Printed Hybrid Systems

SPIE Smart Structures/NDE - 2012
Nano-, Bio-, Info-Tech Sensors and Systems

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Outline

VTT in brief

Introduction - Printed electronics research at VTT

Manufacturing concept

Printed devices and integration methods
  - Roll to roll printed devices: OLED, OPV, Microfluidistics
  - UV nanoimprinted devices: Waveguides, Microfluidistics

Demonstrators
  - Mobile microscope lens
  - Free-form LED lighting
  - Foil laminated illuminators
  - OLED subassembly
  - Optical touch panel

Discussion

Summary and conclusions
VTT’s status as performer of R&D work

Basic research

Applied research

Development

VTT

UNIVERSITIES

INDUSTRY
VTT Group in brief 2011


Customer Sectors
- Biotechnology, pharmaceutical and food industries
- Electronics
  - Energy
  - ICT
  - Real estate and construction
  - Machines and vehicles
  - Services and logistics
  - Forest industry and Process industry and environment

Research Areas
- Applied materials
  - Bio- and chemical processes
- Energy
  - Information and communication technologies
  - Industrial systems management
  - Microtechnologies and electronics
  - Services and the built environment
- Business research

VTT’s Operations
- Research and Development
- Strategic Research
- Business Solutions
- IP Business
- Group Services

VTT’s Companies
- VTT Expert Services Ltd (incl. Labtium Ltd, Enas Ltd)
- VTT Ventures Ltd
- VTT International Ltd
- VTT Memsfab Ltd
VTT Group structure (1.1.2012)

VTT’s R&D produces strategic expertise, customer solutions and new business. VTT Group is supported by Group Services.

VTT’s functions

R&D
- Research personnel
- Research resources
- Project
- Research personnel
- Project
- Research personnel
- Project

Strategic Research
- Self-financed research
- Jointly funded research

Business Solutions
- Management of customer accounts
- Technology licensing as a part of contract research sales

Business Development (1.1.2012)
- Strategic planning and international operations
- New business development
- Technology and business information management

Group Services: Administration, HR, finance, communication

VTT’s companies
VTT on map

Bay Area, USA
Finland
São Paulo, Brazil
Saint Petersburg, Russia
Seoul, South Korea
Shanghai, China
Tokyo, Japan
Smart Spoon Concept

- Resembles an ordinary spoon, but has added functionality
- Measures weight and temperature,
- Can be cleaned with other kitchenware in a regular dishwasher.

- Sensors for temperature and bending integrated into the handle
- Made by combining printed electronics, lamination, and injection molding.
Printed Hybrid Systems are components and systems which:

- Combine printed intelligence and non-printed components and sub-systems in order to optimise both performance and cost
- Integrate several manufacturing processes:
  - printing, laser processing, cutting, placement, lamination, in-mould labelling

**Sensors / sensor arrays**
- Printed large area sensors
- Sensor arrays

**User feedback**
- Displays
- Indicators

**Processing & Communication**
- Silicon-based components
- RFID & NFC
- Printed memories

**Power supplies & Storage**
- Batteries
- Energy scavenging
- Induction

**Antennas and wiring**
- Integration to manufacturing
Level 0: Device
Naked chip, tested or not tested

Level 1: Component
Assembled chip, possibly locally sealed

Level 2: Module
Chips & components integrated into a functional module

Level 3: System
Modules integrated into a functional system

APPLICATIONS
INTRODUCTION
VTT Printed Intelligence

- is a growth oriented strategic VTT initiative
- combines multidisciplinary know-how of VTT: electronics, optics, biotechnology, nanotechnology, chemistry, printing, P&P, process automation
- has a strong established partnership network to research and industry
- strongly orientated towards applications and business

VTT organization and printed intelligence – stages of development:

- **Project mode**
  - late 90s - Various projects throughout VTT

- **Strategic research program**
  - 2006 – 2009
  - Building the basis for a new technological opening

- **Commercialization stage**
  - 2010 -
  - Introduction of technologies from lab to early market trials and commercial adoption

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R2R Pilot facilities and history

Pilot factory based on 10 years of experience and constant development and upgrading of pilot lines

2003 PICO

- # of personnel: 7
- # of prof. operators: 0

Goals and challenges:
- Make compounds cost effectively in larger quantities
- Transfer from sheet to R2R
- Only one printing technique in use (only two layers)

2007 ROKO

- # of personnel: 42
- # of prof. operators: 3

Goals and challenges:
- Different printing techniques
- More layers on one run
- No possibility to print oxygen and moisture sensitive materials
- Not enough drying capacity

2010 NICO

- # of personnel: 85
- # of prof. operators: 5

Goals and challenges:
- Printing inks sensitive for oxygen and humidity
- Curing inks with faster running speeds
Pilot Factory (2012)

Pilot manufacturing facility for ramping-up production

- 4 interchangeable printing unit slots
  - forward and reverse gravure
  - rotary silk screen
  - flexography
  - slot die coating
- Plasma substrate treatment unit
- Lamination unit
- R2R hot embossing unit
- Die cutting unit
- Drying units (air, UV)
- Automatic registration system
- Max. web width 300mm
- Max. web velocity 30m/min
INTEGRATION
IML - In-Mould Labeling

Currently
- Manufacturing method for decorating plastic products
- Foil with printed graphics placed into the mould
- Integrated into the product by overmoulding

Emerging
- Assembled foil over moulding with electronics
Next generation In-Mould-Labelling - From graphic overlays, front panels and labels towards more integrated Assembled Film Over Moulding

3D polymer product

Assembled polymer foils:
- Flexible electronics
- Printing technologies and materials
- Multi-layer lamination
- Chip bonding & embedding
- Assembly of printed components

Assembled foil over-moulding:
- Foil forming
- In-Mould-Labelling
- Injection moulding

Plastic foil

Injection moulding compatibility

Printing of active and passive layers

Discrete electronic components assembly

Lamination / Shaping of the foil

Cutting

Assembly of the foil into the mould

Over-moulding
Hybrid in-mould intelligence value proposition

- Reduced complexity
- Less mechanical parts
- Systems on single substrate
- System size
- System weight
- Reduced volume
- System size
- System weight
- Cost Reduction
- Simplified value chain
- 2D formation
- 3D formation
- Reduced volume
- Design freedom
- 2D formation
- 3D formation
- Seamless integration
- Optics-electronics-mechanics combined
- Elimination of holes and interconnects
- Cost Reduction
- Less sub-systems
- Less suppliers
- Less sub-systems
- Less suppliers
- Reduced complexity
- Simplified value chain
- 2D formation
- 3D formation
- Reduced volume
- Design freedom
- Seamless integration
- Optics-electronics-mechanics combined
- Elimination of holes and interconnects
DEVICES - SENSORS
Printed sensors

- **Resistive sensors**
  - Strain gauge

- **Capacitive sensors**
  - Pressure
  - Moisture

- **Chemical sensors**
  - Gas sensors
  - Liquid sensors

**Challenges**
- Accuracy
- Stability
- Selectivity

**Benefits:**
- Cost efficient, high throughput production
- Flexible, thin
- Large area

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DEVICES - OPV
From laboratory scale cells to R2R printed OPV modules and integrated systems

Lab scale small area gravure printed cell
Gravure printed HTL PEDOT:PSS
Gravure printed active polymer blend P3HT:PCBM
Evaporated cathode Ca/Ag
PCE 3.1 %
Voc = 0.6 V
Isc = 10.2 mA/cm²
FF = 0.54
A = 18 mm²

R2R pilot printed module (8 cells in series)
R2R patterned ITO-PET
R2R gravure printed PEDOT
R2R gravure printed photo active layer
Evaporated cathode Ca/Ag
PCE 1.3%
Voc=3.9
Isc=1.3 mA/cm²
FF = 0.31
A = 15 cm²

Integrated system OPV+battery+circuit
4 printed organic solar modules:
• PCE 2.3%, 15.5cm², Voc 4.6V, Isc 1.1mA/cm²
Printed rechargeable Li battery:
• 36 mAh @ 36 cm²
Thinned control transistor chip
• 30 µm thick flip chip bonded
Rotary screen printed backplane
R2R gravure printed conventional module

8 monolithically connected cells (A=15 cm²)

- $V_{oc}=4.7$ V
- $I_{sc}=16$ mA
- Active area PCE=2.0 %

Other layers R2R processed
Sheet evaporated electron injection layer and electron contact
DEVICES - OLED
Printed OLED activities

- **2002**: Proof-of-principle Lab-scale demonstrators
- **2004**: Development of R2R mf Wireless powering solutions
- **2006**: Lab-scale demonstrators Printing on variable substrates
- **2008**: System integration SoA OLED materials
- **2010**: Lab to R2R processing
- **2011**: Fab to Products

**Printo (TEKES)**
- Investigate the possibilities to fabricate passive and active electrical, optical and optoelectrical elements using roll-to-roll processes
- OLED based temperature indicator on active package

**OLLAS, ROLLED (EU)**
- Organic Light Emitting Diodes for ICT and Lighting Applications
- Roll-to-roll manufacturing technology for flexible OLED devices and arbitrary size and shape displays

Projects (VTT, customers, TEKES & EU)
- R2R patterning technologies
- R2R encapsulation technologies
- Printable anode solutions
- R, G, B, W LEP materials
- Low work function cathode
- Inert gas lamination station
DEVICES - MICROFLUIDISTICS
Roll-to-Roll hot embossing

Benefits of Roll-to-Roll (R2R) hot embossing over other thermoforming processes

- **inexpensive, foil-based raw materials** (PMMA, PS, PC, COC, COP, CA) vs. silicon, glass, PDMS
- **device prototyping and mass manufacturing use the same thermoplastic materials**
- "lab-to-fab" upscaling: flat bed hot embossing → R2R hot embossing
- **very accurate stamp replication** (nanometer resolution)
- **continuous embossing** (compared to part-by-part handling)
- **high repeatability & automation** (compared to operator dependent handling)
- **short cycle times in fractions of a second** (compared to long cycle times in tens of minutes)
- **large stamp area for multiple design variations** (compared to wafer sized embossing stamps)
Process characteristics for R2R hot embossed microfluidics on foil

- Excellent repeatability (channel depth variation < 3%, width variation < 2 %) and surface quality ($R_a < 20 \text{ nm}$)
- Typical feature sizes:
  - horizontal: ~100 nm to some millimeters
  - vertical: ~50 nm to 50 µm or more, depending on film thickness
- Optical components such as lenses and grating couplers can be embossed onto same chip structure
- Fast embossing sleeve production (1-2 weeks from design to chip)
- In-house fabricated stamps for rapid prototyping of new chip designs (2-3 days from design to chip)
R2R hot embossing and custom component integration

Hot-embossing of microfluidics
- Sample delivery & transport
- Structures for sample handling, e.g. filtering, mixing & suction

Printing of custom capture molecule
- Antibodies, enzymes & DNA/RNA
- Surface treatments
- Ensuring high surface density, biological activity and stability

Lidding and packaging
- Vias
- Biocompatible lamination
- Integration of optics & electronics

Microfluidic assay
- Sensitive and selective analyte detection
- Result in minutes
- Easy read-out
DEVICES – OPTICAL WAVEGUIDES
Waveguide fabrication by UV-nanoimprinting
UV-nanoimprinted devices

Microfluidic channels and optical waveguides 638 nm light propagating in a spiral waveguide
DEMONSTRATORS
Overmolded optical structure

- Bare LED chips were wire-bonded to a standard FR4 circuit board with two SMD packaged LEDs
- Circuit board was inserted to a mold cavity and overmolded with PMMA
Flexibility and sustainability in lighting

Flexible Roll-to-Roll printed OLED foil embedded into 3-D mechanical structure by foil over-moulding

Flexible illumination elements by embedding LED bare chips in multilayer laminated plastic structures

**Advantage:**
- Thin, flexible, all size and shapes
- Easily integrated - new shapes and designs
- Environmentally friendly
Combined flexible lighting and Touch control

- Simple 5x5 pixel display concept with embedded iLED chips and capacitive touch/non-touch on/off control switch.
- Desired moving light effect or alphanumerical pattern can be programmed by PC and driven by the control electronics.
- Flexible 300 μm thin structure, can be embedded to product structures by foil over-moulding.

**Possible applications:**
- Decorative lighting
- Signage
- User interfaces
- Backlighting
- Sensors
Towards new embedded user interfaces
Case: Over-moulded optical touch screen

Over-moulded touch screen demonstrator with multi-touch functionality

Commercialisation by spinoff TactoTek

3D forms can be implemented in moulding process, even though touch components can be assembled in planar structure.

**Advantage:**
- Easily integrated - new shapes, designs and ways to interact
- Compactness and robustness
- Scaling up to large-area UI
PRIAM - Printable functionalities for truly autonomous, intelligent lighting and signalling systems

OBJECTIVE: Development of a radically new multifunctional plastic foils to be used in road signals and automotive lighting modules.

• STREP project ICT-2009.3.3
• Started on January 1st, 2010, and will run for 36 months
Hybrid in-mold intelligence technology concept

In-mould integration of printed and surface mount discrete electronics components into seamless and intelligent 3D product structures using roll-to-roll compatible mass manufacturing methods.

Integrated functionalities:
Sensors & Sensor arrays • User feedback • Processing & Communication • Power supplies & Storage • Antennas & Wiring
Roll to Roll bonder

- Assembling SMD components, chips and modules onto the R2R produced roll
Precision assembly

NEWPORT Autoalign

AEi PMAT

FEATURES
• Newport system has been used for about 10 years
• AEi PMAT system will be installed in February 2012
• Both systems include automated ‘active alignment’ routines for characterization and assembly
• Systems can be equipped with various light sources (lasers, LEDs), detectors, VIS-IR cameras, spectrometers, etc…
• PMAT system suitable also for automated small and medium volume photonics assembly

AEi PMAT KEY SPECIFICATIONS
• Two six-axis precision stages
• Sub-100 nm spatial resolution
• 100 mm travel distance in horizontal direction
Hybrid in-mould intelligence key features

Key Embedded Functionalities:
• Indicator light, backlight
• Capacitive touch switches
• Optics
• Sensors

Key Applications and Markets:
• Automotive interiors
• Medical and healthcare products
• Point-of-sale products
• Consumer design products

Demonstrators:
• Large-area printed capacitive sensor system
• Flexible illumination with embedded ILEDs
• Flexible autonomous power source and storage
• In-moulded intelligence
Hybrid in-mould intelligence service offering

Customer needs

- Identification of customer needs
- Determination of functional product requirements

Product conception

- Determination of technical product requirements
- Initial selection of components, materials, processes

Technical feasibility

- Confirmation of technical functionality and performance
- Modification of product design, design for pilot manufacturing

Fast prototyping

- Assessment of mass producibility
- Determination of mass production requirements

Pilot production

- Material cost assessment
- Manufacturing cost assessment

Business feasibility

- JOINT FUNDED TEKES
  - Reactive
  - Short-term (1-2 years)
  - 100% funded by companies
  - 100% IPR for companies
  - Possibility to apply grants from Tekes

- CONTRACT RESEARCH
  - Applied research
  - Mid-term (2-3 years)
  - 60-70% funded by Tekes
  - 30-40% funded by companies and VTT

- JOINT FUNDED EU
  - European consortiums
  - Mid- and long-term (3-4 years)
  - 75% funded by EU

How to deal with us!
More appealing, desirable and eye-catching
Printed functional films embedded into consumer packaged goods and packaging

LED lights can be integrated on consumer products

Hot embossed holographic film injection moulded into plastic.
Further Emerging Components

Printed solar cells
Printed biofuel cell
Fully printed OLED
Hot embossed microfluidics
Plastic integration, combinations with traditional electronics
SUMMARY AND CONCLUSIONS
Summary

VTT is developing manufacturing technology for hybrid systems

- Technology is based on the use of printed electronics and several established manufacturing methods
- Low cost of electronics enables added functionality and new products

Demonstrators have shown that injection molding and lamination are feasible methods for packaging electronic components

- Electronics can be integrated directly to product mechanical structures
- Designers will have more freedom to experiment with shapes
- Integrated products are seamless and robust

The research efforts are continued by investing to a pilot production line, which is used to test the feasibility in large scale production
VTT - 70 years of technology for business and society