Prototyping of Printed TFTs on Pilot Line for Smart Surface Applications
OUTLINE

CEA-Liten & Printed Electronic

PICTIC Printing Pilot Line Platform for Ink & Process Scale-up

Material & Device Engineering Platform

System Integration & prototyping platform : Methodologies & Public demonstration for Flexible Printed Circuits

Summary
PRINTED ELECTRONICS AT CEA-LITEN

Shaping The Future Electronic
Flexible Electronic
Towards Interactives objects and smart surfaces

- Electronic industry = optimizing and scaling the integration of intelligence and interconnections
  (Si - Chip / PCB level / Flat Panel / ...)

- Flexible electronic is a new wave aiming to provide seamless integration of Intelligence in order to provide sense and communication abilities into daily life Object.

Flexible Electronics
- High performance
- Multi-components
- Thin, Robust & Flexible
- Free-Form & Cost effective

Innovative Materials & Process

Innovative Products
Printed Electronic at CEA-LITEN
Towards Interactives objects and smart surfaces

DEDICATED LAB since 2007 with PICTIC Printing Scale up Pilot Line since 2011!

OBJECTIVE: Develop electronic inks and industrialize processes, to functionalize large flexible surfaces (320 x 380 mm) with electronic functions.

- 50 engineers and technicians
- 8M€ investment
- 500 m² clean rooms
- Major equipment include, slot-die, heliogravure and flexographie printers
- Up to ~80 patents +High level journals & conferences (ISSCC, IEDM,..)
- Large partnership including start-ups, material, tool suppliers, RTO and End Users
Printed Electronic at CEA-LITEN

Portfolio of printed devices for SoF

- Signage
- Antennae-Passive Devices
- Electro-Active Devices
- Memories
- Active Circuits
- Integration & Plastronic
- Photo Sensors
- Resistive Sensors
- Chem & Bio-Sensors
- Thermoforming
- Overmolding
Printed Electronic at CEA-LITEN

From Advanced R&D to Industrial Transfer

**Application Lab.**

Printed PVDF based ElectroActive & sensor device

- Printed Sensors /Actuators
- Thin Film Printing (contact/non-contact)
- Custom design & Multi-sensor integration

Applications:

- Impact monitoring
- Mechanical Stress mapping
- Human-Machine Interface
- Energy Harvesting
- Haptic devices

**Spin off**

High Performance Printed photo-detector

- Large spectrum response: Vis + NIR
- Large dynamic range / Low noise with low illumination
- Wide angle of half sensitivity
- Cost effective fully printed process
- Competitive with a-Si and CMOS technologies for large area

Applications:

- Large spectrum response: visible and Non-contact
- HMI (3D): santé, consumer electronic, Smart object / labelling
- Object recognition, logistic, security
- Medical Application
- Biometry

**Industrialization**

Human Machine Interface & Embedded Interconnect

- Capacitive Sensor
- Haptic Feedback
- Flexible PCB
- In Mold integration

Applications:

- Automotive application
PRINTED TRANSISTORS & CIRCUITS

Enabling Smart System with Printed Hybrid Electronic
Flexible/Plastic/Printed Electronic

Emerging Market for ubiquitous electronic & technical needs

Transistor has a major role in interfacing Sensors, Displays, Actuators, Batteries enabling basic RF communication or connection with generic Silicon IC.

Printed TFTs could enable cost effective and optimized integration.
Printed Transistor & Circuit at CEA

Activities along the value chain

From Materials to Design…. including Industrial Steps (e.g. reliability, yield)

Collaboration with chemical industrial leaders

Chemical suppliers

Tool suppliers

Flow optimization

Ink formulation

Robustness

Foundry companies

Process transfert

Software companies

Testing

Design

Modeling

Houses

Reliability

IC testing

Interconnect

Open DTK

Interfacing

IC testing

Prototyping

Specification

Products

makers

End

users

Products

Applications

Materials

Printing

Process flow

Devices

Circuit

System

End users

Collaboration with chemical industrial leaders
Three open platforms set-up to optimize engineering feedback and accelerate Printed Electronic R&D and adoption.

**ADVANCED MATERIALS & MODULES**

**R&D Platform**
- Advanced Materials / Process
- IN-DEPTH Characterization
- Performance Analysis
- Device integration

**Design & Prototyping Platform**
- Modeling & library development
- Co-integration with sensors
- Circuit Prototyping

**SYSTEM DESIGN & INTEGRATION**

**INDUSTRIAL TRANSFERT**

**PICTIC Printing Pilot-Line**
- Pre industrial tools & Process
- Production prototyping (TRL 4-6)
- Yield & Reliability
PRINTING PILOT LINE

DEVELOP AND QUALIFY SOLUTIONS FOR LARGE SCALE PROCESSING READY TO TRANSFER
Printing Pilot Line for Industrial Transfer Prototyping

Platform for ink/Process/Device scale-up

Dedicated platform since 2011 in order to qualify material and device in Large Sheet Format and transform concept to technologies ready for industrial Transfer...

→ Methodologies & Full set of large area characterization Tools (Automatic and statistical approach for electrical mechanical/ optical and ageing characterization)

→ Gen1 320mmx380mm Facilities, 600m2 Clean Room, Class 10,000
Typical OTFT Process –Flow:

- Gold contact on PEN (LASERablation /Litho)
- Surface/injection treatment (PLASMA/Deep Coating)
- OSC direct Print (GRAVURE PRINTING)
- Diel Gate Stack direct Print (low-K, High-K, ...)
  (GRAVURE PRINTING)
- Gate direct Printing (SCREENPRINT/GRAVURE PRINTING)
- Capping Dielectric / Encaps Film

→ Need Performant and Versatile Tools for efficient understanding and optimizing of device structure
→ Robust Printing with High resolution and Good registration

Why direct Printing:

→ Direct Printing is the solution for fast and cost-effective process
Printing Pilot Line for Industrial Transfer Prototyping

Challenges & Methodologies

Challenges: transferring ink / controlling printed pattern profile / set up stable inks and process while scaling up area and resolution

→ Use Printing benchmark protocol from PICTIC with combined analysis (AOI + detailed Profile + Stat) in order to evaluate independently process, design and formulation parameters
Printing Pilot Line for Industrial Transfer Prototyping

Illustration of Capability – ATLASS Project

- **Optimization of Printing Profile:**
  - 500x500µm² Subtractive Process
  - 250x250µm² Printing Process

- **Downscaling Printed Patterns:**
  - 500µm
  - 250µm
  - 150µm
  - 100µm
  - 75µm

- **Improving Process Stability:**
  - 50 nm - OSC
  - 300 nm – Capping Dielectric

- Development of material concept Robust for processing and scalable!!
MATERIAL & DEVICE PLATFORM

Improve Material-electrical Performances And Develop Robust Device Technology
Material & Device Prototyping PLATFORM

Challenge for device development

- Fine and regular patterning of OSC:
  - Surface energy optimization
  - Solvent choice and drying conditions

- Dielectric thickness reduction:
  - Solvent, formulation, etc.
  - Printing conditions / leakage & breakdown

- Mobility performances and stability:
  - Formulation optimization
  - PEN surface treatment

- Threshold voltage control:
  - PEN surface treatment

- Optimization of the injection:
  - Metals for electrodes
  - SAMs, surface treatment
  - OSC crystallisation on surface
Material & Device Prototyping PLATFORM

Complete Electrical Characterization Platform

- Device Engineering
- Device Reliability
- Circuits

- Know how and protocols for TFT characterization and optimization of device and process flow since 2007
- Statistical analysis (20/200/1000), reproducibility and yield engineering, set-up POR
- Dedicated lab for Reliability engineering (experienced with industrialization process with startup)
- Device Optimization driven by Circuits and System evaluation feedback

- Bias Stress
- Light & Environmental Impact
- Ageing & Lifetime
- Physical understanding of stress and intrinsic/extrinsic root cause analysis
Material & Device Prototyping PLATFORM

Illustration of Capability – Public Technologies Set-up

**CMOS**
(10x10 cm² - screen Printing)

- μ = 0.5 cm²/V/S

**High Yield PMOS**
(10x10 cm² - screen Printing)

- Drain Current (A)
- Linear (VDS=-1V)
- Saturation (VDS=-40V)

**High Perf-Large Area PMOS**
(GEN1-32x38cm² Platform- Gravure Printing)

- Drift Current (A)
- 30 TFs
- W/L = 500/20 μm
- COX = 3.9 nF/cm²
- Vds = -1/-20V

→ One of first Printed CMOS!!!
→ Set-up with COSMIC Project in 2010
→ Technology Ready for circuit design
→ Many IC demonstration with Partners

→ Frozen in 2014
→ High yield >99% and Low dispersion
→ Optimized For Active Matrix and multiplexer Application

→ High Performance (μ0.5-> 2cm²/V/s ; VT =3.5 V)
→ Low dispersion On Large Area
→ High On-Off Ratio
→ Active Matrix & Circuits Application
Standardize Printed Technology For Circuit Design And Demonstrate Performance At System Level
CIRCUIT & SYSTEM PROTOTYPING PLATFORM

DESIGN TOOL KIT (DTK) & Silicon Inspired Methodologies

Design flow development
- Design Rule Manual (DRM) compatible with printing tools
- Design kit (DRC, LVS, etc.) under Cadence
- Implementation of model and parameters for circuit simulations

DRM

DC Models

Dynamic Models

Update: A. Joubert

Update: V. Fisher
CIRCUIT & SYSTEM PROTOTYPING PLATFORM
Road towards Electronic Circuits

Printed IC Design Tool-Kit & Fab Platform ready for prototyping with conventional silicon circuit Flow

Architecture Design → Building Block Simulation → System Simulation → Layout (DRC,LVS) → Tape out & Roll Fabrication → Printing Circuits !!!
CIRCUIT & SYSTEM PROTOTYPING PLATFORM

Illustration of capability for Circuit Design --- Smart Printed Sensors

Simple Sensor / Signage Interface

→ Multi-Threshold detection + drive
→ Decoder & LED Driver

Pre-processing Sensor Signal (Analog to Digital Converter)

→ Digitalize information

~150 OTFTs + R

Clock freq. 66.67Hz
Conversion freq. 4.17Hz (16 cycles)
Input freq. 2.05Hz
Power (@Vdd=40V) 540µW
Vdd Nominal 40V - OK at 20V
Resolution 4 bits (Could work at 6 bits)

S. Abdinia et al (TUE; CEA Liten)), ISSCC 2013
A 13.56MHz RFID Tag with Active Envelope Detection in an Organic Complementary TFT Technology

Validation of Silent-Tag Circuit
✓ Rectification
✓ Envelope Detector
✓ Clock generation & decoding

V. Fiore et al at ISSCC2014 (Univ Catania + STMicroelectronics + TUE + CEA-LITEN)
Pushing Printed technologies one step further with CEA Printed Circuit Technologies and partners through European Project Product-oriented Demonstrators

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open access pilot line infrastructure for H-TOLAE technology
Prototyping the capability for interfacing large number of elements and fit to specification in Product relevant configuration

Stacked Integration of Sensors

Tiles of Various sensor

High resolution AM

→ Feasibility of Printed TFT & photodetector for image sensing system

→ Active Matrix for Physical Sensor mapping (Force, Strain, Light, Temp.,)

→ Embedded Gate Driving

→ High resolution Printing and/or Hybrid Processing

→ 50 ppi Demo

S. Jacob et Al IEDM2015
CIRCUIT & SYSTEM PROTOTYPING PLATFORM

Illustration of capability for Smart Surface

Talk of Paul Brookes (session04) or EMD Performance Materials Booth #3011

- Optimization of ink and Demo of OTFT package in 50 ppi active matrix
- High Mobility – low dispersion SP500 OSC (> 2cm²/V/s)
- High resolution gravure printing
- Capability of downscaling with hybrid process
CONCLUSIONS
Drive new comers in Printed Device:

- Demonstrate materials capability at R&D stage
- Drive Optimization of materials and device
- Enable demonstration towards industrial transfer or application
Exploitation of CEA Platforms for Printed Electronic Tools & Methodologies ready to …

Drive new comers in Printed Device:
- Demonstrate materials capability at R&D stage
- Drive Optimization of materials and device
- Enable demonstration towards industrial transfer or application

Support majors in industrialization of Printed electronics:
- Demonstrate materials capability on pilot Line
- Scale-up ink and process for printing technology
- Benchmark & Provide in-depth understanding for device optimization
- Demonstrate materials capability for application
Exploitation of CEA Platforms for Printed Electronic

Tools & Methodologies ready to ...

**Drive new comers in Printed Device:**
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**Evaluate potential of Printed Electronic & Prototype systems:**
- Demonstrate and benchmark functions feasibility and performances regarding applications-case
- Prototype at system level and evaluate integration
- Evaluate small scale manufacturing / Transfer technology
Summary

- Printed Electronic bring strong advantages completing Si-IC for the design of innovative electronic system on the new markets
- Since 2007 LITEN has developed a full range of tools, methodologies and know how for materials benchmarking and industrial prototyping organized in open platforms
- **Printing Pilot Line**: An Open Sheet-To-Sheet Printing Platform for technology up-scaling and process prototyping + methodologies to push robust solution to market
- **Materials and device platform**: Strong know how since 2007 with efficient characterization and dedicated reliability lab + methodologies already experienced on industrialization cases
- **System Integration & prototyping**: Various Flexible Circuits demonstrated. Silicon Inspired model with Design Tool Kit & Fab Platform available for designers to experiment innovative printed systems

Ready for prototyping and scale-up & open for partnership !!!
ACKNOWLEDGMENT

CEA team involved:

Funder & Public Project Partners:
THANK YOU FOR YOUR ATTENTION

www.cea.fr

Grenoble, France

500m²
Class 10000

Pilot Line for Printed Large Area Electronic