SIMTech Flexible and Printed Electronics

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Outline of Presentation

- Brief Background on FPE
- SIMTech FPE Design and Simulation
- SIMTech FPE Materials Development
- SIMTech FPE Equipment and Processes
- SIMTech FPE Industry Collaboration Highlight
**Flexible and Printed Electronics**

**Flexible electronics** is a technology for building electronic devices and integrated circuits or mounting electronic devices on **flexible substrates** such as plastic, textile, paper or metallic foil. They are lightweight, rugged, bendable, rollable, portable, and potentially foldable.

**Printed electronics** is a set of printing methods used to create electronic devices on various substrates. Printing typically uses common printing equipment suitable for defining patterns on material, such as screen printing, flexography, gravure, offset lithography, and inkjet.
Market Size

- IDTechEx predicted that the total market for printed, flexible and organic electronics will grow from $26.54 billion in 2016 to $69.03 billion in 2026.
- We need to grow the flexible & printed electronics industry in Singapore to grasp the business opportunities and enhance our manufacturing competitiveness.
Industry Drivers for Adoption

- Low manufacturing cost
- Large scale and mass production
- Direct printing, coating and patterning
- Less processing steps
- Lightweight, thin, flexible, wearable and portable
- Environmentally friendly
Applications

Logic/Memory:
- Transistors
- On/off display
- Computer memory

Chemical Sensor:
- Biosensors
- PH sensors
- Gas and vapor sensor
- Ion sensors

Lighting:
- General lighting
- Backlighting
- Furniture, art etc.

Energy:
- Solar Cells
- Flexible Battery
- Supercapacitors
- Energy Harvesting

Display:
- OLED
- Electrophoretic/E-wetting
- Electrochromic

Wearable:
- Textiles and fashion
- Health and medical
- Wrist
- Glasses

Physical Sensor:
- Pressure
- Temperature
- Photodetector

Others:
- Smart packaging
- Printed heater
- EMI shielding
- RFID antenna

SIMTech
for Industry
Technical Challenges and Capabilities Needed

**Design, Modeling & Simulation**
- Device configurations
- Circuitry (stretchability)
- Circuit dimension (x, y, z)
- Pitch size
- Performance and reliability

**Printing Processes**
- Slot die coating, Doctor blade
- Gravure, screen & inkjet printing
- Dimension accuracy (x, y, z)
- Consistency & repeatability
- Fulfill specific requirements
- Products
- Performance

**Printing Materials & Inks**
- Electrodes
- Circuitry
- Functional materials and inks
- Substrate (flexible & stretchable)
- Dielectric
- Barrier films

**Post Processing:**
- Curing: UV or thermal
- Sintering: IR and laser
- Thermal forming
- ALD deposition
- PECVD deposition
- Encapsulation and Lamination

**R2R System & Control**
- ALD equipment
- Atmosphere plasma
- Atmosphere PECVD
- Vacuum roll-to-roll
- Tension, alignment & overlay accuracy
- Packaging and assembly equipment

**Interconnect Materials & Microjoining**
- Ag, solder, adhesives
- Microjoining techniques
- Encapsulation and reliability
- Compatibility with roll-to-roll?

**Inspection/Measurement/Reliability/Standards/QC/QA:** In-line and off-line Inspection/Measurement, Reliability/Standards/QC/QA, Documentation, data inventory and library

**Applications:** Lighting, Display, Sensors, Logic/Memory, Energy, Smart Packaging, FHE, Wearable, IoT, etc
Design of Printed Electric Circuit

Research Issues:
- Electronic devices which maintain their electrical properties upon stretching are desirable for various **wearable applications**.
- **Printing electric circuits** on flexible & stretchable polymer films and integrating the printed circuit with LED devices for stretchable light matrix.

Achievements:
- Large area printed bi-axially stretchable LED matrix with stretchability beyond 40% is demonstrated.
- Despite the larger dimensions, these devices are able to exhibit large stretchability (up to 40%), which is sufficient for wearable electronics
- It provides a low cost and scalable method to fabricate large area stretchable devices.

Industry Relevance:
IOT, wearable electronics, flexible electronics

CFD Simulation of Gravure Printing Process

Research Issue
• To explore complete process steps and find the optimal processing parameters in gravure printing
• To simulate ink acquisition and ink dosing of blade by 3D CFD model.
• To simulate roller-ink-substrate interaction for ink transfer & ink wetting by 2D CFD model

Achievements and Features
• It was found that positive blade angle is critical for residue-less ink dosing
• Contact angle of substrate needs to be less than 30° for satisfactory dot-connection
• Ink volume transfer saturates at depth of 45 µm for 35 µm cell
• Able to achieve engraved cell size of 10 µm and printed line width of 20 µm

Industry Relevance
• CFD model can be used to predict optimal processing parameters
• Gravure printing will be used for TC films, printed fine lines for functional devices
Ag Nanowire Ink for Transparent Conductive Film

Research Issues:
• Formulate transparent conductive ink with high transmittance and high conductivity
• Process compatibility & scalability with roll-to-roll printing/coating processes

Achievements:
• Synthesized long and uniform Ag NWs of 20 μm (The longest achieved 250 μm).
• Synthesized world’s smallest Ag nanowire screws: 10 μm length, 80 nm diameter.
• Automated production of long Ag NWs with excellent repeatability and easy scaling up with 32 g/batch or 100 g/day with 2.5 L reactor.
• Optimal ink feeding rate of 15 ml/min for 3 m/min web speed and 170 mm-wide TCF with 0.1 g/m² AgNWs, resulting in TCF with $R = 31.7 \, \Omega/\text{sq}$, $T = 83\%$.
• Cost: $\leq S$5/m² (comparing with ITO: S$15/m² with $R = 90\text{-}120 \, \Omega/\text{sq}$ & $T > 82\%$)

Industry Relevance:
Printed lighting, transparent touch sensor, transparent NFC antenna and EMI shielding.
Carbon Nanomaterials Based Ink

Research Issues:
• Formulate CNT and graphene inks for roll-to-roll printing
• Achieve desired electrical conductivity and optical transparency

Achievements:
• Flexible, transparent CNT and graphene film with >50% increase in conductivity compared to commercial film
• Potentially stretchable due to the flexibility nature of CNTs and graphene.
• Hybrid ink with other nanomaterials/conductive solutions for tunable transparency and conductivity
• New electrodes for energy devices
• Laser process for layers’ patterning and device fabrication

Industry Relevance:
Electronics, MedTech, Transistor, Sensor, etc.

X.N. Ho, J. Wei, “Films of Carbon Nanomaterials for Transparent Conductors”, Materials, 6(6), (27 May 2013) 2155-2181
1000 mm Web-width Roll-to-Roll Pilot Line

Research Issue
• Large area roll-to-roll coating with good uniformity
• Large area printing with fine patterns
• Large area structuring with small features

Achievements and Features
• Integrated capabilities: coating (slot die & doctor blade), printing (rotary screen printing & gravure printing), embossing (UV and thermal), sintering, lamination, inspection, web handling and process monitoring for large area R2R processing.
• Printing speed: up to 30m/min;
• Tension control: 2-10 kg +/-10%
• Thin layer: 200nm ±10%; Thick layer: 50μm ±10%
• 50μm ±10% patterns; 50μm ±10% line/space
• Registration & Alignment: Cross web: ≤ 100μm; Along web: ≤ 100μm; Overlay: ≤ 100μm

Industry Relevance
Printed and flexible electronics such as lighting, displays, batteries, photovoltaics, logic & memory, sensors and conductors etc.
300 mm Web-width Roll-to-Roll Test Line

Research Issue
- Design R2R printing system with high accuracy tension control, speed control and web guiding
- Enhance and improve printing and coating quality

Achievements and Features
- The newly developed 300 mm web-width roll-to-roll line includes slot die coating, doctor blade coating, gravure printing and lamination modules.
- The temperature of ovens (three thermal ovens and one IR oven) can be tuned for different curing profile.
- Precise tension control (disturbance less than 0.5N) and web alignment (variation less than 100 µm) were achieved.
- Printing/coating speed: 0.5 - 15 m/min or 1 - 30 m/min

Industry Relevance
EL films, EL lighting strips and double-side lighting EL panels
Achievements:
• Parametric analysis of in-situ slot deposition
• Multilayer patterning for web width of 10mm to 1000 mm
• Thin film thickness: 300 nm +/- 10%
• Mono layer deposition of phosphor particles on PET substrate.
• Demonstrated for fabricating large area printed lighting films

Industry Relevance:
Building, Smart packaging, Electronics, MedTech, etc
**Roll-to-Roll Screen Printing**

**Research Issues:**
- Ink volume transfer mechanism in the rotary screen printing process for predicting printed layer geometry
- In-situ control of printed layer geometry

**Achievements:**
- Parametric analysis of in-situ screen printed deposition
- Roll-to-roll screen printing coarse to fine features up to 150µm±15%
- Roll-to-roll multilayer screen printing, 100 µm accuracy
- Demonstrated to print heaters and RFID antennas operating at frequency of 13.56MHz

**Industry Relevance:**
Building, Automotive, Electronics, MedTech, etc
**Achievements:**
- Seamless engraving of cells across cylinder circumference, fully populated cells with 10 µm gap
- Optimized process for 20 µm line width
- Cell depth of 75 µm for uniform coating, 6.5 µm Ag thickness, Ag electrode thickness on printed lighting was successfully reduced by two thirds
- Ag ink material cost reduced by 40%
- Without significant changes on lighting performance
  - Brightness of 300~350 lux
  - Color temperature of >10,000 °K

**Industry Relevance:**
Building, Automotive, Electronics, MedTech, etc

**Research Issues:**
- Engraved cell width of 10~35 µm
- Controlled formation of ink droplets to achieve connected line
- Reduce Ag electrode material thickness by converting slot coating to gravure printing process
In-situ Photonic Sintering for Roll-to-Roll Printing

Research Issues:
• Sinter printed circuits on flexible and thermal sensitive polymers commonly used in roll-to-roll applications
• Sinter large printed areas at fast speed and reduce thermal effect on substrates

Achievements:
• The photonic sintering process of screen printed Ag particles by both Laser / Xenon flash lamp established
• The sintering processes of screen printed Cu and CuO particles on PET and PI polymer film by Xenon flash lamp
• An in-situ photonic hybrid sintering process (photonic + oven heating) for roll to roll printing
• Increased circuit conductivity deposited onto polymers at faster rate than thermal convective oven

Industry Relevance:
Localized faster sintering for printed and flexible electronics
Laser Ablation for Scanning Patterns

Research Issues:
• Laser stripping and patterning of high temperature coating materials on low T polymer substrates with minimal thermally induced damage to the substrate.

Achievements:
• Laser isolation of electrical conduction at high speed greater than 300 mm/s was achieved with low cost, IR wavelength, nanosecond pulse laser.
• Stripped width as small as 30 µm with sharp edges was achieved, compared with originally intended <100 µm.
• Minimal thermal effect was achieved with appropriate control of the laser pulse energy deposition rate and pulse-to-pulse overlap in order to ensure most of the heat is carried away by the vaporisation of the coating material with every laser pulse.

Industry Relevance:
• Large area localized dry patterning
Roll-to-Roll Double-Sided Printed EL Lighting

Research Issues:
• A double-sided EL lighting which light can be viewed from either side, had been fabricated with single EL structure via roll-to-roll process

Achievements:
• Structure design involve various transparent materials (ITO, PEDOT:PSS & Ag nanowire) as front/rear electrodes and development of transparent dielectric layer.
• Hybrid organic/inorganic dielectric ink with fluoropolymers/cyanoresins and barium titanate enhances 35% brightness output due to increment of overall capacitance of the EL.
• When the power is on, the film is still translucent but emits light from both sides.
• Thinner double sided EL (75% thickness reduction) with more flexibility compare to conventional method that placing two EL panels back to back.

Industry Relevance
Lighting, advertisement, furniture, building (e.g. window, door, partition wall, rooftop, etc.)
Highly Sensitive Flexible Tactile Sensor Arrays

Research Issues:
• To make tactile sensors with flexibility and high sensitivity at low pressure (<1 kPa).
• The inherent stiffness and brittleness of piezoresistive semiconductors render them unsuitable for flexible devices.

Achievements:
• The microstructured graphene arrays served as the pressure sensitive layer were fabricated on the PDMS substrates by a simple layer-by-layer assembly process.
• Demonstrated an ultra-high sensitivity at low pressure range (~5.5 kPa⁻¹, <100 Pa), a very low detection limit of 1.5 Pa, as well as an ultra-fast response time (0.2 ms).

Industry Relevance:
Prosthesis, robotics, human-machine interfaces.

Wearable Resistive Strain Sensor

Research Issues:
• Hot pressed nanowire network undergoes reversible deformation, making it an ideal strain gauge.
• Nanowire network on elastomer for wearable applications.

Achievements:
• With surface coverage of 72, 96 and 120 mg/m² Ag nanowire, the sheet resistances are 154±46, 35±13 and 15±4 Ω sq⁻¹ and transmittance of the films are 86%, 82% and 77% respectively
• Sensitivity of strain gauge and measurable strain range can be tuned based on demands of applications.

Industry Relevance:
IOT, wearable electronics, flexible electronics

Capacitive Touch Sensors

Research Issues:
• Develop integrated control platform for printed lighting inverter and capacitive touch sensor.
• Printed flexible circuitry on low cost polyester sheet as alternative to conventional rigid board.

Achievement
• Printed capacitive touch sensors on PET and polyester substrates with conductive ink and transparent conductive ink were demonstrated for touch panel applications.
• Buttons, slides/radial slides were demonstrated for touch sensing application.
• Transparent conductive ink PEDOT was used to illuminate the buttons and slides with backlighting.

Industry Relevance:
• Thin adaptable faceplate with transparent touch buttons/slides on dashboard for automotive applications.
• Printed touch sensing can be used for fluid level detection.
Flexible Hybrid Electronics (FHE) combines flexible printed electronics (FPE) with rigid chip/component.

- Develop low temperature (less than 150°C) interconnect techniques.

- Establish the capabilities on design & modeling, materials & processes, integration & packaging, testing & reliability for Flexible/Stretchable FHE.

- Develop thermal forming and in-mold electronics manufacturing processes for Formable/Structural FHE.

- Performance the reliability study and optimize the materials and processes.
We have launched 5 CIPs (with 54 companies) since 2015 to drive the innovation and adoption of Flexible Printed Electronics and grow the emerging industry.

- Materials and Substrates
  - Conductive materials & Transparent Conductive Ink (Quantum chemical)
  - Functional Substrates (Cima, SABIC)

- RZR Printing Processes and Equipment
  - Contract Manufacturers (CEL Coating, Opto Precision)

- Application Development
  - Electronic Substrates & Components (Murata, Linxen, Fabri-tech)

- Market Sectors
  - Automotive Printed lighting & touch
  - Furniture, Building Façade & Interior Printed lighting
  - Electronics Printed Antenna & printed circuitry
  - Advertisement & Media Platform Printed lighting
  - MedTech Printed heater for blood bag warming

- Q1-Q4 2015 – Continue the Roll to Roll Manufacturing of Printed Electronics & Functional firm – 12 companies
- Feb 2015 – Launched CIP on Application of printed electronics in Smart Packaging – 9 companies
- Oct 2015 – Launched CIP on Application of Printed Electronics in Print & Media – 11 companies
- April 2016 - Launched CIP on Application of Printed Electronics in Print & Media – 8 companies
- Mar 2017 - Launched CIP on Smart Product Development using printed electronics & other emerging technology – 14 companies
Development Capability to Incorporate Printed Lighting on PMMA Tiles for Architecture & Building

**Company:** Worldbizz Engineering Pte Ltd

**Objective:** Incorporate printed lighting with PMMA tile for Roof top, Furniture, Architectural Wall, Chill bar and interior lighting, Kitchen Cabinet, shower Screen, Aquarium tanks for mood lighting and night time illumination applications

**Impact:**
- Grow local SME to capture new opportunities in architectural and furniture industry
- To grow the supply chain for application of printed lighting in architecture and building

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Development of capability in adoption of Printed lighting & Printed Electronics to Create new platform for OOH Media

**Company:** Dezign Format Pte Ltd

**Objective:** To develop Dezign format capability to implement printed lighting on advertisement in the following platform
- **Outdoor** Advertisement - Bus Shelter
- **Indoor** Illuminated Advertisement - MRT Station, Shopping mall: EL on pillar, floor graphic, interior train, billboard, etc..
- Vehicle Illuminated Advertisement (Taxi, Bus)

**Impact on Dezign Format:**
- Acquire new technology will enable Dezign Format to provide innovative out-door media solution that enable it to drive growth (both in Singapore & overseas market) and employment for Singapore

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Development of Printed Lighting (EL) Strips with Split Electrodes for Architecture & Building

**Company:** Nejilock Pte Ltd

**Objective:** To develop EL strips with split electrodes that are cuttable-at-any-length and easily integrated with electrical connectors and invertors for light strip function

**Impact:**
- Develop market & application of EL strip for building interior, automotive and wearable for Nejilock
- Develop demand for local made R2R equipment - SpeiseTech
- Develop value chain for printed lighting strip industry in Singapore
Printed Lighting for Illuminated Bus Advertisement

**Company:** Film Screen Pte Ltd  
**Objective:**  
• To develop large area printed lighting for illuminated advertisements on buses (1 x 12 m /double decker bus)

**SIMTech Contributions:**  
• Transferred technology in implementing printed lighting on vehicles to local SME  
• Improved installation methodology and reliability of printed lighting on vehicles  
• Developed Inverter/power supply for printed lighting on buses  
• Provided technical expertise on printed lighting on buses  
• **Bus advertising application:** 35 buses

**Impacts:**  
• Generated large advertisement revenues with Printed Lighting solutions on buses  
• Developed new market opportunities for local companies in Printed Lighting for illuminated advertisement on vehicles

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*Mr Lee Chee Yong*
Managing Director, Film Screen

FILM SCREEN PTE LTD
for Industry
**Company:** Automotive Industry

**Objective:**
- Grow market for printed lighting & printed touch sensor for automotive industry in Singapore

**SIMTech Contribution**
- Developed new reconfigurable faceplate for car infotainment system with printed lighting & printed touch sensor
- Develop & transfer manufacturing process of thermoformed printed lighting & printed touch to Sunningdale to enable it provide total manufacturing solution to automotive industry

**Value Capture**
- Improve product reliability & reduce development cost and time of car infotainment system with printed electronics.
- Reduce the number of new tooling required for new infotainment system from 20+ tooling to (2-3) tooling.
- Equip local PE companies with printed electronics technology and manufacturing knowhow
- Grow value chain for printed lighting and printed touch for automotive industry in Singapore
Printed Electronics for Smart Packaging

**Company:** Honsen Printing Industries Pte Ltd

**Objective:**
To develop Honsen’s capability to design and manufacturer point-of-sale smart packaging product with printed electronics for Nestle - new coffee drink product launch

**SIMTech Team Contribution**
- Provide consultation to conceptualize the total design for smart packaging products
- Establish in-house competency in Honsen to design and deploy Printed lighting & Printed electronics for Smart Packaging

**Value Capture**
- Successful commercialized point-of-sales printed lighting packaging boxes for Nestle new line of coffee for Nestle (Thailand)
- Other Nestle geographical sites also show interest to develop new smart packaging products in Singapore
- Developed local supply chain for smart packaging
- Multiple local companies benefited: Honsen, Colorsan, QTech
SIMTech Large Area Processing (LAP)

1000mm and 300mm Web-width R2R System

Equipment/Process

Materials/Inks → Coating / Patterning → Curing / Sintering → Lamination → Inspection / measurement → Product Demonstrator

Web handling / Registration, Process Monitoring and Control.

Slot Die Coating
Rotary Screen / Gravure Printing
Roller Mold Machining
R2R Embossing
Photonic Sintering
Conformable Protective layer
On-line Measurement
Nurture and Grow New Industry Sector