Javier Ledesma-Fernandez, Christopher Tuck, and Richard Hague, University of Nottingham (UK)* 41

Inkjet printing is one of the most suitable technologies to produce multi-material and multi-layered printed electronics due to its scalability, the wide range of substrates that it can accept and the possibility of mixing and combining numerous fluids in a single process. However, restrictions in material properties such as viscosity, typically below 25 mPa·s, limit the molecular weight of usable polymers and the solid content of inks. In some cases, this leads to volumetric shrinkage, longer post-process treatments and poor performance. Therefore, a high viscosity approach would widen the material catalogue for printed electronics without compromising the advantages of inkjet.

In this work, drop-on-demand micro-dispensing valves that combine mechanic and pneumatic actuation were used to create 2D patterns and 3D structures of a conductive and non-Newtonian carbon paint. The combination of this functional material with a non-conductive photo-curable resin allowed the creation of more complex 3D geometries using the layer-by-layer approach typical from Additive Manufacturing. Printing parameters such as pneumatic pressure, valve closing speed, resolution and drying time are studied and optimised to produce multi-layered tracks, self-standing pillars and a functional demonstrator featuring a printed capacitive switch and an embedded commercial LED.

16:30 **Advancements in Inkjet Technology for Materials Deposition and Manufacturing (Interactive),** *Scott D. Liniger and William Buskirk, ImTech Technologies LLC (USA)* 48

Ink jet technology continues to advance, providing greater opportunities for research, prototyping, and manufacturing. 3D printing continues to evolve, enabling advancements in market segments from medical devices to industrial components. This presentation will provide an overview of the capabilities today's ink jet technologies provide, as well as where this technology is headed. We will target multi-head systems and their uses for research, prototyping, and manufacturing. We will look at some of the current uses of printhead technology for development, research, and manufacturing.

16:35 **Depth Feeling Dependence on Array Condition of Objects (Interactive),** *Yasushi Hoshino, Daiki Hanasaka, and Nobuji Tetsutani, Tokyo Denki University, and Aran Hansuebsai, Chulalongkorn University (Japan)* 52

Depth feeling is important in image quality and expression. Depth feeling is influenced by various factors such as linear perspective, size, overlapping, shade, aerial perspective and so on. Linear perspective is known as a powerful technique for expressing depth on flat surface. But the effect of linear perspective to depth feeling is not yet understood well. In this paper, images of simple object of arrayed sphere are generated by computer graphics method and the depth feeling is subjectively estimated. It is found that the arrayed spheres on two converging lines generate depth feeling.

16:40 – 17:45 Demonstration Session, Exhibit Time, and Coffee Break

Renold C15

DIGITAL PRINTING TECHNOLOGIES TRACK

9:00 – 10:10 Opening Ceremony and Keynote, Renold C16, see page vi.

Exhibit Open: 10:00 – 17:45, Renold C15

Renold C2

Inkjet-Based Processes I

Session Chairs: Mineo Kaneko, Canon Inc.; Werner Zapka, Xaar; and Ross Mills, Vexajet Corporation

10:20 – 16:30

Session sponsored by

10:20 **Evaluation Method of Inkjet First Drop Dissimilarity,** *Kye-Si Kwon and Hyung-Seok Kim, Soonchunhyang University (Korea)* 56

Drop-on-demand inkjet printing has been used as a manufacturing tool for printed electronics, and it has several advantages since a droplet of an exact amount can be deposited on an exact location. Such technology requires positioning the inkjet head on the printing location without jetting, so a jetting pause (non-jetting) idle time is required. Nevertheless, the behavior of the first few drops after the non-jetting pause time is well known to be possibly different from that which occurs in the steady state. The abnormal behavior of the first few drops may result in serious problems regarding printing quality. Therefore, a proper evaluation of a first-droplet failure has become important for the inkjet industry. To this end, in this study we propose the use of a high-speed camera to evaluate first-drop dissimilarity. For this purpose, the image acquisition frame rate was determined to be an integer multiple of the jetting frequency, and in this manner, we can directly compare the droplet locations of each drop in order to characterize the first-drop dissimilarity.

10:40 **Measurement of Inkjet Printhead Reliability by Detecting Every Single Droplet in Flight (Focal),** *Ingo Reinhold,[1] Tomáš Cerný,[2] Maik Müller,[1] and Werner Zapka[1]; [1]XaarJet AB (Sweden) and [2]Xaar plc (UK)* 60

Inkjet printing is adapted for many digital imaging systems including graphical, industrial and advanced manufacturing applications. Reliability was identified to be one of the key challenges for inkjet printheads due to their susceptibility to variations in temperature, ink consistency, debris or external vibration. Hence, lengthy tests with printouts on kilometers of papers are necessary to establish a measure of reliability, which is time-consuming and extends the development cycle for a given application.

In this contribution a line-scan camera is used to observe all droplets from a printhead row in flight at full jetting frequency. This allows for the identification of missing droplets as a function of the printed image, external disturbances as well as the drive waveforms used and other print parameters. This provides a quantitative measurement not only of reliability but also of deviations in droplet velocity and trajectory in a laboratory environment. The paper discusses the necessary hard- and software approaches and details the necessity for various image transformations due to the challenges imposed by the illumination. Furthermore, we will present experimental data as well as speed benchmarks.

11:10 **Titanium Oxo-alkoxide Clusters as a New Source Material for High Quality TiO2 Structures by Inkjet Printing (Interactive),** *Josh Turner,[1,2] Danielle Mehta,[1,2] Helen C. Aspinall,[1] Simon Rushworth,[2] and Kate Black[1]; [1]University of Liverpool and [2]EpiValence (UK)* 64

Inkjet printing offers an attractive route for the manufacture of metal oxide films and allows a low-cost, environmentally friendly route to manufacture. Here we describe a stabilised process for the printing of TiO_2 films. This has been achieved through the use of a range of titanium (IV) ink solutions, employing stabilised $Ti(O^iPr)_4$ or titanium oxo-alkoxide clusters as the source materials. Printed tracks with feature sizes of 156µm have been achieved, along with more complex architectures of TiO_2. XRD analyses shows that the as deposited TiO_2 is amorphous.

11:15 **Reproduction of HDR Image on Paper Medium Using Inkjet Printer (Interactive),** *Xiaozhou Li, Yang Zhao, and Jingqiang Jia, Qilu University of Technology, and Jingjing Liu, Shandong University of Art & Design (China)* 68

Display is the main low dynamic range media to represent HDR image. A lot of tone information and detail information can't be perceived when we use the conventional paper medium to reproduce HDR image because of the disadvantages of low dynamic range and small gamut of paper medium. However, Inkjet printing which is taken as the advanced and new method to reproduce the image has several advantages of larger gamut, higher dynamic as opposed to conventional printing. Inkjet printing was used to reproduce HDR image in view of the advantages in

this paper. The process and characteristics of HDR image represented on paper medium using inkjet printing technique were studied. The tone properties of HDR image and inkjet printing paper were studied and the correlated curves were plotted to show the properties. We took several HDR images as the original images. Inkjet printing was the main method to present HDR image in this study. We developed two digital workflows using Cannon iPF8410s inkjet printer and HP Z6200 inkjet printer. And the color management was also used to guarantee the reproduction quality of digital printing process. The tone of HDR image was partitioned into three parts according to the human vision perception mechanism. The tone of paper medium was got from the process of digital printing workflow. The tone of paper medium was compared with the several tone partitioned from the HDR image. And the compared results were used to build the correlation between the HDR image tone and paper medium tone. Finally a multilevel tone partition system with correlated gamut methods was developed. The mechanism and method developed would help to solve the problems existing methods. The theory and technique foundation will also be promoted in such thesis.

11:20 – 11:50 Coffee Break — in the Exhibit Hall — Renold C15

11:50 **Interaction of Sequential Pulsed Electrohydrodynamic Jets for Drop-on-Demand Printing (Focal),** *Ching-Hsien Chen, Graham D. Martin, and Ian M. Hutchings, University of Cambridge (UK).* 71

A method is demonstrated for studying hydrodynamic effects in pulsed electrohydrodynamic (EHD) jetting, for the drop-on-demand printing of small droplets. The transient behaviour of pulsed EHD jets and the deposition of liquid on to a substrate were investigated by using an ultra-high speed camera (Shimadzu HPV-1) with a Newtonian aqueous liquid (water-glycerol). Time-resolved images of jets induced by two consecutive voltage pulses, with different time delays, were captured. Image analysis was used to determine the jet length, meniscus radius at the nozzle, and deposit volume in each case and revealed that the behaviour of an EHD jet depends strongly on the delay time after a previous ejection event. The effect originates in the time taken for the meniscus shape and position to recover to their equilibrium values and plays a critical role in the design of printing strategies for EHD drop-on-demand applications. It is possible that the maximum printing frequency achievable by pulsed EHD jetting can be increased by optimizing the drive waveform in order to accelerate recovery of the meniscus position.

12:20 **Development of New Aqueous Resin Ink for Sign Graphics,** *Masahiro Kido, Naohiro Toda, Tomohiro Nakagawa, Hidefumi Nagashima, Juichi Furukawa, Noriaki Okada, and Hikaru Kobayashi, Ricoh Co., Ltd. (Japan).* 75

An aqueous resin ink was developed which can offer excellent image qualities on non-permeating media such as plastic media with an inkjet printer. The print speed with this aqueous resin ink reaches the level of solvent-inks diffused as inks for non-permeating media for sign graphic, i.e., at least 30m2/h. In order to increase the print speed, it is important that the ink has good compatibility to the coating layer of non-permeating media. It was found that kinds of solvents added to the ink were highly related to the compatibility. Furthermore, such solvents have a particular feature in common. Solvents with specific range of fractional parameter have high coating layer-solving ability. To show validity of this mechanism, a new method for evaluation of ink fixation was developed. With this new method, it was proved that higher concentration of coating-layer-solving solvent gave ink faster fixation onto the non-permeating media. Furthermore, we also discovered that the characteristics of the pigment dispersion element in an ink formula greatly affected the discharging reliability.

12:40 **Breakthroughs Required in Piezo-on-Demand Inkjets for Production Printing: Satellite Drops, Ink Penetration, and Evaporation,** *Naoki Morita, Toshinobu Hamazaki, Toshinori Ishiyama, Yukari Motosugi, and Susumu Hirakata, Fuji Xerox Co., Ltd. (Japan)* 79

A high-speed digital production printer using an aqueous piezo-on-demand inkjet is considered in terms of its high-speed applicability to electrophotography, which also enables digital printing. Further enhancement of the printing speed and improvement in the image quality will require control of the satellite drops that are generated during ink jetting. Further versatility is necessary for use of paper types that require printing without ink penetration, and as a result, the reliability of moisture evaporation in ink becomes increasingly important.

13:00 – 14:30 Lunch Break (on own)

14:30 – 15:20 State-of-the-Art Invited Talk: 3D Printing
Renold C16, see page vi.

concurrent event
15:20 – 16:30 Colleague Connections: Overview of the UK Innovation Landscape
see details on page xv, Renold C9

15:30 **Influence of Z Number and Pulse Voltage on Drop-on-Demand Inkjet Printability,** *Yuanyuan Liu and Brian Derby, University of Manchester (UK)* 83

Inkjet printing has been applied in manufacturing structural and functional materials for decades. There are two kind of methods known as continuous inkjet (CIJ) printing and drop-on-demand (DOD) inkjet printing. In DOD inkjet printing, drops are generated only when a drop needed by producing a pressure pulse in a chamber filled with inks. And before drop generation, the inkjet printing head will be moved to the desired location to locate the drop in a precise position. DOD inkjet printing is a method that directly places materials on demand, which saves the required raw materials and reduces the printing steps. As a consequence, DOD inkjet printing saves more time with lower waste consumption during production than CIJ printing and the equipment has a smaller footprint.

DOD inkjet printing can be divided into two methods by which the pressure pulse is generated followed by drop ejection: thermal DOD inkjet printing and piezoelectric DOD inkjet printing. In piezoelectric DOD inkjet printing, the pressure pulse is produced by the mechanical actuation of the chamber walls. When a voltage is applied, the piezoelectric material changes shape, which generates a pressure pulse in the fluid forcing a droplet of ink from the nozzle. It is important to know the inkjet printable range to generate accurate and repeatable drops. Fromm had defined ink printability in drop on demand (DOD) printing using a dimensionless Z number which related to the physical properties of the inks. However, it is still not agreed whether there is a precise Z number range for inkjet printability and not known whether the range varies using different actuating pulses.

The goal of our study is to find out the detail relationship between the ink properties and Drop-on-Demand inkjet printing printability and explore whether the printable Z number range change with actuating pulses and different kind of printheads.

Here we investigate the influence of Z number and pulse voltage on printability using two inkjet printheads (10 pl Dimatix and 80 µm MicroFab). We have used 10 model inks made from solvent mixtures of ethylene glycol, diethylene glycol and distilled water. A range of actuating pulse voltages has also been studied. We found that the printable Z number range changes with the pulse voltages applied on inkjet printing. When increasing pulse voltage to print the same ink, it becomes printable under low pulse voltage and flying slow in the air and then printing well until at a certain voltage satellites forms and more satellites form when further increasing the pulse voltage. We also found that the printable voltage range is slightly different among inks with $Z > 8$. Under higher pulse voltages, it is possible to get single droplets with $Z < 4$, but inks with $Z > 4$ are printed out with some satellites. However, accurate and stable drops without satellites could be formed using inks of $Z > 4$ under lower voltages and it is not printable for inks of $Z < 4$ when printed under lower pulse voltages. These results could give an explanation of the different Z number range shown in different researches published when they using different printheads and pulse voltages.

15:50 **Laser Drying Technology Applied to Improvement of Density Variation on Offset-Coated Paper,** *Takuma Ishihara, Akira Sakamoto, Satoshi Hasebe, Takeshi Zengo, Yukari Motoaugi, and Toshinobu Hamazaki, Fuji Xerox Co., Ltd. (Japan)* 85

High-speed inkjet printing system is growing in recent years. Laser-drying technology can dry inks in a very short time (~100ms). This technology has advantages of applicability for various paper types and suppressing paper deformation because heating is focused on an ink without heating a paper. Furthermore, this technology can control occurrence of density variation due to migration and flow of an ink on offset-coated paper by rapid drying. Exposure condition of laser was optimized using high speed camera and drying mechanism was discussed by comparing simulation and actual observations.

16:10 **Application of Antibacterial Coatings on Resin Composite Implant Materials Using Inkjet Printing Technology,** *Henrika Wickström,[1] Annette Anthoni,[1] Mirja Palo,[1] Johan O. Nyman,[1] Anni Määttänen,[1] Mari Nurmi,[1] Niko Moritz,[2] Terhi Oja,[1] Maren Preis,[1] and Niklas Sandler[1]; [1]Åbo Akademi University and [2]University of Turku (Finland)* 89

Fiber-reinforced composite (FRC) implants have shown to be a favorable option as an implant material, compared to titanium, in terms of biocompatibility and mechanical properties. Furthermore, application of antibacterial coatings onto these implant material have been presented as a viable strategy to prevent biofilm formation. The purpose of this study was to analyse the biofilm prevention effect on gentamicin coated fiber-reinforced composite implants, by means of inkjet technology, when exposed to Staphylococcus aureus ATCC 25923 bacteria. Scanning white light interferometry and scanning electron microscopy were used to characterize the surface texture and surface roughness of the pure and printed implant material and titanium (control) specimens. Quantification of the deposited gentamicin amount was performed using a colorimetric assay. Statistically significant biofilm inhibition was seen for the gentamicin coated resin specimens and a more than 100-fold reduction in viable cells was determined. It was concluded that piezoelectric inkjet technology could be a viable technology to precisely deposit anti-biofilm coatings onto implant materials. The presented work is based on results of a master's thesis by Anthoni et al., 2016 conducted at Åbo Akademi University.

16:30 – 17:45 Demonstration Session, Exhibit Time, and Coffee Break

Renold C15

SPECIAL EVENT

COLLEAGUE CONNECTIONS: OVERVIEW OF THE UK INNOVATION LANDSCAPE

Tuesday, 15:20 – 16:30

Renold C9

Learn about what is happening in the UK regarding funding and partnerships; see page xv for details.

MATERIALS, METHODS AND PERFORMANCE TRACK

9:00 – 10:10 Opening Ceremony and Keynote, Renold C16, see page vi.

Exhibit Open: 10:00 – 17:45, Renold C15

Renold C9

Metrology Tools for Digital Printing Processes

Session Chairs: Yumiko Kishi, Ricoh Co., Ltd.; David Stüwe, Notion Systems GmbH; and Paul Best, ImageXpert, Inc.

10:20 – 12:40

10:20 **JIST-First Paper Measurement of Inkjet Drop Volume—The Role of Image Processing,** *Graham D. Martin, William C. Price, and Ian M. Hutchings, University of Cambridge (UK)* 94

The measurement of the volumes of small .10–100 µm/ liquid drops is important in a number of fields including inkjet printing, liquid dispensing and spraying. This article explores the use of synthetic, constructed images, representing shapes with precisely known volumes, and real photographic images of inkjet drops to compare a number of image processing methods designed to estimate drop volume. The synthetic images were generated with a range of sizes, background gray levels and degrees of blur and noise. The image processing methods were chosen to represent a range of approaches, some very simple and some more complex. A comparison of the results from these methods shows that they responded differently to various image features. The process described in this article could be used to compare other existing or new processing methods, and the results should be valuable in the development of standard methods for drop measurement.

10:40 **Development of a Small Built-in Spectrophotometric Sensor for Color Printers (Focal),** *Shun-ichi Ebihara, Masayasu Teramura, Tomohisa Itagaki, and Tatsuya Kobayashi, Canon Inc. (Japan)* . . . 103

A key requirement on color printers is maintaining accurate color reproduction in output images. Reproducing the same colors more precisely on the same printer or between different printers requires a color calibration process involving precise measurement of the output sheet's chromaticity and subsequent chromaticity adjustments. This sort of color calibration has conventionally been a complicated offline process, involving placing and measuring the output sheet in a standalone colorimeter and then editing and adjusting print data based on the colorimetric data. Usability improvement and space saving in this process have been needed. And with the growth seen in the digital color press market in recent years, expectation for the inclusion of more accurate colorimetric sensors and more sophisticated automatic color matching are increasing. In response, we developed a spectrophotometric sensor with excellent colorimetric precision that is small enough to fit inside a color printer. In this paper, we report on the optical technology that was a key to reducing the size of spectrophotometric sensor and examples of applications using the digital press device, imagePRESS C10000VP, which makes use of the developed sensor.

11:10 **A New Out-of-Gamut Determination Method of Image based on Irregular Segmentation (Interactive),** *Maohai Lin and Yin Zhang, Qilu University of Technology (China)* 107

The out-of-gamut determination of images is very important for color gamut mapping which plays an important role in crossmedia color reproduction. In this paper, aiming to achieve an accurate out-of-gamut determination of image and exploit the full potential of the reproduction device gamut, we propose an out-of-gamut determination method of images based on irregular segmentation which divides the color gamut into several parts according to the chroma and lightness of colors in CIELAB color space. First, the device color gamut is divided into the high-chroma and the low-chroma color parts, and the high-chroma parts are divided into more segments through the CIELAB a*b* plane when calculating color gamut descriptors. Then, in each segment the radiuses between the color points and the center point are calculated. For the color points located in the high-chroma parts, the color point with the biggest radius is selected as the gamut boundary descriptor, and for that in the low-chroma parts, if the corresponding outer segments are empty, the color point with the biggest radius is selected as the gamut boundary descriptor. Through the irregular segmentation of gamut, the GBDs distribute more uniformly among the color gamut surface than segment maximum method which treats all colors in the same way wherever they are located in the gamut. After that, determination of the out-of-gamut colors can be done by calculating the position relationship between the source colors and the GBDs. Additionally, GMAs would benefit from this accurate out-of-gamut determination of image. GMAs based on this out-of-gamut determination method validate the promising results.

11:15 – 11:50 Coffee Break — in the Exhibit Hall — Renold C15

11:50 **Basic Study on Evaluation Method of Thermal Conduction through Printing Papers Using 1-Dimentional Thermal Conductivity Measurement (Focal),** *T. Fukue,[1] H. Terao,[2] K. Hirose,[1] Y. Sasaki,[1] T. Wauke,[2] H. Hoshino,[2] T. Tomimura,[3] and Y. Koito[3]; [1]Iwate University, [2]ALPS Electric Co., Ltd, and [3]Kumamoto University (Japan)* 112

This study targets to develop a 1-dimensional evaluation method of thermal conduction process around printing papers in DTP (Direct Thermal Printing) process. Our special attention was paid to investigate an evaluation method of thermal conductivity and contact thermal resistance of the printing papers. The evaluation of thermal conductivity of the printing papers is generally difficult because thermal conductivity of the papers is small like insulation. In addition, contact thermal resistance between the thermal head and the papers cannot be measured directly. Therefore, in this report, the clarification of the level of the thermal conductivity and the contact thermal resistance were targeted by using 1-dimensional thermal conductivity measurement system.

From the measurement of the equivalent thermal conductivity, the level of the difference of the thermal conductivity and the contact resistance of the paper was investigated. In addition, the optimum pressing pressure of the platen roller in order to minimize thermal contact resistance is clarified.

12:20 **Study on Visibility of Density Unevenness in Printed Images Affected by Characteristics in Input Images,** *Natsuko Minegishi, Konica Minolta, Inc., and Keiji Uchikawa, Tokyo Institute of Technology (Japan)* 116

Visibility of density unevenness area appeared on printed images varies depending on some characteristics of input images. We focused on Saliency and Spatial frequency of tone distribution as those characteristics to clarify a mechanism for perceiving image noise.

In this study, we performed examinations for detecting density unevenness area. Shapes of the density unevenness are circle and belt-like. As results, we found that specific spatial frequency components in original tone distribution, which is similar to that of the density unevenness, correlated with the visibility of density unevenness. Trends between statistic values of saliency and visibility of density unevenness showed different depending on the polarity of density change. We could not clarify factors of this phenomenon. Finally, those statistic values of saliency which we studied were not proved as parameters affecting to visibility of density unevenness. All correlations for belt-like density unevenness were weaker than in case of circle. Some impacts of their size or continuity were supposed.

12:40 – 14:30 Lunch Break (on own)

14:30 – 15:20 State-of-the-Art Invited Talk: 3D Printing
Renold C16, see page vi.

Colleague Connections: Overview of the UK Innovation Landscape

Session Chair: TBA

15:20 – 16:30

As this conference is in the UK this year, a session has been devoted to an overview of the UK innovation landscape. This could be particularly valuable to those from outside the UK looking for collaborations or to do business here. It could also be useful for students to gain an understanding of the funding landscape. This is an opportunity to hear a series of short presentations giving a perspective from the following key players:

- The Knowledge Centre for Materials Chemistry
- The UK Knowledge Transfer Network (KTN)
- The University of Manchester

16:30 – 17:45 Demonstration Session, Exhibit Time, and Coffee Break
Renold C15

WEDNESDAY SEPTEMBER 14, 2016

DIGITAL FABRICATION AND 3D PRINTING TRACK

9:00 – 10:00 Wednesday Keynote, Renold C16, see page vii.

Exhibit Open: 10:00 – 16:10, Renold C15

Renold C16

3D Printing and Additive Manufacturing II

Session Chairs: Masahiko Fujii, Fujii Xerox Co., Ltd.; Fritz Bircher, University of Applied Sciences Western Switzerland; and Mike Regan, HP Inc.

10:10 – 14:50

10:10 **Fine Particulate and Chemical Emissions from Desktop 3D Printers,** *Rodney Weber, Qian Zhang, and Jenny Pui Shan Wong, Georgia Institute of Technology; Aika Davis and Marilyn Black, Underwriters Laboratories, Inc. (USA)* 121

Fused deposition modeling (FDM) printers, the more common type of desktop 3D printers, emit volatile gases and particulates that may deteriorate indoor air quality. The developed method for characterizing and quantifying emissions from an operating 3D printer measures fine particulate and volatile organic compound (VOC) concentrations over time using an environment controlled testing chamber.

All tested printers emitted ultrafine particulates (UFP). Approximately 70% of the particulates released from the printers were less than 50 nm in diameter. Emitted UFPs increased in size over time by coagulating with other particles and condensation of printer-generated vapors. Chemical compositions of the released gases varied depending on the filament material. Volatile chemicals such as styrene and ethylbenzene were released from acrylonitrile butadiene styrene (ABS) filament. Caprolactam, originating from a nylon filament, was a predominant released gas. Though polylactic acid (PLA) filament is thought to be safer since it is biodegradable, PLA still released chemicals such as methyl methacrylate. Acetaldehyde and formaldehyde were released from all the studied filaments. ABS emitted more particles than PLA or nylon filaments.

The extrusion nozzle temperature on the printer had the greatest effect on both particles and VOC emissions; the emissions increased as the temperature of the nozzle increased. Depending on the maker of the filaments, the total particle number emissions varied by a factor of 20. Filament colors had minor effects on emissions compared to other parameters studied.

10:30 **Intensive 3D Structure Modeling and Seamless Data Flow to 3D Printers Using Voxel-based Data Format FAV (Fabricatable Voxel),** *Tomonari Takahashi,[1] Atsushi Masumori,[2] Masahiko Fujii,[1] and Hiroya Tanaka[2]; [1]Fuji Xerox Co., Ltd. and [2]Keio University (Japan)* 124

We released a specification of a new voxel-based data format "FAV" (fabricatable voxel) in July, 2016. 3D model data of FAV format is comprised of a voxel which is a three dimensional picture cell. This representation differs from a mesh-based data format like an AMF, 3MF which are recently proposed or STL which has been used as the 'de facto' standard so far. In addition, we are proposing to more effectively utilize abilities of current 3D printers using a fabricatable voxel which is retaining optimized information to be used for fabrication. Utilizing a FAV format, we can realize modeling a 3D model data not only surface but also internal structure and various attributes such as materials to use, full-color information, connection intensity for each voxel, and so on. Furthermore, it can utilize several processes such as design (CAD) and simulation (CAE) mutually and seamlessly without data conversion from FAV format.

In this paper, we introduce a framework of FAV format and structures that FAV can represent. You can design as you like, in detail, regardless of the inside or outside, intensively and minutely using a FAV format. Moreover, FAV format can concurrently maintain three dimensional complicated information of shape and attributes. Accordingly, it is available to be applied to various image processing like a three dimensional half-toning, and to enhance expressiveness of 3D printers.

10:50 **Polymer Spray Deposition: A Novel Aerosol based Electrostatic Digital Deposition System for Additive Manufacturing,** *David M. Johnson, Victor Beck, Michael Valente, Armin Völkel, Norine Chang, Arun Jose, Cory Lancaster, Dave Biegelsen, and Scott Elrod, PARC (USA)* 129

In order to address some of the shortcomings from traditional additive manufacturing methods, PARC, a Xerox Company, is developing a new additive manufacturing method for polymers that uses electrostatic patterning in combination with a new method of creating aerosols to directly pattern a wide range of thermoplastics with high resolution. Our aerosol technology takes advantage of the non-Newtonian nature of polymers to create monodisperse small droplets. In addition, we leverage ionographic printing techniques to pattern thick substrates and create digital thin films. This technology can bring 3D printing of polymers into a performance range where the technology can be used to replace more traditional techniques such as injection molding and machining.

11:10 – 11:50 Coffee Break — in the Exhibit Hall — Renold C15

11:50 **The Impact of 3D Printing on US Copyright and Trademarks (Focal),** *Scott M. Slomowitz, Gary A. Greene, and Nicholas M. Tinari, Caesar Rivise, PC (USA)* 134

The ubiquitous use of additive manufacturing (and subtractive manufacturing), better known as "3D Printing" has forced intellectual property (IP) owners to re-evaluate the various types of well-known IP protections available to them, namely, patents, copyrights, trademarks and trade secrets. In one aspect, by shifting the act of "manufacturing" or "making" of a product from a conventional industrial manufacturer to a consumer, the IP holder must determine which, if any, of the traditional IP protections are worth the investment. Acts which have been the signature of infringement, both patent and copyright, have been the making, using and selling of an IP protected product. But if the entity that is doing any of those acts by printing an IP-protected product is a consumer, the IP owner may not be able to recover any significant damages from that single consumer or consumers who actually print (i.e., "make") the product. IP owners must look to see if there are any remedy(ies) in suing the vendors who sell the software files provided to the consumer that are loaded into their 3D printers. From a trademark aspect, where a trademark identifies the source of goods or services in commerce, IP owners need to be concerned about those they license to 3D-print their products; for example, will the end product have the same quality as when the IP owner actually produced the product, since the IP owner's trademark will appear on that printed product? With regard to copyrights, IP owners need to consider that although photographs have copyright the moment they are created, does software of optically scanned 3D objects have the same benefit?

This paper will survey the impact of 3D printing on copyright and trademark issues and how such IP protections can be, or not be, enforceable to provide value to an IP owner.

12:20 **Estimation of High Speed Sintered Nylon-12 Tensile Strength Using Visible Reflectance Spectroscopy,** *Farhana Norazman and Patrick Smith, University of Sheffield, and Neil Hopkinson, Xaar plc (UK)* 137

Additive Manufacturing (AM) refers to a class of manufacturing processes which produces three dimensional objects directly from 3D model data. A range of AM processes, such as fused deposition modelling and laser sintering are deemed slow compared to injection moulding, as they depend on point-to-point consolidation. In order to progress into high speed manufacturing, a novel process called the High Speed Sintering (HSS) process is currently being developed at the University of Sheffield.

HSS is a powder bed fusion process which employs an inkjet print head to print a cross sectional image of an object in radiation absorbing material (RAM) onto a powder build bed. The build bed is subsequently exposed to infrared radiation to promote selective sintering of RAM coated powder, leaving the surrounding powder to act as a support. Consolidation is obtained by adding a new layer of powder in between printing successive images to form a 3D object. The HSS process uses Nylon-12 as its standard material, and is suitable to use with a range of polymer powder, especially thermoplastics. An overview of the HSS process with its key components is illustrated in Figure 1.

Previous research on HSS has focused on assessing the effect of infrared lamp level, the addition of flow agent and the greyscale value on the mechanical properties of parts. Few studies have been performed on non-destructive characterisation of polymer parts, either by using Differential Scanning Calorimetry (DSC) or NIR spectroscopy for laser sintered parts and rubber parts. This project aims to propose a non-destructive method to estimate the tensile properties of HSS Nylon-12 parts. Previous research based on the "greyscale level" suggested a correlation between the input ink dithering level during sintering process and the resultant parts tensile properties, however this method is not widely applicable across all inkjet print heads due to the difference in specifications. Spectroscopy method has never been used to assess parts made by the high speed sintering process and is advantageous as it quantifies an output grey level.

In this contribution, an overview of the HSS processing of Nylon-12 powder will be provided. Reflectance spectroscopy will be performed on manufactured parts and the results compared with actual tensile tests. The correlation between HSS Nylon-12 parts reflectance values and their corresponding ultimate tensile strength values will be presented.

12:40 **Spinal Bracing for the Future,** *Kathryn Downey, Iain Stalker, and Brian Derby, University of Manchester, and Abby Paterson, Loughborough University (UK)* 138

Several chronic and degenerative illnesses utilize spinal braces to support and correct spinal curvature and gait. Spinal braces are designed to use counter point pressure, putting force in the opposite direction to the unwanted spinal curve in an attempt to counteract the progression of the deviation. Typically this is undertaken during adolescence while the spine is still growing. During teenage years wearing a brace can add additional burden to what is often a challenging period in a young person's life. The key issues contributing to the tolerance of wear include comfort, aesthetics and fit. This research looks at the feasibility of using an additive manufactured (AM) and computer aided design (CAD) approach for the design and fabrication of spinal braces. The aim of the study is to use a digital design workflow that combines existing bracing principles with user specific input in order to create individualized braces.

13:00 – 14:30 Lunch Break (on own)

A new binder jetting process for fabricating metal or ceramic parts has been developed by using coated powder and inkjet technique. In this study, we have developed metal and ceramic particles coated with 100 nanometer thickness of water soluble resin in conjunction with a new concept of ink which includes cross linking agent that acts on the coated resin but does not include any binding ingredients. In this paper, we present a methodology of our new binder jetting process and an overview of mechanical and physical properties of 316L stainless steel parts created by our process.

Printed Electronics I

Session Chairs: Koei Suzuki, Ricoh Co., Ltd.; Patrick Smith, University of Sheffield; and Dinesh Tyagi, Lexmark International, Inc.

14:50 – 17:10

Offset litho printing offers a useful fabrication method for Printed Electronics. It is capable of high speed printing and there is a large installed base of presses on a variety of scales. Paper in various forms offers an interesting substrate for systems integration of Printed Electronics features. It is widely available at attractive prices, compatible with many existing industrial processes and has the potential to add interesting features to functional print. Conductive features are a key element that enable the fabrication of Printed Electronics. The purpose of this paper is to explore some of the key issues arising from the printing of conductive features onto paper using a standard factory litho press. The whole ethos for this work was to use standard equipment and substrates commonly found in a litho print house and explore the issues that this implementation entails.

As a result the paper substrates chosen are those commonly in use for commercial litho printing, the press was an unmodified unit taken straight from commercial print runs and no specific drying protocols were instigated over and above the commercial print industry standard of stacking prints on the factory floor. As such it serves to illustrate the sort of features that could be produced in any commercial litho printing hall.

Passive Direct Methanol Fuel Cells (DMFC) are stand-alone power sources that consist of anode and cathode sandwiched between electrodes. Typically the catalyst layer consists of carbon, platinum and ruthenium particles. Platinum and ruthenium are the catalysts and carbon particles provide electrical conductivity. The catalyst and proton-conducting Nafion can be formulated into a printable ink. We present experiments for formulation of inkjet printable stable inks containing the catalyst and Nafion solution. When printed on suitable substrates the inks can provide layers suitable to be used as a part of membrane electrode assemblies (MEAs) of a DMFC device. Two formulations have been successfully manufactured and inkjet printed with laboratory scale printheads: a water based ink and a solvent based ink. The water based ink was compatible with also industrial scale printheads thus providing possibility for process upscaling. However, the solvent based ink is considered to have more potential in DMFC devices since it requires no surfactant that might interfere with the electrochemical reactions.

With the development of technologies in printed electronics, the products are more low cost and convenient. Nowadays, technologies have solved many problems such as performance, functional inks, printing technology, substrate, etc. The focus is how to design the best efficient circus that suit the Electroluminescent (EL) displays. This study attempts to tell the important ways on designing circus with multiple layers products, to help optimize ways to build a printed circuit.

15:35 – 16:10 Coffee Break — in the Exhibit Hall — Renold C15

The research examines the printing of passive electrical circuit elements, specifically of printed switches. In the introduction, the functional printing and printed electronics are defined, and the composition and functioning of printed switches are explained. The aim of the research was to create printed switches of different sizes and shapes with screen printing, and to explore the optimal conditions for their operation.

In the experimental part, two types of switches were developed, namely with sensors based on two electrodes (electrical capacitor) and sensors based on a single electrode. Various forms of sensors were designed and printed on printing materials (special paper for printed electronic, recycled paper and foil) with functional conductive ink and the screen-printing technology.

Printed sensors were varnished and laminated. On each of them, measurements were performed and the influence of various factors was evaluated, i.e. the shape and size of capacitors/electrodes, printing material, air moisture, varnishing and laminating. Finally, the functionality of sensors was analysed and the sensors were applied onto a packaging as switches for turning on an LED light.

The current method for organic optoelectronic device fabrication, small molecule-based organic light emitting diode (OLED) for example, is vacuum-thermal deposition using a shadow mask to locally pattern the individual layers. For relatively small devices such as cell phones, tablets, and small displays these techniques work very well. However, shadow mask technology cannot provide the required uniformity over the large areas required for large displays. Additionally the vacuum-thermal process is expensive and wasteful. Thus, fabrication processes other than thermal evaporation are required. For several years there has been a large effort in developing solution printing processes. However there is still not a commercial solution printing process. Materials limitations have been a barrier; but the ink-jet process has thus far been unable to deliver the required display quality. In particular pixel uniformity has been problematic.

We have developed a novel method of manufacturing OLED display devices by digital printing techniques. The light-emitting layer is produced in four steps:

1) A polymerizable/crosslink-able dopant emitter-receiving base layer is coated over a pre-coated hole-transporting layer. This layer has a glass transition temperature (Tg) below 80°C. 2) A digital printing technique, such as ink-jet, is used to pattern emitter dopants on the surface of the light-emitting base layer. 3) The coated layers are heated to a temperature below 80°C to diffuse the patterned dopant emitters into the base emitter layer to form the light-emitting pixels. 4) The organic light emitting layer is then subjected to actinic light to crosslink/polymerize the layer and improve its thermal properties.

This process eliminates the need for a shadow mask, provides efficient dopant diffusion at relatively low temperature and restores layer thermal properties for excellent device stability.

In this paper we demonstrate the feasibility of this novel process. An "ink", using Coumarin-6 as the emitting dye, was formulated with low boiling solvents and loaded into the ink cartridge of an Epson C88 ink-jet printer. The dopant ink solvent is chosen to be a non-solvent for the polymerizable/crosslink-able dopant emitter-receiving base layer. The base layer was a dope formulation of molaicular™ AMBI-1206, a bipolar host material dissolved in acetone containing a photosensitizer and a plasticizing cross-linking agent. The dope was blade-coated on an aluminized substrate, using a 1 mil knife and dried on the coating block at 50°C. The coated layer was ~2 microns. The aluminized substrate/base layer was fed through the Epson C88 ink-jet printer and the Coumarin-6 dye ink printed in rectangular patterns. Figure 1 shows the as-printed dye illuminated with 360nm light. The printed fluorescent dye is clearly observable. The printed coating was then heated to 50°C to effect diffusion of the dye into the base layer. The Tg of the base layer was slightly above room temperature. Emission spectra of the Coumarin-6 in the as-printed and dye-diffused emitter layer demonstrated that the spectral characteristics were essentially unchanged.

The Coumarin-6 ink was also printed on a control base layer of molaicular™ AMBI-120 (without crosslinker and photosensitizer). The Coumarin-6 fluorescence in this case, Figure 1, is clearly visible but less intense than the dye-diffused sample. We interpret this difference to Coumarin-6 being on the film surface or diffused into the film.

This report describes the development of a gas sensor platform based on all solution-processed bottom-gate bottom-contact organic field-effect transistors that operate at ≤ -2 V. The sensor was able to detect ammonia as low as 600 ppb under high relative humidity (RH=80%).

DIGITAL PRINTING TECHNOLOGIES TRACK

9:00 – 10:00 Wednesday Keynote, Renold C16, see page vii.

Exhibit Open: 10:00 – 16:10, Renold C15

Renold C2

Inkjet-Based Processes II

Session Chairs: Kye-Si Kwon, Soonchunhyang University; Ingo Reinhold, Xaar; and Devin Mourey, HP Inc.

10:10 – 15:30

10:10 **Key Design Considerations for Measurement of Drops-in-Flight Using Machine Vision,** *Paul Best, ImageXpert, Inc. (USA).* 165

Inkjet technology is in the process of revolutionizing traditional printing and dispensing industries. An ever-increasing number of startups and established companies have been working hard to create their own proprietary inkjet knowledge and advanced materials. Machine vision tools have become integral to this R&D process, especially for imaging and measuring drops in flight. Drop-in-flight imaging is usually accomplished using a strobe light synchronized with the firing frequency, together with a camera and workstation. Analysis is accomplished using machine vision techniques, including automatic thresholding, edge finding, and connectivity.

The implementation of this type of system, however, is far from trivial. In order for measurements to be accurate and repeatable, it's very important that proper system design and analysis methods are used.

In this paper, we will discuss imaging techniques and other important considerations for drop-in-flight volume and velocity measurements. Broadly speaking, categories include print controller requirements, optical design, image analysis algorithms, and calibration, as well as other factors and pitfalls.

The impact of these design choices will be explained using theory, experimental data and practical examples.

10:30 **Inkjet Printing onto Patterned Substrates (Focal),** *Beth Kazmierski, Lisong Yang, Emma Talbot, and Colin D. Bain, Durham University; Li Wei Tan and Dan Walker, Merck Chemicals (UK)* 170

The drying of picolitre droplets printed onto patterned substrates has been imaged. Organic solvents were printed in a drop-on-demand format into 200 μm × 200 μm square wells surrounded by walls of polymer resist which were 1.5 μm high and 20 μm wide. Particle tracking velocimetry (PTV) data revealed the velocity and direction of flows during drying, which could be understood in terms of differential rates of evaporation across the drop. Alongside PTV, interferometry was used to observe the profile of the drop during drying. The measurements revealed that variations in the evaporation rates across the drop were not the only cause of uneven deposits when printing onto patterned substrates. More important was the capillary suction caused by negative curvature in the drop once the level of the fluid dropped below the tops of the walls defining the wells, if the drying droplet was pinned at the tops of the walls. For fast evaporating drops, we observed the formation of a dimple in the centre of the well towards the end of drying.

11:00 **Inkjet Printing of Elastomeric Optical Waveguides (Interactive),** *Aleksandra Samusjew, Krzysztof Krawczyk, Markus Kratzer, and Thomas Griesser, University of Leoben (Austria).* 175

Optical waveguides transmit light in a controlled manner, making its propagation possible over long distances, with only little and predictable loss. This gives a great advantage for optoelectronics and in wavelength sensitive biological systems, allowing fast information transfer without electromagnetic interference. Typically, optical elements (e.g. printed optical circuit boards) are not required to be flexible or stretchable. However, elasticity and stretchability expand the field of waveguide application. Recent efforts focus on creating fully elastic systems, able to withstand complex deformation (stretching, twisting, bending).

The goal of the research was to develop a system that is compatible with an inkjet printing process and allows the fabrication of elastomeric waveguides, employing commercially available products. For that purpose the system has the following requirements:

- The ink should compromise good printing properties and high substrate wettability. It should be chemically stable and photocurable.
- The ink should have good elastomeric properties after curing, and the mechanical properties of the ink should match the ones of the cladding, to avoid delamination at the waveguide/cladding interface at higher strains.
- The cladding should have a lower refractive index than the cured ink, and this difference should be possibly big.
- The printed channel should be homogenous, with stable contact lines, stable cross section along the long axis and possibly big contact angle. Bulge formation has to be avoided.

The first three requirements are met by optimising the composition of polyurethane acrylate inks, and using PDMS as a substrate and the cladding material. Requirement 4 poses a difficult problem to overcome, since the stability of printed channels decreases for high contact angles. The contact angle can be adjusted by modifying the sur-

face energy and viscosity of both the ink and the substrate. A method which allowed us to obtain homogenous lines with a high contact angle is described. All structures were fabricated with a standard laboratory printer (Dimatix DMP-2831), with an attached LED lamp (Omni Cure LED, Series 1000).

11:05 **Improved Color Performance of Reactive Dye Inkjet Printing on Cotton Fabrics by Controlling Ink Droplets Spreading (Interactive),** *Zundong Liu,[1] Kuanjun Fang,[1,3] Hongguo Gao,[2] Xiuming Liu,[1] Yuqing Cai,[3] and Fujie Li[3]; [1]Tianjin Polytechnic University, [2]Shandong Huanghe Delta Institute of Textile Science and Technology, Inc., and [3]Qingdao University (China)* 177

Ink drop spreading is an important factor influencing the ink dots distribution which determines the color performance of reactive dye inkjet printed cotton fabrics. In order to control the ink drop spreading, a higher fatty acid derivative (PT) was introduced in the traditional pretreatment solution of sodium alginate. When compared with the untreated fabric, the ink drop spreading area was reduced from 104.9 to 92.5 and 72.3 mm2 on sodium alginate treated and sodium alginate plus PT treated fabrics, respectively. The ink dots on the inkjet printed fabrics with the pretreatment of sodium alginate plus PT were narrow and short. Colorimetric values indicate that the color performance of sodium alginate plus PT treated fabrics was better than that of sodium alginate treated fabrics. Thus, the color performance of reactive dye inkjet printing was improved by the ink droplet spreading inhibitor PT.

11:10 – 11:50 Coffee Break — in the Exhibit Hall — Renold C15

11:50 **Refilling Characteristics of High Frequency Piezo Driven Inkjet Print Heads (Focal),** *J. Frits Dijksman and J.M. Bur, University of Twente (the Netherlands)* 181

A piezo driven ink jet print head is in principle an open microfluidic system, there are no valves that control the direction of the flow. In order to avoid flooding of the nozzle plate at nozzle level a small under-pressure is maintained. In equilibrium the meniscus of the ink is retracted and pinned to the rim of the nozzle. This equilibrium is controlled by the surface tension of the ink and the setting of under-pressure controller. Operated at low frequencies, after droplet formation, there is ample time for the ink to return to the equilibrium state and to be ready for the next firing of a droplet. Driven at higher frequencies, in between droplets, there is no time to return to the equilibrium state and other mechanisms for refilling come into view. When the meniscus has retracted in the nozzle, the next pressure pulse needs to accelerate a relatively small amount of ink. Moreover the viscous drag in a partly filled nozzle is less compared to a completely filled nozzle. With a constant surface tension pressure, the Washburn equation learns that the refilling speed of a partly filled nozzle increases with decreasing filling of the nozzle. Both effects are supposed to cause that a print head driven at high frequency delivers enough fluid to nozzle to maintain droplet emission. In this paper this theoretical framework is extended by taken into account:

- Droplet formation on the dynamics of the fluid motion,
- Change of droplet volume at high frequencies,
- Inertia effects due to the variable mass in the nozzle.
- A complete non-linear analysis will be outlined including:
- Limitation of the capillary pressure; only close to the nozzle the capillary pressure becomes a linear function of the meniscus displacement, otherwise it is a constant,
- The dependence of the viscous drag on the filling of the nozzle,
- The effects of droplet formation,
- Inertia effects due to the variable mass in the nozzle.

Calculations will be performed for a sample pump of which the dimensions are representative for a standard print head. Two inks will be investigated one with a viscosity of 0.01 Pa.s and another with a low viscosity equal to 0.002 Pa.s.

The non-linear analysis will reveal many details of the fluid dynamics of the ink in a print head, including effects of surface tension, viscosity, droplet formation, pulse shape and repeat rate.

12:20 **Textile Inkjet Printing to Support US Manufacture Reshoring,** *Yi Ding, Lisa Parrillo Chapman, and Harold S. Freeman, North Carolina State University (USA)* 189

This research involved the examination of pigment-based and disperse dye-based inksets applied to polyester fabric by textile inkjet printing. Colorimetric data were recorded for each color, as well as the mixed colors generated through RIPMaster V11 software. Color Table (CTB) profiles were created to compare spot colors and International color consortium (ICC) profiles were created to evaluate color gamut volumes. Four-color and seven-color disperse inksets were compared, while six-color and eight-color pigment inksets were compared. As expected, the additional colors increased color gamuts significantly. It was also found that the disperse dye-based inkset provided deeper color shades, and excellent wet and dry crock fastness properties. However, the light fastness for disperse dye-based inksets was not as good as the levels obtained using pigment-based inksets.

12:40 **JIST-First Paper Multi Pulse Train Modelling of Piezo-Drop-on-Demand Inkjet Print-Head Response,** *Stephen D. Hoath, University of Cambridge (UK)* 194

Resonant oscillations set up internal fluid waves within a piezo-drop-on-demand (DoD) print-head channel as a result of actuation drive pulses. Such waves will persist for some time after droplet ejection from the nozzle, and the

residual wave amplitude can interfere (constructively or destructively) with all succeeding actuation drive pulses, potentially altering the speed and volume of successive droplets. As uncontrolled interference would worsen printing quality, residual waves are usually reduced by a combination of print-head design and waveform optimization for better performance at continuous (steady state) printing frequencies. However, the residual waves following any changes of printing frequency can influence "first" drops and short bursts of drops. Exact analytic expressions are provided here for the N-pulse burst DoD print-head response function with fixed printing frequency. This article explains the purpose and application of the model predictions to published piezo-driven DoD data. An examination of the effect of fluid properties, the identification of unexpected jetting behavior and some issues with manufacturing prototype quality, tests of assumptions made in the simple model and extensions to the prediction of print-head performance using realistic complex waveforms are also discussed. An earlier shorter article, mainly introducing the multi pulse train modeling approach and some applications within Xaar, was first presented at NIP31/DF2015 [S. D. Hoath, A simple model for DoD inkjet frequency response, Proc. IS&Ts 31st Int'l. Conf. on Digital Printing Technologies (IS&T, Springfield, VA 2015), 8–12].

13:00 **The Effect of Paper's Properties on the Dot Reproduction of Image in Inkjet Printing (Interactive),**
Fuqiang Chu and Xin Wang, Qilu University of Technology (China) 203
The property of printing substrate plays an important role in the image reproduction of ink-jet printing. The paper's properties such as roughness, gloss, surface wettability and other factors have great influence on the dot reproduction attributes of presswork. The main purpose of this paper is to provide a new method to analyze the influence of paper's properties on the dot reproduction. Different paper factor has different effect weight on the image reproduction. The grey relational analysis is a multi-factor statistical analysis method, which is based on the sample data and the grey incidence of various factors and is used to describe the strength, size and the order of the relationship between the factors. The grey relational analysis is applied to analyze the influence law and the effect weight of paper factors on the dot reproduction during ink-jet printing, which could provide theoretical guidance for improving the printability of paper.

In this experiment, five types of ink-jet printing paper were used to test their printing performance, and then the dot gain data were dealt with by the grey relational analysis method. The parameters of the inkjet printer were

adjusted to match the paper type. And then, the CMYK step-wedges designed by Adobe Photoshop CS were printed by the printer with 600dpi print resolution. The step-wedge consisted of the color patches with 1%, 2%, 5%, 25%, 50% and 75% dot coverage respectively. The printed dots were taken photos by Microscope to analyze the ink setting condition. The dot gains of highlights, mid-tone and shadow area in each printed sample were measured by the spectrophotometer. At last, the grey relational analysis was used to analyze the dot reproduction attributes.

Results showed that paper properties had a great influence on ink setting. Ink drop diffused and deformed less and dot gain was small when paper had smooth surface and tight texture. According to the correlation coefficient degree of paper properties which influence on the dot gain of inkjet printing, the sequence was whiteness, roughness, surface wettability and gloss. Whiteness and roughness could significantly influence dot gain, followed by surface wettability, and gloss with minimal impact. Experiments indicated that the grey relational analysis was a simple and effective tool to analyze the influence of paper properties on the dot reproduction of presswork.

13:05 – 14:30 Lunch Break (on own)

14:30 **Ink Recirculation—Xaar TF Technology™: A Study of the Benefits,** *Mark Crankshaw, Mark Rulman, Hanifeh Zarezadeh, Maëlle Douaire, and Angus Condie, Xaar plc (UK)* 207

When Xaar launched the revolutionary 1001 printhead with patented TF Technology® in 2007 it opened up a number of applications to digital print. The ability to handle heavily pigmented inks, avoiding problems such as sedimentation, has been a crucial enabler in areas, for example ceramic tile decoration, glazes, and for white inks.
Since then, recirculation of ink within the printhead has been widely adopted by manufacturers, and a number of printheads offer an ink recirculation capability. Their approaches to recirculation and operational ranges differ. Xaar TF Technology® recirculates the ink through the actuator channels, immediately past the nozzles, and with relatively high flow rates; other printheads recirculate through the ink manifolds, and/or ink flow rates used by different printheads vary significantly.

Besides the challenges of heavily pigmented inks, ink recirculation can have an impact on other aspects of printhead performance. The flow of ink can move debris and bubbles from the ink path, both before they have a chance to impact jetting, and after to recover from a jetting failure. It may even act to maintain the nozzles themselves, but only when the recirculating flow is close to the nozzles.

This publication presents a study on the important factors needed for ink recirculation to offer advantages, and what those advantages are. The study considers aspects such as print reliability, both prevention of and recovery from failures, nozzle latency (decap), and priming. It also considers the interactions between recirculation and stability of inks, in particular high pigment loading inks.

Using the TF Technology™ of the Xaar 1003 printhead, Xaar's latest evolution of the 1001, factors such as the flow rate of the ink and its impact on the above aspects are studied.

The work presented shows that recirculating flow, when it occurs immediately behind the nozzle in a Xaar 1003 printhead, does interact with the fluid in the nozzle itself. This in turn improves nozzle latency such that if recirculation of ink continues when the nozzles are idle, the length of time a nozzle can be left idle for before an adverse effect is seen with some inks can be increased. This is in contrast to some previous results with alternative recirculation conditions. Testing also shows that an ink that shows a level of unreliability at a low recirculation flow rate can operate reliably with a higher recirculation rate. Therefore it is not simply having ink recirculation that is important, but the precise operating conditions, and in particular a sufficient flow rate.

14:50 **Development of Wound Dressings for Biofilm Inhibition by Means of Inkjet Printing (Focal),** *Mirja Palo,[1,2] Jeannette Öhman,[1] Terhi Oja,[1] and Niklas Sandler[1]; [1]Åbo Akademi University (Finland) and [2]University of Tartu (Estonia)* 212

Printing technology has given new opportunities for the fabrication of pharmaceutical dosage forms. The utilization of inkjet printing allows obtaining drug delivery systems with controlled and precise dosing of low dose medications. The healing process of wounds is hindered due to the biofilm formation by the bacteria. Therefore, effective antimicrobial treatments are crucial in wound care.

In this study, the use of inkjet printing technology for the fabrication of antibacterial drug formulations for topical applications was investigated. The customized formulations with antibiotic gentamicin sulfate printed on medical grade silicon sheeting were prepared. The results showed that the inhibition of biofilm formation was achieved with all the printed formulations in pre-exposure assay to Staphylococcus aureus on static method agar plates.

This study provided insight into the feasibility of inkjet printing for the fabrication of topical drug delivery systems. By adjusting the dose and drug-covered area in the wound dressings, inkjet printing could provide the flexibility that is needed to improve the personalization of wound care.

15:20 – 15:30 Free Time to Visit Exhibit or Other Sessions

15:30 – 16:10 Coffee Break — in the Exhibit Hall — Renold C15

Workflow

Session Chairs: Yasushi Hoshino, Tokyo Denki University, and Bob Ulichney, HP Inc.

16:10 – 16:55

16:10 **Optimized Image Rendition with White Colorant in a Digital Electrophotographic Printing Process,** *Chunghui Kuo, Eastman Kodak Company (USA)* 217

The rapid advances in the display and mobile communication technologies have profoundly challenged the traditional analog high-speed printing press as well as the still-evolving digital printing technology in delivering information to consumers. While the mobile technologies are very efficient to provide instantaneous feed of current affairs to consumers, printing on varieties of substrates beyond plain paper is still irreplaceable to marketing, packaging and additive manufacturing in the real world applications. When printing on nonwhite substrates such as glass and metallics, white colorant is often required along with the other primary colors to properly reproduce the intended color. In this paper, we will introduce a digital color control algorithm that enable white printing capability while satisfying the constraints of simultaneously achieving optimal image quality and minimal total cost of consumption.

16:30 **Development of a Supervision System: Towards Closing the Control Loop in 3D Printing Systems,** *Alvaro J. Rojas Arciniegas and Juan C. Amaya Hurtado, Universidad Autonoma de Occidente (Colombia)* 221

During the 3D printing process errors can occur and go unnoticed until it reaches the user due to the lack of closed loop control. The low-end FFF printers usually suffer more of these failures caused by absence of material or movement of the filament interrupted by different reasons: The filament spool gets tangled causing that the filament cannot reach the extrusion nozzle, the motor that feeds the extruder stop working, or an external object is blocking the movement of the filament. To address these, the work reported takes the first steps towards closing the loop: supervising the extrusion nozzle, detecting material flowing out, and correlating it to the printing process to determine if it is occurring when it should. The supervision is performed with a camera pointing at the nozzle and an interface has been developed to select one of 10 common filament colors that can be monitored. The system then process the image captured and identifies only the filament as it's coming out of the nozzle, enabling to detect discontinuities on the material flow. Although the system is being developed for FFF printers, the need for feedback and closing the loop on the printing process would benefit all additive manufacture processes; therefore, the work proposed is seen as a test case that can later be scaled to other printing technologies.

16:50 **Functional Coating Developments for the Digital Manufacturing Age (Interactive),** *Daniel Loosli and Patrick Le Galudec, Sihl AG (Switzerland)* 227

Sihl in Bern has developed for two decades inkjet receptive coatings enabling images to bond with media surfaces and deliver high quality prints. This has contributed to the growth of digital art reproduction, poster and advertising to name just a few applications.

As progress were achieved with inks—better, cheaper, faster drying—demands on matching coating performances kept researchers busy. These were days when everything had to be coated before printing, with price being a second level consideration.

Good things never last forever: progress of inks enables decent to good output on several types of uncoated media. Graphic industry suffers worldwide from lower appetite for print, and tends to accept "good enough" quality in order to cut costs. Manufacturing and 3D printing emerge as the new "hot place to be" for ambitious developers.

Luckily, wide-format printer users are often quite creative and try to add value beyond colour deposition to their activities. Sihl had noticed already some interest for coated materials with enhanced functionalities (water-resistance, fire-resistance, hardened surfaces). We did take some conventional coating contracts, to discover that this was a well-established and rather mature market.

The market opportunities seemed to be at the junction between digital imaging and coating, and a different set of tools were needed to unlock these new markets.

Sihl invested thus into coating line enhancements, adding a station dedicated to the deposition of thick functional materials, so that one pass functional + receptive imaging layer deposition could be achieved at high speed.

Foam deposition is among the first practical developments: Sihl can apply foam layers, with adjusted thickness, softness, printability features on film and non-woven media. The resulting products are of great interest for indoor architects looking for decorative and noise control features.

Longer term, as inkjet devices reach speed and width similar to coating machines, it becomes conceivable to have single-pass on demand manufacturing of complex media or finished products, incorporating variable material deposition, functionality addition and imaging.

MATERIALS, METHODS, AND PERFORMANCE TRACK

9:00 – 10:00 Wednesday Keynote, Renold C16, see page vii.

Exhibit Open: 10:00 – 16:10, Renold C15

Renold C9

Performance of Print Products (Quality, Robustness, Permanence, and Functionality

Session Chairs: Teruaki Mitsuya, Ricoh Co., Ltd.; Wolfgang Schmidt, Schoeller Technocell GmbH & Co. KG; and Devon Mourey, HP Inc.

10:10 – 13:00

10:10 **The Relationship between Dispersion Stability and Print Qualities on the Coated Paper,** *Takayuki Suzuki, Yasufumi Ueda, and Daisuke Hamada, Kao Corporation (Japan)*. 229

Inkjet printing on the coated paper has been required for many years, but it is known that because of poor penetration ability of the coated paper, residual ink on the coated paper causes bad effects on print performance. To investigate the relationship between dispersion stability of ink and print quality, three types of dispersion were prepared (self-dispersed pigment type, surfactant-dispersed pigment type and polymer-dispersed pigment type). Ink with higher dispersion stability is less likely to aggregate during drying process, which leads to less roughness, high optical density, gloss and good abrasion resistance. When humectant in ink was optimized in terms of penetration into coated paper, polymer-dispersed pigment showed prominent print quality.

10:30 **Visualization and Quantitation Technology of Carbon Black Dispersion State in Intermediate Transfer Belt Using Confocal Laser Scanning Microscope,** *Ayano Momose, Akira Izutani, and Mitsuhiro Tomoda, Ricoh Co., Ltd. (Japan)* 233

The intermediate transfer belt for electrophotography is an important component which affects the image quality. To express the transfer function of the belt, it is required to stably control its electrical characteristics. Conventionally, it has been difficult to observe the state of the Carbon Black (CB) dispersed all over the cross-section of the intermediate transfer belt with a wide field of view using an electron microscope while keeping high resolution. This time, therefore, as a new technology for observation, we have introduced confocal fluorescence microscope which is used for biological sample observation and succeeded in observing the CB dispersion state in Poly Vinylidene di Fluoride (PVDF) as a scattered image. Based on this image we quantified the CB dispersion state using the quadrat method and as a result, we confirmed a good correlation in the electric characteristics of the belt. In this report, we will confirm the effectiveness of the new technology for observation and quantitation to visualize the CB dispersion state in the composition where electro conductive CB has been dispersed in PVDF. Furthermore, we will discuss the relation between the quantified CB dispersion state and the electric characteristics of the belt.

10:50 **Development of Image Quality and Reliability Enhancing Technology for 29 x 23 Size Digital Inkjet Press KM-1,** *Toshiyuki Mizutani, Kenichirou Hiramoto, Mitsuru Obata, Toshiyuki Takabayashi, and Toyoaki Sugaya, Konica Minolta, Inc. (Japan)* 237

We have developed a single-pass inkjet digital press AccurioJet KM-1, which can achieve off-set like high image quality with high productivity, 3,000 sheets per hour.

To success in the commercial printing field, high image quality and high consistency are required to be achieved.

For achieving high image quality, undesirable image defect such as banding should be improved. Therefore we have classified image banding into two, narrow banding (streak) and wide banding.

To solve the narrow banding issue, we developed a unique halftoning and a nozzle compensation techniques by means of image simulation process. We also improved the wide banding issue by adjusting the dot size and the dot density.

As for the high consistency, we developed a streak detection system, which scans images on every sheet, checks the existence of streaks, and feeds the results back to the image compensation systems.

11:10 **Motion Illusion Brought by Arrays of Arrowhead Patterns (Interactive),** *Kazuhiro Otsuki and Makoto Omodani, Tokai University (Japan)*. 241

We can know better about human vision as a result of revealing unknown mechanisms of various visual illusions. Motion illusions are typical illusions those mechanisms have not been clarified; why still images can be seen as if they are moving. In this study, we used arrowhead figure as a basic element of motion illusion patterns. We evaluated recognition of motion illusion on various arrowhead array patterns. We have found that a remarkable rate of observers recognized motion to the arrowhead direction on each pattern. This results suggest us that arrowhead patterns can generally cause motion illusion towards the arrowheads. This result was utilized to explain the strange bi-directional motion recognition on the Fraser-Wilcox illusion pattern.

11:15 – 11:50 Coffee Break — in the Exhibit Hall — Renold C15

11:50 **Evaluating Gonio-Appearance in Advanced Printing Materials with Quality Control Procedures and Instrumentation Used for Automotive Coatings (Focal),** *Bárbara Micó-Vicent, Omar Gómez, Elisabet Chorro, Esther Perales, Valentín Viqueira, and Francisco M. Martínez-Verdú, University of Alicante (Spain)* 245

The future and current digital economy and society is based on the perceptual choice by the consumer of many real objects (cards, cosmetics, toys, etc.), but increasingly from digital simulations with a great photorealism. Due to the existence on the market of new and sophisticated gonio-apparent pigments, with aesthetic and physic-chemical aspects changing according to the illumination and observation directions, nowadays, it is a current great challenge the simulation on digital media (displays, virtual reality, printing technologies), of objects, with different shape and size, with the maximum perceptual realism. Regarding printing technologies, above all multi-channel and 3D printing technologies, needs to be checked the actual and future capacities to be used in the automotive sector in order to get more colored plastic pieces (add-on parts for the car body) with the same or better aesthetic and physic-chemical features.

In this contribution, we will provide a general overview of a recent funded Spanish project called ADIREVGAO (Advanced DIgital REproduction of Visual Gonio-Appearance of Objects) for three years. One of the main goals of this project is to go into detail about the reproduction capabilities of the gonio-appearance on several printing technologies, above all on multi-channel inkjet and 3D printing (additive manufacturing, FDM technology).

Only the interplay of concepts and terminology (gonio-appearance, measurement geometries, etc.), in addition to available commercial instruments, color & texture quality control by models, and the characterization techniques, and guidelines for testing gonio-apparent 3D printed materials, will be shown in this work.

12:20 **3D Printing in the Development of an Endoscopic Probe,** *D. I. Nikitichev, University College London, and Simeon J. West, University College Hospital (UK)* 251

In this work we demonstrate the possibility of the development of an optical endoscopic probe. The accuracy of printing of small needle stylet objects of two polyjet printers (Objet 30 Pro, Objet Connex 350) are compared. The minimum outer diameter of the stylet 460 µm is achieved, while the holes in stylets as small as ~400 µm are created. The minimum wall thickness for small objects in the range of 500 µm is achieved. To keep fibers fixed at proximal end of the needle a novel custom made fibers-needle connector was developed. This connector simplifies the clamping of the fibers and connection to the needle.

12:40 **Quantification of Faithful "Color Appearance" Reproduction, and Application to New Products,** *Takumi Kaneko, Katsushi Hara, and Tomokazu Yanai, Canon Inc. (Japan)* 255

In photographic prints, color reproducibility is an important factor for print quality. For quantification method of color, lightness (CIEL* a* b*) and optical density (OD) based on spectral reflectance measurement method (45deg incidence/0deg light reception) is used widely. However, there is often a case that the measured L* a* b* and the result from subjective evaluation does not match depending on observing environment. Therefore we examined new methods to evaluate "color appearance" reproduction, which highly correlated to the subjective evaluation. And we used this new evaluation method to develop the new "imagePROGRAF PRO" series printers, and realized high optical density in black area and wide color gamut.

13:00 – 14:30 Lunch Break (on own)

Physics and Chemistry of Materials I

Session Chairs: Nobuyuki Nagayama, Fuji Xerox Co., Ltd.; Steven Hoath, University of Cambridge; and Jim Stasiak, HP Inc.

14:30 – 17:00

Session sponsored by

RICOH

14:30 **Dispersion Control of Liquid Toner by Dispersant and Analysis of Adsorption Structure,** *Tatsuya Yamada, Yoko Hanada, Kosuke Takeda, Nobumichi Kamiyoshi, and Masahito Yamazaki, Kao Corporation (Japan)* 259

Dispersant which is effective for dispersion of liquid toner and adsorption structure of the dispersant were investigated. In order to disperse polyester toner particles in paraffin oil, a basic dispersant was examined. As the adsorbing unit, polyethyleneimine was selected, which can adsorb to carboxylic acid of polyester toner by acid-base interaction. Homopolymer of 12-hydroxystearic acid was selected as the dispersing unit because it has low polarity and it is easy to control molecular weight. Amide dispersants were synthesized by condensation reaction between adsorbing units and dispersing units of different molecular weight.

After the evaluation of liquid toner dispersibility with synthesized or commercially available dispersants, it was found that the dispersant with low molecular weight adsorbing units showed better dispersibility than one with high molecular weight adsorbing units. To compare the adsorption structure of dispersants, interaction force between surfaces adsorbed with each dispersant was analyzed by colloidal probe AFM. It was indicated that the adsorbing

unit of high molecular weight forms train-loop-tail structure, while that of low molecular weight forms the brush-like layer. In the case of dispersant of high molecular weight, it was suggested that some of the adsorbing unit may adsorb to more than a single particle, which causes cross-linking between particles and leads to bad dispersibility.

14:50 **Understanding Dynamic Relaxation of Inks at a Timescale Relevant to High Frequency Drop-on-Demand Printing,** *Nick Jackson, Tri Tuladhar, Maëlle Douaire, John Tatum, and Angus Condie, Xaar plc (UK)* 264

As the drop-on-demand (DOD) inkjet industry moves towards higher print frequencies to achieve higher productivity, the nozzle recovery rate and turnover time becomes increasingly important, in that attempting to jet from a nozzle that has not fully recovered results in meniscus instability and poor reliability.

We have developed a new, simple, and rapid quantitative technique to measure the microsecond relaxation time of inks at a timescale relevant to DOD inkjet waveforms by exploiting the Piezo-Axial Vibrator (PAV). This microsecond relaxation has been found to be directly relevant to the maximum inkjet print frequency achievable. This has allowed for inks of any type to be screened, compared for batch variations and tailored for suitability for specific high-frequency jetting applications.

The results show that this relatively inexpensive and compact equipment can detect changes in the microsecond relaxation with a high degree of sensitivity, with the effect of dynamic fluid properties beyond surface tension, viscosity or density able to be detected and quantified, allowing for new formulations to be developed with higher print frequencies in mind.

15:10 **Inkjet Printed MoS2 Electronics (Interactive),** *Keshav Sharma, Pei He, Mark Bissett, and Brian Derby, University of Manchester (UK)* 269

Inkjet printing of two-dimensional (2D) layered materials has attracted a substantial interest for emerging electronic applications. Layered Metal dichalcogenide (LMDC) molybdenum disulphide (MoS_2) is seen as a new age 2D material beyond graphene, owing to its novel electronic and optical properties, which opens up a wide range of applications. Liquid phase exfoliation (LPE) is a promising technique to produce high yield and stable dispersions of 2D materials for printing purposes. A number of strategies have emerged to produce inks and printing methods for electronic device performance, including: tailoring the surface energy and viscosity of the ink or using different substrate surface treatments prior to printing. Here we demonstrate inkjet printing as a viable large area method for MoS_2 based device fabrication. We have developed a LPE MoS_2 based ink using a mixed IPA/water (7:1) solvent. This produces MoS_2 inks with concentration up to 1.5mg/ml and a MoS_2 flake size distribution from 200-500 nm with thickness ranging from monolayer to few layers. Surface tension and viscosity studies were conducted to examine the printability of the ink. Substrate surface modification treatments including O2 etching and hexamethyldisilazanization (HMDS) has been applied to aid the printing process. AFM and SEM characterization were used to show that thin films produced by inkjet printing were uniform and continuous. MoS_2 traces were printed on silicon substrate to produce thin film transistors. Conductivity as a function of film thickness was measured for bare substrate, HMDS treated substrate and O2 treated substrate. Output and transfer characteristics of inkjet printed thin film transistors were measured which shows a promising development.

15:15 **Preparation and Application of Polyurethane Polymer Modified by Nano Silica (Interactive),** *Qing Wang, Guangxue Chen, Junfei Tian, Minghui He, and Jinglei Tai, South China University of Technology (China)* 270

One kind of nano silica was prepared by KH550 and TEOS via sol-gel method, and this kind of nano silica was then applied for modification of solvent free polyurethane used for Paper/Al laminating. The chemical structure and morphology of the nano silica were characterized by FT-IR, SEM and laser particle size analyzer. The mechanical properties of the polyurethane polymer were well studied by Universal tensile testing machine, shore durometer and thermogravimetric analysis. Results indicated that KH550 was successfully synthesized to the nano silica and the particle size of the silica was within sub-micro. The adding of nano silica enhanced the bonding strength of the polyurethane but increased the hardness of the cuing film. Meanwhile too much nano silica with low density was hard to disperse evenly in the film. The content of nano silica should be controlled within 0.8%wt.

15:20 **Shape Control Synthesis of Silver Hierarchical Microcrystals (Interactive),** *Shi-dong Nie, Chun-yan Liu, and Zhi-ying Zhang, Chinese Academy of Sciences (China)* 274

Effective efforts have promoted the development of the shape controlled synthesis of silver nanoparticles in recent decades. However, there was limited success in the morphology controlled synthesis of silver microcrystals, especially large scale synthesis in aqueous solutions. Here, series of mono-dispersed silver hierarchical microcrystals (AgHMCs) with high yield have been produced by the reduction of silver nitrate with ascorbic acid in nitric acid-mediated aqueous solutions (Fig.1). The physical characterization revealed that (111) facets become dominant exposed on the surface of nano- or submicro-Ag planes, which assembled to form AgHMCs. It is suggested that the oxidative etching effect of nitric acid and selective deposition of reduced Ag atoms based on surface free energy took mainly effect in determining the formation of AgHMCs.

15:25 – 16:10 Coffee Break — in the Exhibit Hall — Renold C15

16:10 **Inkjet Printing with Inks that Phase Separate during Drying,** *Ashley S. Johns and Colin. D. Bain, Durham University (UK).* 275

Ink-jet formulations that have been designed to phase separate upon deposition onto the substrate have been investigated using model fluids. A physical model of expected separation behavior for an aqueous solution of butanol suggested that the butanol-rich phase would form at the contact line as an annular ring. The surface tensions in air of the saturated fluids and the interfacial tension between them were combined with measured contact angles on the substrate to show that the butanol-rich phase would partially undercut the water-rich phase. Printing trials with a 6 %wt butanol solution, however, did not show phase separation and the observed internal Marangoni flows were consistent with the more rapid evaporation of butanol than water. The origin of this behavior is the highly non-ideal vapor pressure for butanol at saturation. A criterion for predicting whether or not a particular mixture would phase separate was developed based on the non-ideal component vapor pressures. Aqueous glycol ether solutions show the correct properties and a 15.1 %wt dipropylene glycol methyl ether acetate solution displayed phase separation. Separation occurred first at the contact line and the phase boundary moved radially inwards until water evaporation was complete.

16:30 **Semi-Conductive Printing Rolls for Improved Print Quality,** *M.K. Davies and J. Altland, Fenner Precision (USA).* 281

In the evolution of producing an ink/toner transfer roll for electrophotography, the resultant print quality is a complex function of many variables and variable-interactions within a given print system. Print system component compatibility, including semi-conductive rollers, inks/toners, substrates, and system configurations can be evaluated independently on a limited basis, but ultimately, print quality must be evaluated in the complete print system. Key to roller performance are dielectric properties, surface properties, and wear properties. Uniform and stable dielectric properties are critical to desired print quality through the expected service life of semi-conductive rollers. Volume resistivity, for example, is a basic electrical measurement that can be used to correlate with print quality over a roller's service life. OEM print system components and design must be factored into the design and construction of semi-conductive rollers – including polymer selection. Targets for expected service life and print quality can then be used to design these rollers to ensure achieving total print system performance. Electrical and mechanical characteristics of these rollers are optimized through design of experiments. Determination and design of performance attributes of semi-conductive rollers will be presented. A model resin system with active dielectric and mechanical additives has been extensively tested for electrical, surface, and wear properties to optimize print quality.

16:50 **Predicting Paper Wrinkles in Fusing Process of Laser Printers Using Dynamic FEA (Interactive),** *ByoungHo Yoo, JeHwan You, and TaeHan Kim, Samsung Electronics Co., Ltd. (Korea)* 282

One of the persistent problems in the development of laser printer is paper wrinkles in fusing process. Factors affecting this problem are due to internal factors of fuser and layout factors between transfer roller and fuser. This paper suggests modeling methods to simulate mechanical characteristics to predict the possibility of paper wrinkle in fuser by change of layout parameter. Layout parameters are relative position and angle of fuser about transfer roller and inlet guide position from fuser nip.

Through 3D dynamic simulation, it calculates the compressive plastic strain of the paper passing through the fuser unit, and wrinkle criteria were set up on the basis of jig experiments. The analysis method can be extended to a variety of practical paper wrinkle problems, and the scalability is considered high. The usefulness of these methods was validated by the comparison with experimental results.

16:55 **Preparing Anti-Bacterial Printing Toner via Emulsion Aggregation Method (Interactive),** *Maryam Ataeefard, Institute for Color Science and Technology (Iran)* 286

Silver nanoparticles and carbon black were incorporated into poly (styrene-co-acrylic acid) using eco-friendly emulsion aggregation (EA) approach, with final application as an antibacterial electrophotographic printing ink, called toner. This approach was based on dispersing and coagulating the nanosilver (nAg) and carbon black particles in styrene-coacrylic latex (previously synthesized by the emulsion polymerization). XRD, and SEM-EDX revealed the silver nanoparticles to be located in the polymeric structure of toner. The antibacterial properties were determined using the agarwell diffusion method against gram-negative (Escherichia coli). The nanocomposite produced via emulsion aggregation method showed highly potent antibacterial activity toward bacteria compared with the neat black toner, which makes it useful in anti-bacterial printing application. The antibacterial property was, also, observed to increase with the concentration of the silver powder in nonlinear behavior.

17:00 **Synthesis of Guar Gum Derivatives in [BMIM]Cl Ionic Liquids and Their Application on Pulping and Papermaking (Interactive),** *Nan Li,[1] Wei Chen,[2] and Guangxue Chen[1]; [1]South China University of Technology and [2]Qufu Normal University (China).* 291

In this paper, Dodecenyl succinic anhydride(DDSA), Octadecenylsuccinic Anhydride(ODSA), and Octenylsuccinic Anhydride(OSA) with catalyst TMAOH was used to modify guar gum in 1-Butyl-3-methyl imidazolium chloride ionic liquid. The modified guar gum exhibit good retention and drainage properties in reconstituted tobacco pulp. The results of this study demonstrated that the modified guar gum could be used as a useful retention and drainage aid in reconstituted tobacco pulp.

THURSDAY SEPTEMBER 15, 2016

DIGITAL FABRICATION AND 3D PRINTING TRACK

9:00 – 10:10 Thursday Keynote and IS&T Awards, Renold C16, see page vii.

concurrent event

10:20 – 11:00 Colleague Connections—Late Breaking News/Success Stories
see page xxxv, Renold C9

Renold C16

Printed Electronics II

Session Chairs: Shinichi Nishi, Konica Minolta Inc.; Roger Bollström, Omya International AG; and Dinesh Tyagi, Lexmark International, Inc.

10:20 – 14:50

Session sponsored by

IOP Institute of Physics
Printing and Graphics Science Group

10:20 **Optical Waveguides Fabricated by Combination of Inkjet and Flexographic Printing,** *Patrick Bollgruen,[1] Tim Wolfer,[2] Uwe Gleissner,[1] Dario Mager,[3] Christof Megnin,[1] Thomas Hanemann,[1,3] Ludger Overmeyer,[2] and Jan Korvink[3]; [1]University of Freiburg, [2]Universitat Hannover, and [3]Karlsruhe Institute of Technology (Germany)* 294

We present polymer optical waveguides on foils created by a combination of flexographic and ink-jet printing. While prior work focused on the creation of bare polymer tracks to guide light, this work looks into optical waveguides with a printed lower cladding layer, which makes the waveguide design independent from the optical properties of the foil substrate. First, the lower cladding is printed by flexographic printing on PMMA foil. Then, the sample is placed in an ink-jet printer, where the waveguide core is created. To control the wetting behaviour, temperature and oxygen plasma treatment are used, and continuous tracks are obtained. The waveguide functionality is demonstrated by guiding 785 nm laser light through a 20mm long sample.

10:40 **JIST-First Paper Investigation on an Inkjet Printed Passive Sensor for Wireless Ice Detection on Wind Rotor Blades,** *M. Hartwig,[1] M. Gaitzsh,[1] T. D. Großmann,[1] M. Heinrich,[2] L. Kroll,[1,2] T. Gessner,[1] and R. R. Baumann[1]; [1]Technische Universität Chemnitz and [2]Fraunhofer Institute of Machine Tools and Forming Technology (IWU) (Germany)* 298

Wireless reliability tests of lightweight composite materials by electromagnetic waves have become more and more interesting in the aerospace and automotive fields. The embedding of conductive printed patterns as electromagnetic resonators seems to be one of the useful techniques. The printing technology is a resource as well as time and cost efficient fabrication method to manufacture electronic devices. In particular, contactless and digital technologies like inkjet printing have great potential to be combined with integration processes like resin infusion technology. The combination of these manufacturing processes enables fast and efficient production of smart lightweight applications. The main focus of this work is the manufacture of a passive high frequency resonator on flexible substrates using inkjet printing. The conductive patterns are integrated into a composite material by resin infusion, enabling sensor applications in the field of clean energy, particularly for wireless ice detection on wind rotor blades.

11:00 – 12:00 Coffee Break and **Interacive Paper Session I,** *Renold C15*

12:00 **Flexible Pressure Sensor Driven by All-Printed Organic TFT Array Film (Focal),** *Shinichi Nishi,[1,2] Tohru Miyoshi,[1,3] Hiroyuki Endoh,[1,4] and Toshihide Kamata[1,5]; [1]Japan Advanced Printed Electronics Technology Research Association (JAPERA), [2]Konica Minolta Inc., [3]Dai Nippon Printing Co., Ltd., [4]NEC Corporation, and [5]The National Institute of Advanced Industrial Science and Technology (AIST) (Japan)* 305

We have constructed a sheet-to-sheet (S2S) manufacturing line in order to prove the possibility and reality of production technologies and integrated processes of all-printed electronics devices. In our automated and continuously operated manufacturing line, we operated the reverse offset printer for electrode pattern, digital inkjet printer for organic semiconductor layer, slit-die coater for insulator layer, and screen printer for electrode and inter-layer insulator.

SPECIAL EVENT

CONFERENCE RECEPTION

Wednesday, 19:00 – 22:00
Museum of Science and Industry (MOSI)
Liverpool Road, Manchester

Join colleagues for an enjoyable evening socializing and exploring the Textile and Power galleries.

The average mobility of organic TFT is 0.7 cm2/Vs, average ON current is 5 uA with less than 10% sigma in A4 size area, and ON/OFF current ratio is ten of order 6. We have been acquiring successful results of TFT array flexible film in a reasonable high yield.

These all-printed organic TFT array back-plane is applied to the flexible and light-weight pressure sensor which is driven in active matrix mode, and which is applied for a touch pad of writing with pressure grey scale or a commodity inventory system.

12:30 **JIST-First Paper Intense Pulsed Light Sintering of an Inkjet Printed Silver Nanoparticle Ink Depending on the Spectral Absorption and Reflection of the Background,** *Dana Mitra, Kalyan Yoti Mitra, Melinda Hartwig, and Reinhard R. Baumann, Technische Universitat Chemnitz (Germany)* . 309

The development of novel manufacturing methods for flexible, light weight and cost-efficient electronics has attracted great interest in recent years. The inkjet printing technology is an attractive fabrication process due to its additive, high precision and up-scalable deposition process. One of the key components of printed electronic devices is the conductive track. A major requirement is a desired and device dependent electrical performance induced by an appropriate post treatment process. Here, the novel method of using intense pulsed light (IPL) to convert printed liquid films into solid and functionalized metallic layers has great potential when it comes to fabrication of electronics on thin, flexible and even stretchable polymeric foils. Within this research, the IPL sintering and its dependence on the spectral absorption and reflection of various materials is investigated. A nanoparticle silver ink is inkjet printed on a transparent PET foil. Afterwards, the printed samples are placed at a defined distance from the background inside the photonic sintering equipment and flashed on one hand with various flashing parameters and on the other with changing background materials and colors. Changing the background color influences the reflection and absorption properties of the flashlight; the electrical performance of the IPL processed conductive layers can be drastically changed when such a phenomenon occurs. Highly conductive silver tracks or electrodes can be manufactured on thin and flexible polymeric substrates without damage.

12:50 **The First International Standards for IEC/TC 119 Printed Electronics Materials Substrate and Conductive Ink,** *Masaaki Oda,[1] Satoshi Maeda,[2] Tadanobu Sato,[3] and Chizu Sekine[4]; [1]Japan Advanced Printed Electronics Research Association, [2]Toyobo Co., Ltd., [3]Fujifilm Co. Ltd., and [4]Sumitomo Chemical Co., Ltd. (Japan)* 314

The first international standards for IEC/TC119 printed electronics materials substrates and conductive ink were published on Feb. 25th 2016. Printed electronics is one of the growing technology fields and expected to have a large market in the future. Standardization of materials has been discussed in WG2 of IEC/TC119 (Technical committee of printed electronics). One of the authors of this paper, Ms. Sekine is the convener of WG2 and has been leading the activities in WG2. Thus first of all, two new proposals of generic standards including measurement methods concerning material substrate and conductive ink were proposed to lead standardization in printed electronics materials and accelerate developments in printed electronics from Japan. I was selected as the project leader of standardization of conductive ink. Contents of the both IS will be introduced.

13:10 – 14:30 Lunch Break

14:30 **Multicolor Electrochromic Device with LSPR of Silver Electrodeposition Toward Color Reflective Display,** *Norihisa Kobayashi, Kazuki Nakamura, Jineui Hong, and Riho Tejima, Chiba University (Japan)* 319

Novel multicolor electrochromic (EC) device based on electrochemical silver deposition was successfully demonstrated. The EC device exhibited reversible multicolor change of primary colors—transparent, magenta, cyan, yellow, black (CMYK) and silver mirror—in a single cell by using electrochemical method which controlled the morphology of silver deposit. In this paper, we particularly analyzed the coloration mechanism in detail.

concurrent event

14:30 – 17:30 Colleague Connections—Connections for Innovation in Security Printing

see page xxxviii, Renold D7

Printed Sensors

Session Chairs: Oh Hyun Baek, Samsung Electronics Inc.; Dana Mitra, Technische Universitat Chemnitz; and Devin Mourey, HP Inc.

14:50 – 17:10

14:50 **Switchable Passive Wireless Vapour Sensors from Inkjet Printed Electronic Components on Poly(dimethylsiloxane),** *Kate E. Belsey,[1] Adam V. S. Parry,[2] Christina V. Rumens,[1] Mohammed A. Ziai,[1] Stephen G. Yeates,[2] John C. Batchelor,[1] and Simon J. Holder[1]; [1]University of Kent and [2]University of Manchester (UK)* 323

A potential route to printed, inexpensive and disposable Radio Frequency Identification (RFID) sensor tags for chemical sensing such as the monitoring of food spoilage is described. The stimuli responsive material poly(dimethylsiloxane) (PDMS), is known to swell upon exposure to organic vapors. Colloidal silver ink solutions

were printed and sintered onto surface modified PDMS to give conductive silver feed loops. These loops act as the active sensing component in antennae for passive (battery-free) (RFID) tags. When the tags were exposed to certain solvent vapors (e.g. ether, dichloromethane, acetaldehyde) the printed feed loop fractured. This was accompanied by a rapid increase in resistance and ultimately loss of conductivity. This led to a change in the transmitted power and read range of the wireless device. Remarkably upon removal from the vapor, the fractured feed loops reassemble and become conductive again, making them switchable and "multi-use". The selectivity for the response to the vapors could be directly correlated to a function of the Hansen solubility parameters and vapor pressures of the solvents giving rise to the vapours. Significant differences in the solubility parameters between PDMS and the organic volatile and/or low vapor pressures lead to no significant response (e.g. methanol, acetic acid, popan-1-ol). This work paves the way to a fully inkjet printed RFID substrate for vapor detection.

15:10 **Packaging Added Value Solutions by Thermochromic Liquid Crystal-based Printed Labels (Interactive),** *Maja Jakovljevic and Branka Lozo, University of Zagreb (Croatia), and Marta Klanjsek Gunde, National Institute of Chemisty (Slovenia).* 325

Thermochromic liquid crystals (TLC) printing inks show specific, temperature dependant optical properties. The color change of TLC ink appears only inside the activation region where the color changes gradually, due to specific structural changes in the microencapsulated active thermochromic material, the TLCs. Throughout the activation region the color changes as a rainbow, i.e. the spectral color along the whole visible spectrum, the effect is called "the color play". Temperature dependant optical properties of TLC materials enable the usage of these inks in various fields of application, including the functional packaging. Divers kinds of temperature indicators facilitate monitoring and control of the conditions of the packed goods. Still, the usage of TLC printing inks is not widely applied in the area of functional packaging, despite the expansion of application options. The paper presents a number of possible applications of TLC inks in the area of functional packaging and/or labels for added value packaging. The spectral reflections for each temperature within the activation region of the used TLC ink was acquired by spectrometric measurements. The CIELAB colorimetric values were calculated and presented, showing the "color play" throughout the whole spectra. The results of the presented measurements may contribute in defining the colorimetric parameters of dynamic color change of TLC printing inks as well as to the development of new applications in the field of functional packaging.

15:15 **A Part Complexity Measurement Method Supporting 3D Printing (Interactive),** *Luiz Araújo, Ender Özcan, Jason Atkin, and Martin Baumers, University of Nottingham (UK)* 329

The use of packing algorithms to fill build volumes in 3D printing promotes both more efficient processes and better utilisation of the available build space. There are various packing techniques, and the choice of an appropriate one is often highly dependent on the characteristics of the parts to be printed, among other factors. Part complexity, and particularly convexity, is an important factor. This paper presents metrics for quantitatively evaluating part complexity, extending a 2D metric to a 3D situation. These metrics are then available for classifying problems and identifying appropriate packing algorithms.

15:20 **Watermarking Embedding Algorithm for Color QR Code based on Image Normalization and Contourlet Transform (Interactive),** *Qian Guo, Guangxue Chen, and Ting Chen, South China University of Technology (China)* 335

In this paper, an algorithm that embed watermarking into color QR code based on image normalization and contourlet transform is proposed, which is based on image normalization and invariant centroid theory. For the purpose of enhancing the invisibility and resistance to geometric attack of watermarking, we first encrypt the watermarking with chaotic method before information embedding, and then eliminate the effect of geometric change by utilizing image normalization. Based on the matrix singular value decomposition in contourlet domain, suggests an adaptive watermarking scheme that watermarks are embedded into the above resulted images. Corresponding, we perform inverse transform to the QR code which is attacked by geometric transformation and non geometric transformation including blurring, JPEG compression, noise addition, sharpening, scaling, rotation, and cropping before extracting the watermarking. Thus, we can prove the truth of the attacked QR code by the extracted watermarking which is recognizable.

15:25 – 16:30 Coffee Break and **Interacive Paper Session II,** *Renold C15*

16:30 **Inkjet Printed Micro Saddle Coil for MR Imaging,** *Nan Wang,[1] Aleksandr Egunov,[2] Nils Spengler,[1] Nikolaus Nestle,[3] Valeriy Luchnikov,[2] Dario Mager,[1] and Jan G. Korvink[1]; [1]Karlsruhe Institute of Technology (KIT) (Germany), [2]Institute of Material Science of Mulhouse (IS2M) (France), and [3]BASF (Germany)* 339

This paper demonstrates novel approaches to fabricate micro-scale saddle coils via a combination of rolling-up of thin polymer films and ink-jet printing technique. The printed conductive patterns can be directly electroplated, allowing for better conductivity and less signal loss for high frequency applications. To roll up 3D structures starting from 2D planar patterns, two methods were investigated. The performance of rolled-up coils were tested in a 500MHz spectrometer and an MR image of a water-filled capillary was successfully acquired.

16:50 **Inkjet Printed Polyelectrolytes for Microfluidic Paper-based Analytical Devices,** *Risto Koivunen,[1] Eveliina Jutila,[1] Roger Bollström,[2] and Patrick Gane[1,2]; [1]Aalto University (Finland) and [2]Omya International AG (Switzerland)* 343

Paper-based microfluidic devices can provide practical analytics platforms for applications such as point-of-care medical diagnostics. So far immobilisation or separation of analytes on such devices has received limited attention. This study introduces inkjet printed polyelectrolyte patterns as possible platforms for immobilisation of cationic and anionic compounds through surface charge interaction. Both cationic (polydiallyldimethylammonium chloride) and anionic (sodium polyacrylate) polyelectrolytes were inkjet printed on a custom designed porous pigment coating, having fine particle internal pore structure to ensure high surface contact between the analytical sample and modified pore walls. Printed polyelectrolyte patterns were themselves largely invisible, including under UV light. In a proof of principle test, a controllable degree of separation of anionic Uranine and Tartrazine dyes from aqueous solution passing through a printed cationic polyelectrolyte region could be observed. However, weakly cationic Rhodamine B could not be captured on anionic regions.

19:00 – 22:00 Conference Reception
Museum of Science and Industry
Liverpool Road, Manchester, UK

DIGITAL PRINTING TECHNOLOGIES TRACK

9:00 – 10:10 Thursday Keynote and IS&T Awards, Renold C16, see page vii.

concurrent event
10:20 – 11:00 Colleague Connections—Late Breaking News/Success Stories
Renold C2

Renold C9

Printing and Fabrication Principles and Processes

Session Chairs: Masaaki Oda, JAPERA; Mark Crankshaw, Xaar; Ross Mills, Vexajet Corporation
10:20 – 13:10

10:20 **Meniscus Motion Inside a Drop-on-Demand Inkjet Print-Head Nozzle,** *Claudio S. Ravasio, Wolfson College; Stephen D. Hoath and Graham D. Martin, University of Cambridge; Peter Boltryk and Marko Dorrestijn, Xaar (UK)* 348

A new study of the jetting performance for drop-on-demand (DoD) inkjet print heads investigated meniscus motions inside the transparent nozzles of MicroFab inkjet print heads. A composite image representation of the observed meniscus motions, imaged at high resolution using a spark flash light source, was developed for our subsequent analyses of the influences of drive voltage and pulse dwell time and also the ink properties. At higher drive voltages a slow damped refill (following de-pinning of the meniscus from the very edge of the nozzle exit) was also clearly observed. This and many other interesting phenomena were observed with the composite images: internal bubbles that progressed through the nozzle region over relatively long timescales, internal break-off of the jet from the meniscus surface, satellite formation and merging, and the contact line de-pinning not previously observed before.

10:40 **Digital UV Printing of 3 Dimensional Objects at High Speeds,** *Volker Till, Till GmbH (Germany)* . 353

The packaging of mass products is mostly packaging of consumer goods in various kind of packaging materials depending on the product.

The expectations in this highly visible market mostly dominated by multinational brands. They are sensible about their market share and their expectations for image quality and correctness is extremely high, as packaging is supply a very competitive market.

Purchase decisions at the point of sale are spontaneous and consumers and their attitude are changing more and more rapidly. The paper will talk about the changes of consumers and their growing influence to market leading brands.

It will as well show how this influences the task and solutions to decorate finished packaging which can be given only by digital printing with appropriate machinery concepts allowing to print 3 Mio m^2 per year.

The printing of objects is in contrary to standard printers not continuously, but requires the change of the individual e dimensional packaging up to 15 times/second.

The paper furthermore addresses the need and the execution to clean the printer without interruption of the

production, as a lot of production is continuous and cannot be stopped. This cleaning and its relation to image and print quality check by camera system incorporated into a system is part of the paper as well.

The paper describes the development of such a machine and its concept for a production environment for a variety of packaging materials. This speed can only be reached with appropriate print heads and the paper will as well compare the available today´s technology with the requirements of the packaging printing in future.

Computer / software concepts are needed to enable RIP-ing of multiple images per second to enable a unique decoration per packaging. The paper highlights these aspects as a part of the conceptual work for a practical application.

An additional influence for machine concepts is given by the type of inks. The handling of finished packaging at a speed of 15 packs / second requires rapidly drying inks, which are provided by UV curing inks. The expected inks properties for food safety and performance criteria are furthermore different to the normal application in the printing industry. Ecological aspects of packaging and inks are playing a major role in this. Analytical science and environmental groups check more and more aspects of protecting consumers as well as our environment. Consumers are more and more influenced by these publications and discuss the results in the social networks. Mistakes have nowadays a bigger impact than in the past. The paper includes the safety in development and production of inks with examples from an ink maker providing inks for a food packaging application.

11:00 **Geometric Element Test Targets (Getts™) for Determination of 3D Printers' Resolutions (Interactive),** *Shu Chang, Heng Li, and Nathan Ostrout, RIT (USA)* 354

This study presents a concept to address the dimensional and geometric viability of three-dimensional (3D) printers with test artifacts. These test artifacts we named as Geometric Element Test Targets (GETT™). GETT™ offers a simple method for quantitative appraisals of the dimensional performance of additive manufacturing processes. The design of GETT™ relies on logistically positioned and decreased feature dimensions. One characteristic of GETT™ is that the dimensional failures introduced may be inspected visually and quantitatively assessed through graphical analyses. We will illustrate the use of GETT™ to determine a printer's resolution through samples produced from fused deposition modeling (FDM) printers. Although the demonstration is from FDM systems, the concept is expected to hold for all 3D printing processes and can be process-specific. The potential applications of GETT™ include standardization, reference targets, in-line system control, and more.

11:05 **Inks of Organic Cu-Precursors with Short Carbon Chain (Interactive),** *Wen-dong Yang, Chun-yan Liu, and Zhi-ying Zhang, Chinese Academy of Sciences (China)* 359

Based-Cu printing inks (20wt% Cu) and (9.6wt% Cu) were prepared using the short carbon chain organic Cu-precursors formed during the preparation of the inks, which can easy form a favourable conductive film onto glass slides at 290 and 200. The resistance of the film induced by the oxidation of Cu and remainder of long carbon chain Cu-precursors markedly decreased, than usual. The influence factors on the formation and conductive mechanism of the copper ink and film were discussed.

11:10 – 12:00 Coffee Break and **Interacive Paper Session I,** *Renold C15*

12:00 **Elastomer Fatigue in Belt Fusing,** *David Battat, Lexmark International, Inc. (USA)* 360

Fatigue failure often shows up towards the end of life in the backup roll (BUR) in belt fusing, as shown in Figure 1. This paper has two objectives: (1) To develop a model or description of what drives fatigue in an elastomer from material and loading perspectives, that can be applied in fusing irrespective of the particular application at hand; and (2) to use this capability to examine fatigue, clarify the reason for the catastrophic failure in printers, and identify directions to meet the spec on life, as well as assess the impact this might have on other fusing attributes.

12:20 **Toner Mask Method for Imaging on Niobium (Interactive),** *Isao Komatsu and Shuichi Maeda, Tokai University (Japan)* 366

An anodized niobium (Nb_2O_5) layer on a niobium (Nb) plate makes various colors. A driving force of the coloration is considered to be the thin film interference between Nb_2O_5 layer and the Nb plate. In this study, we explore the possibility that a toner mask method could be used for preparing a digital image on the Nb plate by an anodization. And we tried to erase the image on the Nb plate. We found that 1% hydrofluoric acid solution is able to erase the image, although a ghost image appeared. We also explored how to prevent the ghost image appearance.

12:25 **Control of Titania Layer of Dye-Sensitized Solar Cell (DSC) (Interactive),** *Yuki Nakamura,[1] Kengo Takamori,[2] Yoshihito Kunugi,[1] Satoru Iwamori,[1] and Shinjiro Umezu[2]; [1]Tokai University and [2]Waseda University (Japan)* 370

In recent days, green technology that is based on solar cell is highly focused for sustainable society. So, the efficiency of Si type of solar cell is drastically improved. On the other hand, dye-sensitized solar cell (DSC) is also highly focused because of flexibility and design in spite of low efficiency. To clear the low efficiency problem, many studies on the development of dye and titania were carried out. Because the dye was developed, then the absorbed wavelength became broad and the absorption ratio on each wavelength was increased. Due to the study on titania, unique shapes of titania were suggested and the absorption characteristics were improved. In spite that many studies on chemical view were

carried out, few studies on fabrication process were carried out. So, we focused on fabrication of titania layer of DSC. Usually, the titania layer was fabricated by the doctor blade method or the screen print method. The inside of the fabricated titania layer utilizing the ordinary method had little porous. In the case that the porous titania layer was formed, then the flow of electricity was increased due to the increased surface of titania layer. We applied the electrostatic inkjet method for fabrication of the titania layer because the porous layer was formed due to evaporation effect utilizing the electrostatice inkjet method. We already formed porous titania layer and achieved the efficiency improvement. In this paper, we investigated the fundamental characteristics on fabrication of porous titania layer utilizing the evaporation effect. The experimental set-up to investigate the characteristics was shown as follows. Titania paste was filled with the ink tank. Nozzle was installed at the end of the tank. FTO glass electrode was set on the XY linear stage and the rotation stage. When the high voltage was applied between the nozzle and the glass electrode, small droplets were ejected because the electrostatic inkjet method was took place. Formation and ejection of the small droplets were observed with a high-speed camera and a light. The evaluation of the porous titania layer was carried out with the SEM and XRR. We investigated the characteristics of the porous titania layer in case that the rotation speed was changed.

12:30 **3D Printed Ceramics: Current Challenges and Future Potential,** *David Huson, University of the West of England (UK)* 374

Materials and processes for additive layer manufacture have advanced considerably in the last few years and have moved the application of the technology away from prototyping to fabrication and manufacture. One area that still has little effective presence is that of 3D printed ceramics. Ceramic materials have proved difficult to integrate with 3D printing technologies and there is still a considerable way to go before the characteristics of most of these materials can be considered adequate.

The problems experienced are high firing contractions, low density and strength and potential incompatibility with glazes. For general tableware and giftware ceramics giftware ceramics two main methods of 3D printing are used, paste extrusion through a syringe and fine nozzle and a powder binder system that ink jets binder onto a powder bed containing a mix of ceramic powder and an organic binder.

The paste extrusion system has the advantage that conventional ceramic pastes and bodies can be used but the layer thickness is coarse and there can be problems with maintaining an even extrusion of a thin bead, the main issue with this method however is the restriction on geometric freedom that cannot compete with other 3D printing methods.

The powder/binder process gives the ability to form complex shapes, but has an inherent high porosity due to the burn out of organic binders and the restriction on particle size range required for the process to function correctly. The manufacture of high performance monolithic ceramics such as alumina and zirconia is achieved by using photo cure resins with a high loading of ceramic material, this requires a thermal de-bonding process that results in a very high firing shrinkage that can affect the dimensional stability in the firing/sintering.

The reasons for wanting to use ceramic materials are to utilise their unique properties but the limitations of the available processes make these properties difficult to realise by current additive manufacturing methods.

This paper will review and compare contemporary ceramic additive manufacturing processes and explain why the above issues exist and what potential solutions may be available. The Centre for Fine Print Research at the University of the West of England in Bristol has a history of over eight years research into 3D printed ceramics and has developed and patented materials and processes in this area, and has collaborated with leading ceramic manufacturers and material suppliers in the U.K. to improve and refine the process.

Our ongoing research into this area is exploring potential solutions to these issues including hybrid extrusion/machining for paste extrusion ceramics, colloidal infiltration of preformed powder/binder 3D printed and novel methods of pre-processing the ceramic powders used in powder/binder 3D printing to increase the density and fired performance of the ceramic material.

12:50 **Simulations of Drop Formation in Complex Rheological Fluids – Can Rheology Improve Jetting Performance?,** *Oliver G. Harlen and Neil F. Morrison, University of Leeds (UK)* 378

The processes of jetting and drop formation is strongly affected by fluid rheology, which may be complex, particularly under the extreme conditions of high shear and extensions rates that occur during jetting. Fluids containing a particulate phase are normally shear-thinning and so may have different characteristic viscosities during different key stages of the inkjet flow. Moreover, even trace amounts of long chain polymers can cause substantially different breakup dynamics compared to that of an ordinary (Newtonian) fluid.

In this work we investigate the dependency of jet breakup behaviour upon viscoelastic and shear-thinning effects in the context of drop-on-demand inkjet drop formation. In drop-on-demand printing, each ejected drop remains connected temporarily to the printhead by a trailing ligament of fluid which undergoes capillary thinning while the drop is in flight. Upon pinch-off the severed ligament may recoil downstream towards the leading drop, or alternatively it may fragment into multiple satellite droplets. Whilst complex rheology is often seen as a problem, particularly given the lack of instrumentation able to measure and characterize fluid properties at the appropriate deformation rates and timescales, it also offers a potential solution to controlling satellite drops at higher printing speeds.

We show the results of numerical simulations of drop-on-demand inkjet printing with fluids that exhibit different types of non-Newtonian behaviour (shear-thinning and viscoelasticity) and compare with experiments on model inks. Our aim is to establish the parameter values controlling the break-up length and character of jet breakup. In particular, we examine whether for appropriate choices of rheological parameters it is possible to prevent or impede the creation of satellite drops without compromising on printing speed.

13:10 – 14:30 Lunch Break

14:30 – 17:30 Colleague Connections—Connections for Innovation in Security Printing
see page xxxviii, Renold D7

19:00 – 22:00 Conference Reception
Museum of Science and Industry
Liverpool Road, Manchester, UK

DIGITAL PRINTING APPLICATIONS TRACK

9:00 – 10:10 Thursday Keynote and IS&T Awards, Renold C16, see page vii.

Renold C2

Colleague Connections: Late Breaking News/Success Stories

Session Chair: Werner Zapka, Xaar

10:20 – 11:00

Join colleagues to discuss the latest news in digital printing and printing for fabrication, including technologies introduced at drupa in June.

11:00 – 12:00 Coffee Break and **Interacive Paper Session I,** *Renold C15*

Security Printing

Session Chairs: Hiroshi Yamazaki, The Imaging Society of Japan; Alan Hodgson, Alan Hodgson Consulting Ltd.; and Bob Ulichney, HP Inc.

12:00 – 13:10

12:00 **Security Print Features based on Additive Manufacturing – Threat or Opportunity? (Focal),** *Alan Hodgson[1,2] and Rachel Saunders[2]; [1]Alan Hodgson Consulting Ltd. and [2]University of Manchester (UK)* 382

Additive Manufacturing technologies have the potential to be of significance in the field of secure documents. The aim of this paper is to show with examples areas where these could arise. It concentrates on the areas where Additive Manufacturing can add tactile features to a document as this could well be the area where the technology has earliest significance in security printing.

To a certain extent 2.5D printing already exists in the security sector, but not specifically from the digital domain. It may well be that Additive Manufacturing will initially be a threat to these established features, rather than

a source of new ones. So the paper illustrates the potential for Additive Manufacturing systems to duplicate existing tactile security features and then shows where this knowledge could be the source of new features.

The work also considers the possibility for the fabrication of optical features for secure documents by Additive Manufacturing.

12:30 **Effect of Non-Integer Scaling on the Recovery of Data Bearing Marks,** *Robert Ulichney, Yufang Sun, and Matthew Gaubatz, HP Inc. (USA) and Stephen Pollard, HP Inc. (UK)* 386
The spatial quantization imparted by printed pixels becomes significant when printing finely detailed bitonal images such as data-bearing halftones. This paper explores the consequences non-integer scaling has on data recovery error from such data-bearing marks. We verify that different printer manufacturers use nearest-neighbor scaling, and conducted hundreds of print and mobile camera capture measurements to quantify data recovery errors as a function of printed pixel replication factor. We tested the effects of multiple payloads represented by several data-bearing images, printed on a variety of printers, and captured at different camera distances. The analog print–and–capture experiments are compared with digital simulations, using several error measures. The results support a surprising conclusion: there is no significant advantage in forcing printed pixel replication to be an integer.

12:50 **Comparison of Technologies for Card Printing Applications,** *Mark B. Mizen, HID Global (USA)* . . . 392
The printing of identity cards differs significantly from other printing technologies in that the substrate is well-defined, generally PVC or polycarbonate, and relatively small, typically 2.125" x 3.370." Because the substrate is non-porous, the dyes and pigments used must penetrate into the substrate or be held in place by an adhesive or binder that adheres to the surface or penetrates into it. The simplest printing system capable of producing a printed plastic card is dye sublimation. In this process dyes penetrate into the substrate producing a durable dye-based image. Requirements for edge-to-edge printing as well as the need to print technology cards that may not be perfectly flat have led to retransfer dye sub printing systems, which uses an intermediate transfer ribbon. Finally, electrophotographic and inkjet systems are also present in the market. This presentation will provide a technological assessment comparing advantages and disadvantages of various printing systems, allowing the user to identify the preferred technology for different applications.

13:10 – 14:30 Lunch Break

concurrent event

14:30 – 17:30 Colleague Connections—Connections for Innovation in Security Printing

see page xxxviii, Renold D7

BIOPRINTING

Renold C2

Bioprinting I

Session Chairs: Shinjio Umezu, Waseda University; Liisa Hakola, VTT Research Centre of Finland; and Thomas Boland, University of Texas at El Pasco

14:30 – 17:30

14:30 **Dispensing of Hydrogel Ink onto Electrospun Biodegradable Paper for Biomedical Applications,** *Sandra Stier,[1] Achim Weber,[1,2] and Kirsten Borchers[1,2]; [1]Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB and [2]University of Stuttgart (Germany)* 397
In this contribution we present the development of a biobased hybrid material made from a mechanically stable, paper-like fleece combined with a hydrogel, which mimics the extracellular matrix (ECM) of soft tissue. We used methacryl-modified gelatin as described earlier for the formulation of dispensable hydrogel precursor-solutions (bioinks). By variation of the degree of modification we provided viscous liquid inks and physically gelling inks. After deposition, such bioinks could be chemically crosslinkend by UVB irradiation to form non-soluble hydrogels. We produced cell-free hydrogels as well as hydrogels loaded with human fibroblasts from skin biopsies. Freeform fabrication of thin hydrogel-coatings or of three-dimensional (3D) hydrogel constructs was achieved by application of digital 3D printing (bioprinting). For stabilization of the hydrogels we used fleece substrates produced from the biodegradable polymer poly (L-lactide) (PLA) and the modified biopolymer gelatin by electrospinning. The presence of the biomolecule component in the fleece added a more hydrophilic character to the PLA non-wovens, which was crucial for stable bonding of hydrogel and fleece.

14:50 **Effect of Thermal Inkjet Printing on Bacterial Cells,** *Cornelius C. Dodoo, Paul Stapleton, and Simon Gaisford, University College London (UK)* 402
Ink jetting is a technique with varied applications. The process of bubble/droplet formation of thermal ink jet printers

is one that is known to involve a high temperature. This high temperature is however localized and short-lived. Investigations are hereby carried out to evaluate the effect of thermal droplet formation on bacterial cells. Bacterial viability tests were done by colony plate counting and measurement of bacterial absorbance after thermal ink jetting. Bacterial cells were also printed directly onto agar coated glass slides using different templates and incubated. The effect of thermal ink jetting on bacterial cell wall was also conducted by gram staining ink jetted cells. The results obtained indicated that the process of bubble formation did not have any significant effect on bacterial viability as compared to the pipetted versions. Also, bacteria printed directly onto agar gave colonies similar to templates used in printing. Gram staining experiments revealed that the bacterial cells still maintained ability to give a positive gram stain test.

15:10 **Regenerated Silk Fibroin as Inkjet Printable Biomaterials,** *Yu Zhang, David A. Gregory, Patrick J. Smith, and Xiubo Zhao, University of Sheffield (UK)* 406

Regenerated silk fibroin (RSF) protein is an FDA approved biomaterial and has been used as a bio-ink to fabricate structures using inkjet printing. Silk can be present in water soluble amorphous (Silk I) and water insoluble crystalline conformations (Silk II) made up of beta-sheet structures. Here we show the generation of silk scaffolds by inkjet printing of water soluble RSF inks and then converting them into insoluble beta-sheet (Silk II) structure via a second ink containing methanol. This paper focuses on optimising printing conditions of RSF bio-ink through establishing the relationships between RSF peptide concentrations, number of layers and the total thickness of the printed layers. Various patterns such as dot arrays, lines, films, particles and logos have successfully been fabricated. The emerging of inkjet printing of RSF ink allows us to print delicate silk scaffold patterns for different applications specifically in biomedical field.

15:30 **3D Printed Ultrasound Phantoms for Clinical Training (Interactive),** *James L. Robertson,[1] Emma Hill,[1] Andrew A. Plumb,[1] Simon Choong,[2] Simeon J. West,[2] and Daniil I. Nikitichev[1]; [1]University College London and [2]University College Hospital (UK)* 410

Ultrasound is a ubiquitous, portable structural imaging technique which is used to provide visual feedback for a range of diagnostic and surgical techniques. Training for these techniques demands a range of teaching models tailored for each application. Existing anatomical models are often overly simple or prohibitively expensive, causing difficulties in obtaining patient or procedure specific models. In this study we present ultrasonic rib phantoms for clinical teaching and training purposes, fabricated by three-dimensional (3D) printing technologies. Models were produced using freely available software and data, and their effectiveness as teaching phantoms evaluated using clinical ultrasound scans of the phantoms.

15:35 **A Method for Detecting the Fluorescence-Emission Wavelength and Visualization of Biological Traces (Interactive),** *Yun Zou,[1] Bei Jiang,[2] Wenbin Liu,[1] Xuejun Zhao,[1] Nengbin Cai,[3] Xiaochun Huang,[3] Liuhu Cui,[3] and Xianfeng Chen[2]; [1]Shanghai Research Institute of Criminal Science and Technology, [2]Shanghai Jiao Tong University, and [3]Institute of Forensic Science (China)* 416

The contribution of biological trace detection has been fundamental in forensic cases. This paper describes a method for the rapid and non-destructive method for latent biological trace detection on the surface of the non-porous substrates by laser reflection. The absorption and emission of the biological trace from the spectrophotometer and fluorophotometer are analyzed. Visualization of latent biological traces is realized by femtosecond laser and its parametric amplification system. Applicability of the ultraviolet (UV) from femtosecond laser to latent blood fingerprints detection has rarely been reported, especially in the range of multi-wavelengths laser. Results demonstrated that the latent blood fingerprints can be visualized through UV imaging system instruments.

15:40 – 16:30 Coffee Break and **Interacive Paper Session II,** *Renold C15*

16:30 **The Use of Inkjet Printing and Thermal Phase Change Inks to Create Sacrificial Prevascular Networks,** *Leon Edney, Patrick J. Smith, and Paul Hatton, University of Sheffield (UK)* 419

Within Tissue Engineering one of the greatest challenges is providing cells in an engineered tissue with nutrients and oxygen via blood or serum. The process, otherwise known as perfusion, brings these vital supplies to within 100-200 microns of all cells by means of the vascular network. If perfusion is insufficient cells begin to die (necrosis) which effectively self-regulates cell growth to within 150-200 micron of a diffusive oxygen source and limits the useful thickness of cellularised tissue that can be engineered in vitro. A spectrum of research approaches ranging from cell-based therapies that attempt to induce spontaneous budding of capillary structures to scaffold based therapies that provide a spatial prevascular structure to guide the formation of the vascular network are currently being investigated. This contribution discusses the research that has been undertaken to indirectly fabricate prevascular scaffolds. Inkjet printing is used to make sacrificial three-dimensional microstructures that are initially employed in the production of the biomimetic 3D microfluidic devices. The process is complimented by the use of low temperature thermal phase change materials e.g. Hexadecane and Octadecane, as inks that enable structurally sound three-dimensional microstructures to be constructed, and then sacrificed without damage to the biocompatible materials (gelatin with a variety of cross linking mechanisms) used for the prevascular scaffold.

16:50 **Novel Approach for Predicting Coffee-Ring-Effect in Drying Droplets based on Binary Solvent Mixture from Substance Data,** *Danny Lehmann, Hauke Langner, Vico Haverkamp, and Klaus Krüger, Helmut-Schmidt-University/University of the Federal Armed Forces (Germany)* 424

In this study we present a novel approach using dimensionless numbers that allows for the prediction of ring-like structures in drying ink drops based on binary solvent mixtures by substance data. Mechanisms considered in this approach are suppression of Marangoni-flows due to fast evaporation times as well as the potential strength of Marangoni-flows. The proposed approach is validated experimentally. Single spots based on various solvent compositions are inkjet-printed and characterized with respect to the structure by means of microscopy.

17:10 **In Vivo Characterization of Bioprinted Capillaries,** *Maria Yanez, Julio E. Rincon, and Thomas Boland, The University of Texas at El Paso (USA)* 428

We present two studies that assessed vascularization of implanted bioprinted grafts. The first study involves bioprinted vascular networks build into skin grafts. A modified inkjet printer allowed depositing human microvascular endothelial cells into fibrin networked channels. Neonatal human dermal fibroblast cells and neonatal human epidermal keratinocytes were manually mixed into a collagen matrix, which sandwiched the networks. A full thickness wound was created at the top of the back of athymic nude mice and the graft covered this wound. As control, a commercial Apligraf dressing was used and as a further control, no treatment was done. Wound contraction with the graft improved by up to 10% when compared with the control groups. Histological analysis showed the neoskin having similar appearance than normal skin. Both layers, dermis and epidermis were present with thicknesses resembling normal skin. Immunohistochemistry analysis showed the implanted cells were serving as neo-vessels in the regenerated skin. The second study involved sandwiching the vascular networks into subcutaneous adipose grafts. Volume retention was measured over time. Good graft acceptance was found. Immunohistochemistry analysis revealed the presence of new vessels formation involving the implanted cells. Both studies showed that bioprinted vascular capillaries will incorporate into host tissue, either by direct anastomosis or by being recruited by the host and help form neo-vessels. Although the exact mechanism by which this happens remains to be resolved, the findings point to a faster and more complete incorporation of the grafts into the host tissue. This will allow in the future for more functional tissues being constructed, where survival of the implanted cells is paramount.

19:00 – 22:00 Conference Reception
Museum of Science and Industry
Liverpool Road, Manchester, UK

SECURITY PRINTING WORKSHOP

Moderator: Alan Hodgson, Alan Hodgson Consulting Ltd.
14:30 – 17:30

Renold D7
See details below.

COLLEAGUE CONNECTIONS—CONNECTIONS FOR INNOVATION IN SECURITY PRINTING

Thursday, 14:30 – 17:30 PM
Moderator: Alan Hodgson, Alan Hodgson Consulting Ltd.

The aim of this workshop is to facilitate the connection and building of collaborations around new printing technologies for high value security documents and products. The goal is to bring together a network of participants from across the value chain and together define a roadmap going forward. It focuses on connecting the technical challenges faced by the industry and customers with the resources of universities and start-up companies.

The workshop consists of 3 parts.

1. Three short presentations on the topic from the perspective of a University spin-out, UK technology developer CPI, and the customer perspective.
2. A series of table top group discussions aimed at collating the thoughts of participants
3. A feedback session to collate the results

This workshop is appropriate for anyone with either interest in or a connection to the world of security printing.

Workshop sponsored by

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TECHNOLOGIES IN DIGITAL PHOTO FULFILLMENT 2016

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In cooperation with the Royal Photographic Society.

Renold C9

Welcome Remarks and Company Introductions

Session Chair: Joseph E. LaBarca, Pixel Preservation International (USA)

14:30 – 15:00

Tools and Strategies of Print Preservation

Session Chair: Reiner Fageth, CEWE Stiftung & Co. KGaA

15:10 – 17:30

15:10 **Printing to Preserve—How Are We Doing Today?,** *Joseph E. LaBarca, Pixel Preservation International (USA)*
Much has changed in the digital imaging industry in the last five years. This includes advances in cameras and optics and especially the continued tremendous growth in the use of smartphones. With smartphone in hand more people than ever have a camera ready to shoot at a moment's notice. Yet printing for long term preservation has not followed in this growth. While the number of hard copy prints, including prints and photo books, has increased, the rate of increase has not kept pace with the growth in capture. This means there is a bigger opportunity than ever for photo fulfillment through the production of prints and photo books. There have been positive signs in the industry in terms of photo organization, software for easier layout and design of photo books, and apps to make prints and photo books from the smartphone. But the awareness by end consumers on the risks of technology change and how to access their digital images 10 to 20 years from now is still very low. There have been positive signs on the web addressing this topic but uptake by social media remains low. This paper will discuss the positive trends seen on the web, ongoing trends in hard copy output from the last several years, and ways to further energize the digital photo fulfillment industry on the potential for printing for long term preservation.

15:40 – 16:30 Coffee Break and **Interacive Paper Session II** Renold C15

16:30 Kodak Professional Endura Premier Paper for the Premium Photo Book Market, *Patrick W. Webber, Kodak Alaris (USA)*
There are a wide range of digital print technologies available today for use in photo books. This includes Inkjet, Electro Photographic, Dye Sublimation and Silver Halide. However, only one technology, silver halide paper, incorporates imaging technology and image quality that is the gold standard in the photographic marketplace. This allows providers to exceed consumer expectations for photo book image quality resulting in a delighted customer experience and the ability to offer a premium product in this growing, but crowed category. KODAK PROFESSIONAL ENDURA Premier Paper is a silver halide photographic paper which incorporates new technology specifically for digital printing and continues to advance the state of the art of silver halide technology. In addition to the positive customer experience that silver halide paper provides to the photo book market, the use of ENDURA Premier Paper provides the optimal balance of high image quality, long-term permanence, high productivity, and low cost. This paper will discuss silver halide technology for use in photo books, and specifically how KODAK PROFESSIONAL ENDURA Premier Paper, meets the needs of the premium photo book market. In addition, the paper will discuss how the optimal image longevity performance of KODAK PROFESSIONAL ENDURA Premier Paper provides a solution to the consumer needs for long-term preservation of digital image files using premium photo books, the photo album of the 21st century.

17:00 Original Photopaper Developments and Applications to Further the Advancement and Growth of the Premium Photo Book Segment, *Anthony Pieters and Evert Groen, FUJIFILM Europe B.V. (the Netherlands)*
Original Photopaper is now leading Premium photo book segment, next developments will not only bring the medium segment in reach for Original Photopaper photo books, but will attract also new players into Original Photopaper technology. Listening to customer needs, listening to central lab needs, continuously innovating and the success of honest cost – margin calculations leading to new Original Photopaper developments and its applications. Since first time FUJIFILM is developing papers specific for central lab high speed printing equipment. Next to that FUJIFILM organizes cooperation of best in class Original Photopaper equipment manufacturers who will bring our industry into next era where central lab production will be leading in costs, quality and speed of fulfilling customers needs. It's also the era where pure digital printing companies decide to enter the Original Photopaper production technologies, as we see several companies starting with it the last couple of months.

19:00 – 22:00 Conference Reception

Museum of Science and Industry—Liverpool Road, Manchester, UK

FRIDAY SEPTEMBER 16, 2016

BIOPRINTING TRACK

9:00 – 10:00 Friday Keynote, Renold C16, see page vii.

Renold C16

Bioprinting II

Session Chairs: Koei Suzuki, Ricoh Co., Ltd.; Kirsten Borchers, Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB; Thomas Boland, University of Texas at El Pasco

10:10 – 13:00

10:10 **Fabrication of ZrO2-SiO2 Binary Oxides Scaffold by Inkjet Printing for Bone Tissue Engineering Applications,** *Vasanthavel Subramaniyan, Brian Derby, and Kannan Sanjeevi, University of Manchester (UK)* 429

Musculoskeletal disorders and bone defects have been established as one of the most important diseases affecting human health. The occurrence of bone defects due to the growing number of traffic accidents and osteoporosis have led to demand for mass numbers of bone implants. ZrO_2-SiO_2 binary oxide as a potential candidate with the features of mechanical strength and biocompatibility that precisely mimic the host bone has been synthesized using so-gel technique (1). Fabrication of ZrO_2-SiO_2 binary oxides into 3D porous scaffold is essential for structural stability of the bone implant enables them as a substrate for cells, growth factors and waste removal through their interconnected pores. Stereo lithography (SL) is one the most efficient Rapid Prototyping (RP) technique that has been adopted to fabricate 3D ceramic scaffolds with controlled architecture of desired shape, pore size and interconnectivity (2). The printed scaffold has been analysed for its surface morphology, porosity and interconnectivity through Scanning Electron Microscopy. The mechanical stability of the scaffold has been assessed using compression and bending strength tests.

10:30 **Placenta Vasculature 3D Printed Imaging and Teaching Phantoms,** *D. I. Nikitichev,[1] W. Xia,[1] B. Daher,[1] E. Hill,[1] R. Y. J. Wong,[1] A. L. David,[2] A. E. Desjardins,[1] S. Ourselin,[1] and T. Vercauteren[1]; [1]University College London and [2]University College Hospital (UK)* 431

Three-dimensional printing makes it possible to create patient-specific, complex anatomical geometries that can be used for training, teaching and surgical planning. The human placenta is a vital organ that transports nutrients from the mothers' uterine circulation to the fetus via a complex vasculature. Complications of the fetal vasculature are increasingly being imaged with ultrasound and treated before birth using invasive fetal therapy. There is a need for human placenta training phantoms such as placental anastomoses that occur in monochorionic twin pregnancy and can cause twin-to-twin transfusion syndrome and fetal death, if untreated. In this study we developed two phantoms based on the human placenta using 3D printing technology: an ultrasound imaging phantom and an anatomical teaching model.

10:50 **Printed Electronics and 3D Printing as New Manufacturing Technologies – New Opportunities for Bio-based Materials,** *Tingjie Li, Joseph Aspler, Joelle Grenon, Tony Manfred, Lyne M. Cormier, and Xuejun Zou, FPInnovations (Canada)* 435

Printing has made significant impact on our society and daily life, particularly through process improvement (high speed, high volume) and technology advancement (e.g. digital printing, personalized printing). However, in recent years, the spreading of internet has created significant impact on printing, leading to the decline in demand for graphic printing. Despite these challenges, printing as a well-established technology is now being explored for new applications including printing electronics and 3D printing. With these manufacturing technologies, new opportunities/applications for bio-based materials, including lignocellulosic materials are being explored, as reviewed in this report.

11:10 – 11:40 Coffee Break

11:40 **Reactive Inkjet Printing Applications for Tissue Engineering (Focal),** *Christopher Tse and Patrick Smith, University of Sheffield (UK).* 442

A crosslinking agent (glutaraldehyde) was selectively inkjet printed at predetermined locations onto a sheet of virgin gelatin and washed to create biocompatible scaffolds of bespoke shapes. Fibroblasts were seeded onto these scaffolds and were shown to proliferate with no detrimental effects for 3 days compared to controls. This method of creating biocompatible scaffolds takes advantage of inkjet printing's ability to create complicated designs without compromise at a range of fibre diameters from as thin as 80μm. Fibroblasts were seen to cover the entire surface. Future research will be focused on using such technology in nerve repair.

12:10 **JIST-First Paper Growth-Inhibitory Effect of Chemotherapeutic Drugs Dispensed by Inkjet Bioprinting on Cancer and Non-Cancer Cells,** *Jorge I. Rodríguez-Dévora,[1,2] Mohammod Bhuyan,[2] Daniel Reyna-Soriano[2], and Thomas Boland[2]; [1]Clemson University and [2]University of Texas at El Paso (USA)* 446

Thermal inkjet technology has long been used in the printing industry, but little has been studied on the benefits that it can provide to the drug-screening field. The objective of the work reported here was a proof of concept of using a modified inkjet printer to have a more accessible and miniature cellomic anticancer drug-screening platform. The authors' previous findings have shown that inkjet-based screening can reliably create isolated arrays of spots of living cells and antibiotics at low volume (180 pl) and high throughput (213 spots/sec) [J. I. Rodríguez-Dévora, B. Zhang, D. Reyna, Z. D. Shi, and T. Xu, "High throughput miniature drug-screening platform using bioprinting technology," Biofabrication 4, 035001 (2012)]. The methodology of the work reported here included using a modified office inkjet printing device; the authors studied the inhibitory effects of dichloroacetate sodium (DCA) over hepatocellular carcinoma (HepG2) and epithelial cells (EpC). A DCA drug concentration gradient was printed over cell cultures to evaluate the drug's cytotoxic effect. Half maximal and ninety percent inhibitory concentrations (IC50, IC90) were obtained from the dose–response curves and compared with concentrations obtained using the traditional micropipetting technique. The resulting inhibitory concentration values obtained by both dispensing techniques fall within the millimolar range. The significance of these finding is that the proposed screening platform closely mimics the traditional screening outcome at a miniaturized volume rate, thus downsizing the screening process from traditional sub-microliter to nano- or even picoliter range. Inkjet technology shows promise in miniaturizing and expediting the drug-screening process. This platform can be used to asses a preliminary dose–response curve in order to improve the treatment modalities using the patient's limited supply of biopsied cells toward personalized medicine.

12:30 **Altering the Bubble Release of Reactive Inkjet Printed Silk Micro-Rockets (Focal),** *David A. Gregory, Yu Zhang, Patrick J. Smith, Stephen J. Ebbens, and Xiubo Zhao, University of Sheffield (UK).* 452

A novel approach of using layer-by-layer (LBL) reactive inkjet printing (RIJ) of regenerated silk fibroin (RSF) was used to generate micron-sized silk rockets which have the enzyme catalase immobilised inside the silk scaffold structure and use the catalase enzyme to drive their motion in samples containing H_2O_2 as a fuel. By using the LBL printing approach we show that is it possible to generate 3D structures where different materials can be incorporated into the structure at defined locations. The use of silk together with an inkjet printing method has great potential to easily incorporate different enzymes, proteins, chemicals or other biomolecules and build versatile devices by entrapping them into the silk scaffold. This allows us to generate small-scale devices that can generate thrust via catalytic reactions within fluidic environments for potential applications including environmental monitoring and remediation, in vivo drug delivery and repair, and lab-on-a-chip diagnostics. In contrast, current manufacturing processes of micromotors often use slow and lengthy production processes (e.g. evaporation) combined with expensive materials such as platinum. The location of catalyst on these devices has been shown to influence trajectory behaviour, which is not easy to control using conventional methods. Furthermore devices using platinum as a catalyst can undergo biofouling thus inhibiting their catalytic reactions. By using biocompatible silk scaffolds, created by RIJ, the devices generated here have the potential to overcome all these problems.

13:00 – 14:00 Lunch Break

DIGITAL PRINTING TECHNOLOGIES TRACK

Renold C16

Ink Substrate Interactions

Session Chairs: Maëlle Douaire, Xaar, and Jay C. Bhatt, HP Inc.

14:00 – 15:00

14:00 **The Effect of Nanoparticle Binders and Modified Precipitated Calcium Carbonate on Ink Absorption Behavior in a Multilayered Coating Layer,** *Katriina Mielonen, Teija Laukala, and Kaj Backfolk, Lappeenranta University of Technology (Finland)* 457

The effect of binders and modified precipitated calcium carbonate on ink absorption behavior and print quality in multilayered coating layers was studied. Also the effect of the number of multilayer was investigated, the target being on determining the role of the deposited hydrophilic binder layer. The coating layers of anionic NaCMC and cationic PCC were alternately spray-coated onto the substrate. It was found that a small amount of binder in the outer coating layer improved the print quality, whereas thicker binder layers closed the pores and reduced the print quality. The effect of the first hydrophilic pre-coating layer on ink spreading and absorption in the three-structure coating was relatively small although better than the reference which was free from a pre-coating.

14:20 **Inkjet Alchemy – Inkjet Printing of Thin Metal Oxide Films with Dichroic and Metallic Appearance,** *Vladek Kasperchik, Vladimir Jakubek, and Jay C. Bhatt, HP Inc. (USA)* 461

In this paper, we describe a new way of producing digital prints with high reflectivity and dichroic or metallic appearance. The special visual effect is achieved using conventional office class inkjet printers and jetting inks containing metal oxide nano-particles onto surface of nano-porous substrates, such as inkjet photo papers. A thin metal oxide layer of uniform thickness in ~10-1000μm range may be produced almost instantly by ambient drying of the print. The formation of metal oxide layer of highly uniform thickness is a result of interaction of metal oxide ink with surface of inkjet media of certain pore structure and high volume porosity. Capillary forces drain liquid phase of the ink into the substrate, while retaining the nanoparticles on the surface. These forces also help to flatten jetted metal oxide particles into optically uniform and continuous layer with high optical reflectivity.

The appearance of the films produced is highly dependent on refractive index, native coloration and printed layer thickness of the metal oxide used. Inks based on magnetite (Fe3O4, refractive index ~2.5) printed into layers with ~ 50-100-nm thickness produce prints with visual appearance of metallic gold. Inkjet printing may also be used for stacking high refractive index metal oxide films with layers of conventional colorants (organic pigment particles) and produce prints with metallic color appearance.

14:40 **Controlling "Coffee Staining" Effect of Inkjet-Printed Droplets from Graphene Oxide Inks,** *Pei He and Brian Derby, University of Manchester (UK)* 466

Here, we investigate the formation of inkjet-printed graphene oxide (GO) droplets with different flake size. It is shown that the size of GO flakes has strong influence to the drop morphology and can be used to control the CRE. The CRE was eliminated gradually with increased mean GO flake size (from 0.68 to ~ 36 μm). The result suggests a new strategy to control the CRE, and our observation about the morphology of inkjet-printed droplets with different flake size will be very effective to print uniform two-dimensional materials based patterns.

15:30 – 17:00 Optional Behind-the-Scenes Tours

MATERIALS, METHODS, AND PERFORMANCE TRACK

9:00 – 10:00 Friday Keynote, Renold C16, see page vii.

Renold C2

Physics and Chemistry of Materials II

Session Chairs: Atsushi Tomotake, Konica Minolta Inc.; Frits Dijksman, University of Twente; and Jim Stasiak, HP Inc.

10:10 – 14:20

10:10 **Hi Resolution Inkjet Printing of OLEDs at Merck,** *Daniel Walker,[1] Hamish Leith,[1] Lisa Duff,[1] Li Wei Tan,[1] Hsin-Rong Tseng,[2] Thorsten Schenk,[2] and Peter Levermore[2]; [1]Merck Chemicals Ltd. (UK) and [2]Merck KGaA (Germany).* 469

We report performance of an inkjet printed OLED device suitable for a 55 inch display at 4k2k resolution. Device efficiency, voltage, emission spectra and lifetime are presented and the effect of the uniformity of the printed layers on these parameters is discussed. The manuscript then goes on to discuss the readiness of inkjet print technology and the requirements of the inks for producing high resolution OLED displays.

10:30 **Fully Solution Processed Organic Light-Emitting Electrochemical Cells (OLEC) with ZnO Interlayer for Lab-on-Chip Applications,** *Zhe Shu,[1,2] Erik Beckert,[2] Ramona Eberhardt,[2] and Andreas Tuennermann[1,2]; [1]Friedrich Schiller University Jena and [2]Fraunhofer Institute for Applied Optics and Precision Engineering IOF (Germany)* 472

Microfluidic lab-on-a-chip devices can be used for chemical and biological analyses such as DNA tests or environmental monitoring. In order to make a monolithic and cost-efficient/disposable sensing device, direct integration of excitation light source for fluorescent sensing is often required. A manufacturing process for fully solution-processed blue organic light-emitting electrochemical cells (OLECs) is presented, which consist of pre-patterned ITO, spin-coated ZnO buffer layer and blue light-emitting polymer plus dopants and an inkjet-printed PEDOT:PSS transparent top anode. Furthermore, the fully transparent blue OLEC is able to emit > 2000 cd/m2 light under pulsed driving mode, which fulfils requirements for simple fluorescent on-chip sensing applications. Furthermore, ITO electrodes can be replace by PEDOT:PSS transparent electrodes when a ZnO interlayer is solution processed on top, which enable the mask-free and fully solution processing integration on chips.

10:50 **Application of Vinylcarbonates as Low-Toxic Monomers in Digital Inkjet Inks,** *Matthias Edler,[1] Florian H. Mostegel,[1] Meinhart Roth,[1] Andreas Oesterreicher,[1] Richard Piock,[2] and Thomas Griesser[1]; [1]Montanuniversitaet Leoben and [2]Durst Phototechnik DIT GmbH (Austria)* 475

During the last decade, the research on digital inks has seen a strong increase with the focus to bring this technique into new markets. In this regard, many experts predict huge market potential for ink-jet inks for printing on food packaging, textiles and garments. However, commercially available inks contain noxious substances or solvents, which limit or completely prevent their application in these specific fields. Especially, UV-curable inks that offer unique advantages such as instantaneous drying, the absence of VOCs, good adhesion on substrates and excellent film forming properties consist of precarious monomers mainly based on (meth)acrylates.

One remarkable drawback of (meth)acrylates is their comparably high irritancy and even cytotoxicity in their uncured state. This disadvantageous behaviour can be mainly attributed to the reactivity of the acrylate double bond towards Michael Addition reactions with amino- or thiol-groups of proteins or DNA. This fact together with the incomplete curing behavior of (meth)acrylates prevents their usability for substrates which are in contact with food or the human body.

Recently, several radical curable functionalities such as vinylcarbonates, vinylesters and vinylcarbamates have been introduced as interesting alternatives to (meth)acrylate based resins providing a significant lower cytotoxicity.

The focus of this work was to evaluate vinylcarbonates as reactive building blocks in UV- curable digital inks in order to overcome the health issues which are related to (meth)arylates. For that purpose, a multitude of vinylcarbonate monomers was synthesized and studied regarding their reactivity, conversion and printability.

Although, the viscosity and surface tension of these monomers are appropriate for ink-jet printing, the curing speed is far too low for high speed printing processes. One possibility to circumvent this limitation is to use thiol-vinylcarbonate formulations offering reactivities and double bond conversions (DBC) similar to those of acrylates. For that purpose, a multifunctional thiol was synthesized providing low odour and also an appropriate low viscosity facilitating the formulation of pigmented ink-jet inks. These basic digital inks offer an excellent jetting behaviour together with good film forming properties and adhesion on PET. Ongoing experiments concentrate on the storage stability of this system to allow the implementation of these thiol-vinylcarbonate inks in industrial printing processes.

11:10 – 11:40 Coffee Break

11:40 **Sub-Micron Patterning of Polymer Brushes by Controllable Deposition of Polyelectrolyte Monolayers (Focal),** *Adam V. S. Parry,[1] Alexander J. Straub,[1,2] Lianne M. Jordan,[1] Aadil Patel,[1] Stephen G. Yeates,[1] and Steve Edmondson[1]; [1]University of Manchester (UK) and [2]Universitat Freiburg (Germany)* 477

The controlled deposition of polyelectrolyte macroinitiators for polymer brush growth is investigated. High resolution patterns are created for periodic array gratings towards responsive polymer brush sensors. Further, controlling the segregation of the macroinitiator to the droplet edge by careful manipulation of the constituent solutes leads to sub-micron patterning of polymer brushes.

12:10 **Inkjet Printing of Graphene Inks for Wearable Electronic Applications,** *Shaila Afroj, Mohammad Nazmul Karim, Amor Abdelkader, Alexander Casson, and Stephen Yeates, University of Manchester (UK)* 480

Inkjet printing of graphene-based conductive inks is an encouraging research approach in the field of printed electronics as both the benefits of inkjet printing and extra-ordinary electronic, optical and mechanical properties of graphene can be exploited. Inkjet printing is one of the most promising techniques for the fabrication of wearable electronics due to number of advantages over conventional manufacturing techniques such as digital and additive patterning, reduction in material waste, deposition of controlled amount of materials and compatibility with various substrates. In addition, graphene is a single atom thick two-dimensional closely packed honeycomb lattice of sp2 carbon allotropes, which has been focus of mass investigations in recent years because of its unique physical and chemical properties.

Currently silver nanoparticles (NPs) as inkjet printing inks are the most reported and utilised conductive inks because of their excellent electrical conductivity and strong antioxidant characteristics. However higher concentration of NPs and higher sintering temperatures are required in order to obtain continuous metallic phase, with numerous percolation paths between metal particles within the printed pattern, which increased processing cost and limited the choice of substrates to be printed because of their heat sensitivity. Inkjet printing of reduced graphene oxide (rGO) are reported in several studies as a popular choice to fabricate wearable devices due its advantages such as readily dispersible in water and high volume production at lower cost. However large number of unreduced oxygen-containing functional groups and inter-sheet junctions between the graphene domains limits the conductivity achieved with rGO. In order to overcome the limitations associated with rGO inkjet inks, pristine graphene inks were developed and printed.

Herein we report exfoliation of pristine graphene dispersions produced in gram scale quantities based on literature review. Liquid phase exfoliation method was used by shear mixing in the presence of a polymer stabilizer, ethyl cellulose which enhances the ink stability as well as printing performance. To formulate ink for inkjet printing graphene/ethyl cellulose powder was directly dispersed in a mixture of solvents by bath sonication. Then the formulated inks were successfully inkjet printed onto textile substrate in order to fabricate an Electro-Oculogram (EOG) device for healthcare applications, Figure 1.

12:30 **Multi-Functional Carbon Fibre Composites Obtained Using Inkjet Printed Polyme (Focal),** *Patrick J. Smith and Yi Zhang, University of Sheffield (UK)* 482

Tougher and stronger carbon fibre reinforced composites have been prepared using inkjet printing to deposit discrete polymer droplets onto the composite precursor. The polymer system that has been inkjet printed is a dual material system, in which half of the deposited droplets contain PMMA and the other half contain PEG.

The resultant uni-directional carbon fibre reinforced composite exhibits improved mechanical properties with a barely noticeable increase in weight. For the dual material PMMA & PEG system, mode I interlaminar fracture toughness is increased by 40%, with evidence that higher values are possible. Additionally, initial experiments indicate that a significant increase (~5%) in apparent interlaminar shear strength is also observed.

13:00 – 14:00 Lunch Break

14:00 **JIST-First Paper Liquid Exfoliation of Layered Materials in Water for Inkjet Prinitng,** *Viviane Forsberg, Renyun Zhang, Henrik Andersson, Joakim Bäckström, Christina Dahlström, Magnus Norgren, Britta Andres, and Håkan Olin; Mid Sweden University (Sweden)* 486

MoS_2 is a layered material which is abundant and non-toxic and has been increasingly studied during the last few years as a semiconducting alternative to graphene. While most studies have been performed on single MoS_2 nanosheets, for example to demonstrate high-performance electronic transistors, more work is needed to explore the use of MoS_2 in printed electronics. The importance of using MoS_2 as a printed electronic material could be understood by considering the several orders higher electron mobility in MoS_2, even in several nanometer thick layers, compared to the organic and other materials used today. In the few studies performed so far on printing MoS_2, the developed dispersions used mainly organic solvents that might be detrimental for the environment. Here, we show an environmentally friendly liquid-based exfoliation method in water where the solution was stabilized by sodium dodecyl sulfate (SDS) surfactant. The dispersions consisted of very thin MoS_2 nanosheets with average lateral size of about 150 nm, surface tension of 28 mN m^{-1} and a shelf life of a year. Although both the concentration and viscosity was less than optimal, we were able to inkjet print the MoS_2 solution on paper and on PET films, using multiple printing passes. By tuning the concentration/viscosity, this approach might lead to an environmentally friendly MoS_2 ink suitable for printed electronics.

Laser Imaging and Patterning

Session Chairs: Teruaki Mitsuya, Ricoh Co., Ltd. and Jim Mrvos, Lexmark International, Inc.

14:20 – 15:10

14:20 **Development for Secondary Color Graininess Separation Method for the Electrophotographic Imaging (Focal),** *Yumiko Kishi, Kazuki Funahashi, and Makoto Hino, Ricoh Co., Ltd. (Japan)*. . . . 493

To improve the graininess of electrophotographic images, it is important to determine not only graininess values but also the root cause of graininess deterioration so as to provide feedback for use in electrophotographic image system development. In a previous report, a graininess separation method for clarifying the cause of graininess deterioration and its use to optimize an electrophotographic system was reported. It was clarified that using the method improved image processing, achieved better graininess, and made system development more effective. The method separates image graininess into 1) lightness fluctuation in background areas, 2) lightness fluctuation in dotted areas, and 3) dot size fluctuation. These factors are the root cause of image graininess deterioration. Therefore, being able to clarify the effect each factor has on graininess makes it possible to improve electrographic systems easily. This report describes a graininess separation devised for secondary images and examines its validity. The method makes it possible to identify the cause of graininess degradation merely by taking a picture of an arbitrary secondary colour image. It also makes it possible to assume what colours need to be improved and what processing of the system need to be optimized. By using this method, electrophotographic system can be optimized efficiently.

14:50 **Laser Color Marking Using Thermo-Sensitive Recording Paper – Study of Condition for Magenta and Cyan Development,** *Nobuki Nemoto, Fumitoshi Morimoto, Kengo Wakamatsu, Yoko Todo, and Yoshihiro Ishikawa, Toshiba Corp., and Ryoichi Umezawa, Nidec Copal Corp. (Japan)*. 498

Direct laser marking techniques are widely used for various applications. Laser marking method has technical issues for full-color marking due to its printing principles. We have conducted the study of condition for single magenta and cyan developing in the direct color marking method which selectively develops three color layers by direct laser irradiation to thermo-sensitive recording paper. We tried to estimate duration time for heating by thermal transfer simulation with one-dimensional model and conducted study of condition of laser irradiation based on a result of thermal transfer simulation As a result of the condition study, we revealed that non-contact direct single magenta and cyan color marking with laser was possible using our method. In this paper, we report on process to develop single magenta and cyan by laser irradiation.

15:30 – 17:00 Optional Behind-the-Scenes Tours

TECHNOLOGIES IN DIGITAL PHOTO FULFILLMENT 2016

**Note that papers from the 7th International Symposium on Technologies in Digital Photo Fulfillment 2016 are available for free download on the IS&T digital library, and are not considered, nor cited, as part of the Printing for Fabrication Proceedings.*

In cooperation with the Royal Photographic Society.

Renold C9

Photo Book Construction and Preservation

Session Chair: Ina Hilker, Felix Schoeller

10:10 – 12:10

10:10 Long-Term Digital Preservation of Photo Books, *Mark B. Mizen, All About Images (USA)*

Preservation of photo books extends beyond simply preserving the physical object. Preservation requires understanding the photo book production process, which begins with taking digital photos, includes digital file creation, and extends to manufacturing the book in its final form. Unfortunately, the intermediate steps are often lost, with manufacturers generally unwilling to supply intermediate files in some false belief that doing so threatens future profitability. Overall, this business practice is short-sighted and is in fact counterproductive when it comes to photo book preservation.

10:40 Using Technology to Acquire Customers in the Personalised Photo Market, *Dianne Moralee, Taopix Limited (USA)*

Taopix will present a live demonstration of a personalised photo platform that includes image upload, automated image placement, creation tools, order and payment for photo products and post-order functions such as 'Send to a Friend'.

11:10 – 11:40 Coffee Break

11:40 Customer Photo Books for the Future, *Brigitte Peleman-Vantieghem, Luc Augustinus, and Bruno Herroelen, Peleman Industries, Inc. (USA)*

Unibind leads the evolution of the PhotoBook with 2 new innovations. Herewith is the first innovation for the inside of the PhotoBook with the lay flat paper solution call UniPaper. This new product of Unibind brings the solution for the lay flat paper: The UniPaper.

The first photobooks were the evolution from the albums, where pictures were fixed with glue or with other attachments. These albums were made with heavy paper and the need for lay flat was not a point, seen the different pictures in the same paper. Previously there were no panorama cameras for panorama pictures. Recently cameras were developed with the very wide angle or with a movie application, both resulting in pictures with a double landscape view. Since the double landscape picture exists, and if the printer can print these double landscapes, then the industry of photobooks must develop also photobooks with these double landscape printed paper.

Unibind has developed this solution, the UniPaper, thanks to the special folding technique and thanks to the system of binding based on the steel channel. The main requirement for Customer Photo Books in the future must lay flat when open. Punching holes in the beautiful pictures is not acceptable now. Only binding with resin will be acceptable in the future. The lay Flat will be an absolute condition, but resin binding and Lay Flat are conflicting. Today there are only (2) possibilities to combine in a positive way for the resin to Lay Flat by specifically treating the paper for this purpose by either:

Made in the factory with the paper selected by the user-printer.

Made in the printer factory with the paper before or after the print.

UniPaper will economically be less costly.

Factors that Influence Permanence and Durability of Photo Books

Session Chair: Alan Hodgson, Alan Hodgson Consulting, Ltd.

12:30 – 15:00

12:30 Safety of Freezing Inkjet Prints for Long Term Storage, *Ivey Barker and Daniel Burge, Image Permanence Institute, Rochester of Institute of Technology (USA)*

Through the history of inkjet printing, a wide variety of colorants, coatings, and supports have been used to create fine art and professional photographs collected by museums and other cultural institutions. These materials have

shown, through anecdotal experience as well as scientific study, a high degree of variability with respect to decay under room condition storage. Theory, as well as experimentation, has indicated that progressively lower storage temperatures should result in progressively longer lifespans. However, there is concern that crossing the threshold into freezing conditions could have adverse effects on the image quality of prints or the physical integrity of coatings and supports as has been found with other fine art and photographic materials through history. The experiments in this project investigated whether freezing and thawing would significantly alter the physical integrity or visual appearance of inkjet prints. Printed targets and non-printed sheets were tested for a variety of common deterioration forms including ink bleed, paper yellowing, change in gloss, coating embrittlement, and increase in abrasion sensitivity. Non-frozen controls and samples that had been frozen at -12° Celsius for one week and then thawed were tested and compared for the above types of decay. The freezing and thawing was shown to have no adverse effects on the prints. Freezing conditions can therefore be used as a storage option to maximize life expectancy for these materials. Validation of the use of below freezing temperature storage conditions for these materials is a critical addition to the literature on the subject of inkjet print care.

13:00 – 14:00 Lunch Break

14:00 **Photo Book Permanence and Durability Standards and Their Impact on the Fulfillment Industry,** *Stuart T. Gordon, Kodak Alaris (USA)*

Standardized testing and reporting of image permanence and durability performance using ISO standardized methods allows photo fulfillment companies to assess and promote product performance in a way that is easily comparable by both professional fulfillment laboratories and consumers. A previous paper reviewed standards being developed to test the performance of printed pages. This paper will focus on the development of a test method standard for photo book durability that will provide a common testing platform for photo book producers to help create high quality products in this important growth category.

14:30 **A Guide for the Assessment and Mitigation of Bleed, Gloss Change, and Mold in Inkjet Prints During High-Humidity Conditions,** *Jennifer Burger, University of Rochester, and Daniel Burge, Image Permanence Institute (USA)*

The purpose of this project was to define the absolute ceiling limits for time and relative humidity (RH) combinations at room temperature to prevent damage to inkjet printed materials in museums, libraries, and archives when they are inadvertently exposed to short-term high-humidity conditions (under 28 days). Unintentional elevated humidity exposure can occur during HVAC malfunctions, transport, following water emergencies, and in uncontrolled storage or exhibition areas. Previous research has shown that colorant bleed, gloss change, and mold germination are the three most common forms of inkjet deterioration during high-humidity conditions. In order to provide collections care professionals with the necessary information to mitigate all three deterioration types, time limits for each needed to be compiled into a single, concise guide. Data on ink bleed and mold germination limits were collected from previous research, while the gloss change data required further experimental investigation. Gloss change experiments were performed with dye on polymer-coated RC paper, as previous studies have shown this ink/paper combination to be particularly sensitive to gloss change during exposure to elevated humidity. During the tests, samples were exposed to a series of time and RH variations. The results showed that while prints can be sensitive to gloss change at elevated humidities, inkjet prints are even more sensitive to colorant bleed, which is therefore the limiting factor. A guide for RH deterioration mitigation was developed and can now be used to predict how prints have or will respond to elevated humidity exposure for times less than 28 days. While all inkjet print types should be safe at humidities at or below 65% for up to 28 days, relative humidity exposures above 80% should be avoided at all costs as the most sensitive print types will likely be damaged within 24 hours. The guide provides predictive times to damage for RH values between 65% and 80% that can be interpolated to determine risk at these intermediate conditions.

15:30 – 17:00 Optional Behind-the-Scenes Tours

Author Index

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