PROJECT FULLFLEX: A MULTIFUNCTIONAL FLEXIBLE ELECTRONIC LABEL

Jean-Christophe P. Gabriel

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Abstract: We will present a CEA joint effort that delivered a multifunctional label prototype that integrates flexibles: (i) photovoltaic cells; (ii) a nanoparticle based Li-battery; (iii) a battery management system; (iv) a tension regulator; (v) a temperature sensor; (vi) a light sensor; (vii) a silver nanowire based transparent capacitive touch sensor; (viii) four LEDs; (ix) an electronic motherboard integrating a micro-controller.

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PROJECT FULLFLEX:

A MULTIFUNCTIONAL FLEXIBLE ELECTRONIC LABEL

Dr. Jean-Christophe P. Gabriel
Dep. Director Nanoscience & ChimTronic Programs

Printed & Flexible Electronics Congress
February 21st, 2017
~17800 collaborators (~16000 staff members)

Budget: €4.1 BN, including €2.8 BN in subsidies

4,900 Scientific publications (in 2014 ISI base; IF = 4.5)

85 ERC grants

1,150 PhD students

5,840 Patent families in portfolio

735 Delivered priority patents deposited

850 M€ Revenues (460 M€ ind. Rev.): Research vs Industry

187 CEA’s Spin-off since 1972 (124 since 2000)

1st Reuters’ Ranking of Innovative Research Institutions

51 Joint research groups (including CNRS)
CAN A LOT BE DONE FROM NEW PARADIGMS?  
THE EXAMPLE OF CNTS

- 2001-2007 @ Nanomix (nano.com): CNT integration – Chemical sensors

Molecular Wires for Molecular Sensing

- First commercial sensors in 2005: H₂ sensor on Si wafers
- Printed NT sensors deployed in West Africa during Ebola crisis in 2015.
- $36M raised over 15 years!!!


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Leverage effect (period 2008-2013, 98 projects, budget 7M€) : 170%

Direct income: 7M€ (32 projets: ANR, FP7,…)
Indirect incomes: 5M€ (15 projets: ANR, FP7, ERC,…)
Overall awarded money (with partners) : 78M€

260 articles de journaux sur 2009-2016 (4806 citations)
31% of articles (80) in top 10% (according to ESI Physics criteria)
6% of articles (16) in top 1%

4 start-up benefited directly from results initiated with program
29 patents (2008-2013)

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Objectif: go beyond germination!

Build a prototype Integrating technological components developed within Nanoscience & ChimTronic seed projects

- Reach higher TRL
FULLFLEX PROTOTYPE CHALLENGE?

Objectif: go beyond germination!

Build a prototype Integrating technological components developped within Nanoscience & ChimTronic seed projects

- Reach higher TRL
- Development of new technologies of flexible interconnects
- => A new prototype for CEA's Showroom
Objectif: go beyond germination!

Build a prototype integrating technological components developed within Nanoscience & ChimTronic seed projects

- Reach higher TRL
- Development of new technologies of flexible interconnects
- => A new prototype for CEA’s Showroom

Initial Concept: a flexible autonomous, multifunctions label
# FULLFLEX: WHAT TEAM?

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Printed Temperature Sensors

Abdelkader Aliane
PRINTED ORGANIC ELECTRONICS @CEA/LITEN

PLED (Polymer Light-Emitting Diodes)
- HMI, signage
- Devices, systems
- Single digit, matrix
- Logos

cf Talk Tony Maindron (OLED)

Antennas

Sensors
- Temperature (Resistors)
- Capacitive
- Pressure sensitive

Large Surface Printing Platform (PICTIC):
- 50 researchers and technicians
- €9 million in investment
- 600 sq. m of clean rooms
- Slot-die, gravure, flexography process equipment
- Industrial partnerships, startup (ISORG)
Photovoltaic flexible modules

Renaud DEMADRILLE – DRF / INAC / LEMOH
Solen Berson – DRT/INES/SMPV

• 2 Interpenetrated percolating networks
• Optimal phase segregation (10-20nm)

Photo-induced charge transfer $< 10^{-12}$ s

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Innovative materials and fabrication of flexible modules

Development of new materials for use in the active layer

Laboratoire des Modules Photovoltaïques Organiques (LMPO) – S. Berson (DRT-INES)

Development of OPV modules by printing techniques (ink-jet)
First examples with P3HT

P3HT-Fullerene

S = 11.04 cm²

PCE = 2.9%
Voc = 1.61 V
Jsc = 3 mA/cm²
FF= 60 %

Printed modules : S.Berson, R. De Bettignies, DRT-INES

P = 30mW

Cf talk Solenn Berson

Polymer Chem., 2016, 7, 4160

Compatible with Li Ion batteries
Vmin = 3.7V

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Voc = 6.2 V
Jsc = 0.577 mA/cm²
FF = 48.2 %
PCE = 1.73 %
Vmax = 4.1V
Imax = 35.8 mA
Silicium NP based battery

Nathalie Herlin, Séverine Jouanneau, Willy Porcher
AVANTAGE : Max = 3578 mAh/g (Si → Li₃.₇₅Si) = 10x graphite

DISAVANTAGE: $V_{inc} = +280\%$

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Core-shell amorphous silicon-carbon nanoparticles for high performance anodes in lithium ion batteries

*Journal of Power Sources* **328** (2016) 527-535

- 1 startup (Nanomakers)

NP Si@C: Amorphous C layer = 3nm, 10 nm, 15 nm

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Core-shell amorphous silicon-carbon nanoparticles for high performance anodes in lithium ion batteries

*Journal of Power Sources* **328** (2016) 527-535


1 startup (Nanomakers)

Overall

Positive Electrode: NMC (LiNi\(_{1/3}\)Mn\(_{1/3}\)Co\(_{1/3}\)O\(_2\))
Ref. Element: 3Ah for 3x3 cm x 5 mm cell
Power < 3W
Surface capacity: 3 mAh/cm\(^2\)
Voltage : 3.5 V

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To simplify or solve several technological barriers, another battery architecture is possible: the interdigitated planar design

- **The interdigitated concept reverses at 90 ° stacked architecture**
  - Architectured current collectors on the same plane
  - Electrodes printed side by side on respective collectors
  - Separator printed between the electrodes printed on the entire surface
  - Gellified electrolyte

- **Constraints of the concept:**
  - High printing resolution (10µm +/- 1µm)

- **Dimensions:**
  - Width of lines: 200µm
  - Distance between lines: <100µm (target 50µm) → electrolyte compartment

- **Solid electrolyte configuration**
- No densification

=> Thomas Yohann

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Flexible and fully printed multi materials

Non stacked configuration

Non contact printing technique

Interdigitated design

Nano inks

High resolution

- More flexibility
- Design
- Interfaces
- Versatility of shapes

Current collectors
Electrodes
Electrolyte

Current collectors
Electrodes
Electrolyte

Width of lines: 200µm
Distance between lines: <100µm (target 50µm) \(\rightarrow\) electrolyte compartment

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Transparent Electrode + Capacitive Sensors

JEAN-PIERRE SIMONATO
NEW TECHNOLOGIES = NEW NEEDS

A NEW NEED FOR FLEXIBLE TRANSPARENT ELECTRODES

TCOs (ITO) have serious limitations
- *Indium is a major critical raw material*
- *High cost process (capex, material)*
- *Brittleness*

Alternatives
- ✓ Conductivity / Transparency
- ✓ Flexibility / stretchability
- ✓ Low cost (material / process)

SUBSTITUTION of ITO by Nanomaterials
### POTENTIAL ALTERNATIVES

- **Conducting polymers**
- **Carbon Nanotubes**
- **Graphene**
- **Metallic nanowires**

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### POTENTIAL ALTERNATIVES

| Conducting polymers | \( J. \text{ Mater. Chem. C}, 2014 \)  
|                     | \( \text{Chemical Science}, 2015 \)  
|                     | \( \text{Chemistry of Materials}, 2016 \) |
| Carbon Nanotubes    | \( \text{Nano Letters}, 2003 \)  
|                     | \( \text{Carbon}, 2012 \)  
|                     | \( \text{Carbon}, 2014 \) |
| Graphene           | \( \text{Applied Physics Letters}, 2014 \)  
|                     | \( \text{Ultramicroscopy}, 2015 \) |
| Metallic nanowires  | \( \text{Nanoscale}, 2015 \)  
|                     | \( \text{Small}, 2016 \)  
|                     | \( \text{Nano Research}, 2012, 2014 \)  
|                     | \( \text{Nanotechnology}, 2013 \times 2 \)  
|                     | \( \text{Nano Letters}, 2016 \) |
Ag NW SYNTHESIS: COMPLICATED?

AgNO₃
PVP
Ethylene Glycol
NaCl

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PERCOLATIVE RANDOM NETWORKS OF Ag NANOWIRES

Percolation

~ 15 PATENTS
PERFORMANCES?

Resistance per square ($\Omega / \square$)

$\#$ of bendings (radius of Curvature = 5 mm)

PERFORMANCES?

Resistance per square ($\Omega/\square$)

# of bendings (radius of Curvature = 5 mm)

Nanowire based LED

JOËL EYMERY, FRANÇOIS LEVY
NITRITE NW BY CATALYST-FREE MOVPE

1. Nitridation under NH$_3$ and SiN deposition

2. Wire growth under Silane injection and low V/III ratio

3. InGaN QW growth and p-GaN capping layer

Nanowire morphology

- **Diameter**: 500 nm – 2 µm
- **Height**: 10 – 30 µm
- **Density**: $10^7$ cm$^{-2}$

Spontaneous growth – big surface available for process optimization

*MOCVD growth by C. Durand, J. Eymery (CEA-Grenoble)*

*Koester et al., Nanotechnology 21, 015602 (2010)*

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GAN NW BASED LEDS: FROM SOLID SUBSTRATES…

A-L Bavencove et al., Nanotechnology 22 (2011) 345705
Submicrometre resolved optical characterization of green nanowire-based light emitting diodes

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InGaN/GaN NWs / PDMS

Main challenge – transparent flexible contact
• Thin TCO layers
• Graphene and/or graphene µ-flakes
• Silver nanowire mesh

• GaN nanowires embedded into PDMS
• Mechanical lift-off of the composite film
• Back-side metallization and mounting on PET substrate


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• Large area flexible LEDs (active area of several cm$^2$)
• No I-V or EL degradation after 10 bending cycles ($R_{\text{bending}} \approx 0.3 \text{ cm}$)
• Further improvement of emission homogeneity with organized NW arrays is under investigation

D. Xing et al, NanoLetters, 2015
La Recherche 2016 Award
Three Sensors: Light, temperature, capacitive

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Silver Nanowires
Transparent electrode

Copyright CEA, all rights reserved
Flexible electronic mother board

Mother-board: μ-controller & drivers

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Printed Resistors
NTS + PTS

Copyright CEA, all rights reserved
Flexible PV
• Capacitive mode (movie)
• Temperature alarm mode (movie)
• Light mode (movie)
1 year project, successful
Deadline met
4 CEA’s new techno. integrated

Since then:
3 startups, 20 patents, numerous H2020 projects + industrial contracts

More info:
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