Centre for Nanotechnology and Smart Materials

A short introduction to PRINTED ELECTRONICS

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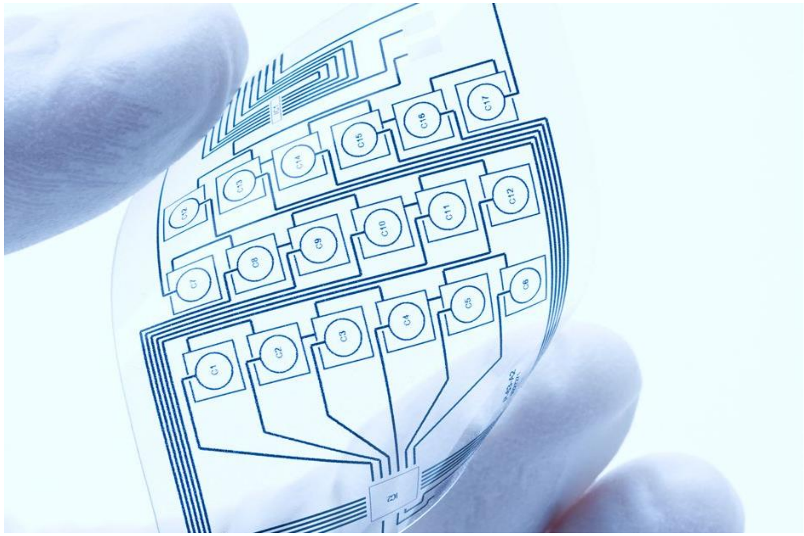
OUTLOOK

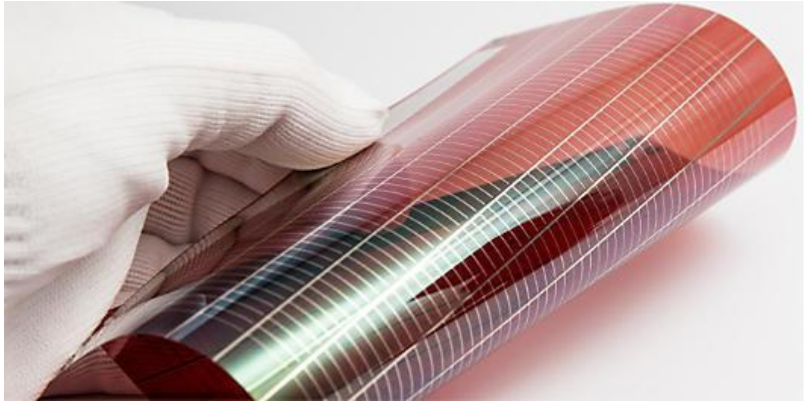
- Introduction
  - Why printed electronics (PE)?
  - Brief History
  - Conventional vs printed electronics
  - Global market forecast and sector applications
- Printing technologies
- Materials: Inks and Substrates
- Main technical / economical challenges

Introduction

Why Printed Electronics (PE)?

- Low cost
- Large areas and flexible substrates
- Additive process (low waste)
- Low number of fabrication steps
- Potentially a more environmentally friendly process
- Low capital investment





http://www.dupont.com

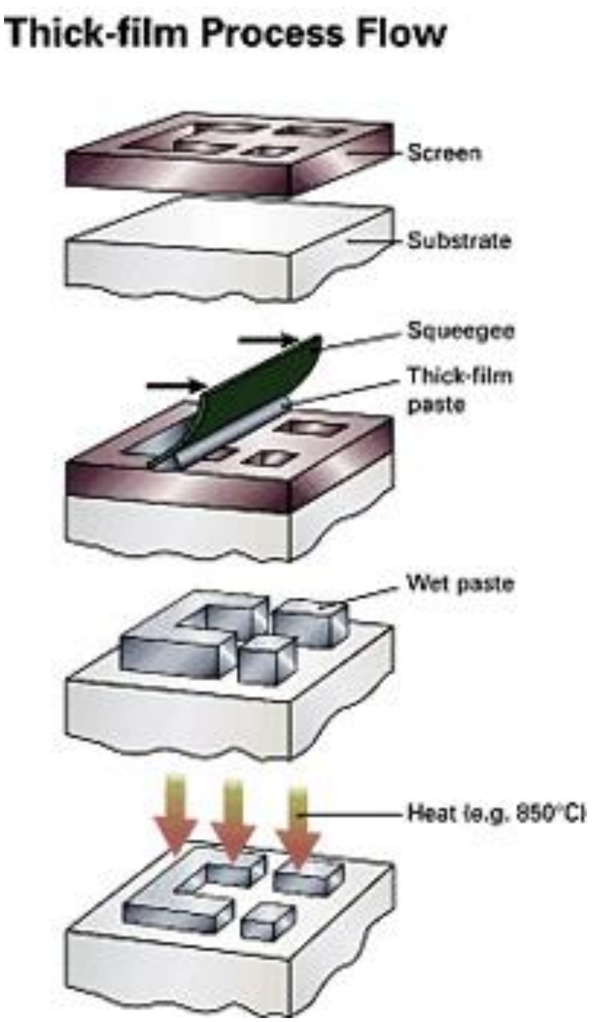
Brief History of Printing Electronics

1899 - Voigt and Haeffner patented printed and fired meanders for resistive components.

1945 - Deyrup et al. reported preparation of capacitors using particulate-based films (i.e. films from inks containing metal together with glass powders).

Early 1960s – The term ‘thick-film technology’ was coined to distinguish it from ‘thin films’, typically applied by a vapor deposition process, vacuum evaporation or sputtering.

1960s - The very beginning of the thick-film hybrid circuit industry as we know it today with the first ‘fired on’ resistors adopted by the military for the Minuteman missile and by IBM for its System 360.

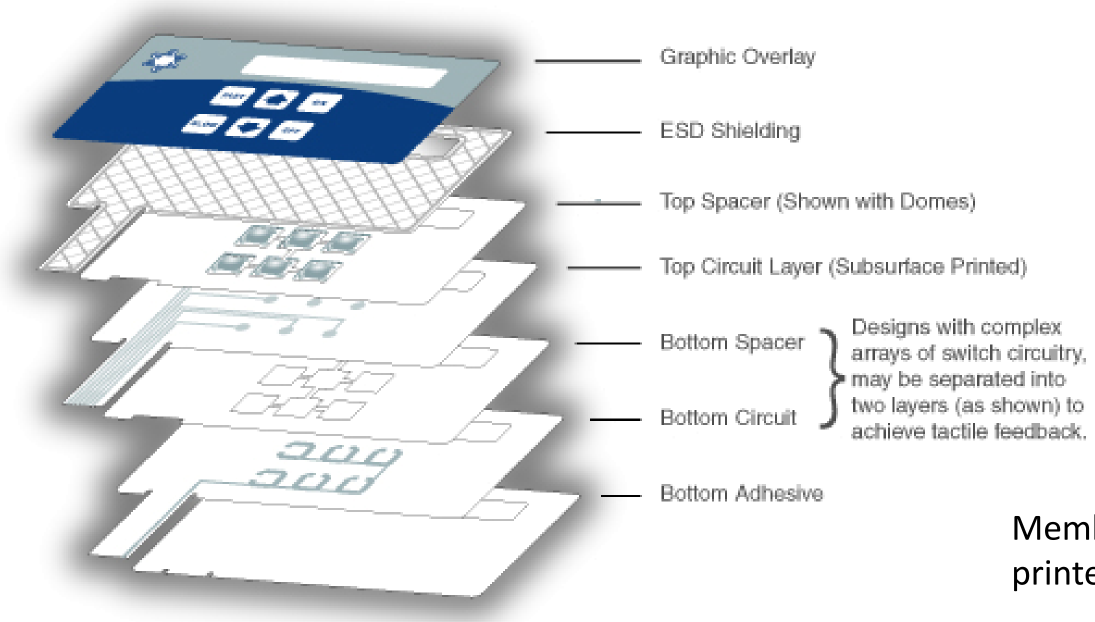


http://www.deamertek.com/Film.aspx

M. Prudenziati and J. Hormadaly, "Technologies for printed films", in Printed films, Elsevier, 2012.

Brief History of Printing Electronics (cont.)

1970s - Membrane touch switches (Hicks et al. , 1980)
- Thick film defoggers for windshields (Tarnapol and Snyder, 1969)
- Piezoresistive effects in thick-film resistors were investigated and exploited in mechanical sensing systems (Canali et al. , 1980; Cattaneo et al. , 1980; Morten et al. , 1983).
- Pioneering studies on screen-printed metallization of silicon solar cells were published (e.g. Bube et al., 1980; Frisson et al., 1978, p. 590)
- Development of first photoformable compositions (Jolley et al., 1974).



Membrane touch switches with printed electrodes

http://www.design-mark.com/design-mark-blog/

M. Prudenziati and J. Hormadaly, "Technologies for printed films", in Printed films, Elsevier, 2012.

Brief History of Printing Electronics (cont.)

1980s - The use of "thick-film technology" was extended to the manufacture of solid-state sensors for mechanical, chemical, thermal quantities and biosensors, heating resistors for kettles, and platinum electrodes for exhaust gas sensors.

- Studies were promoted for printed film fine lines fabrication (Shankin, 1978): innovations included improved photolithographic processes (for pattern definition on dried films) and photo-etching processes (pattern definition on fired films), MD-Films® (Naguib et al., 1980), MicroPen writing (Drumhelelr, 1982), and Ink-jet printing (Teng and Vest, 1987).
- Low-temperature co-fired ceramics entered the market, driven mainly by the need for radio-frequency (RF)-circuits to operate above 10 GHz (Vitriol and Steinberg, 1983).

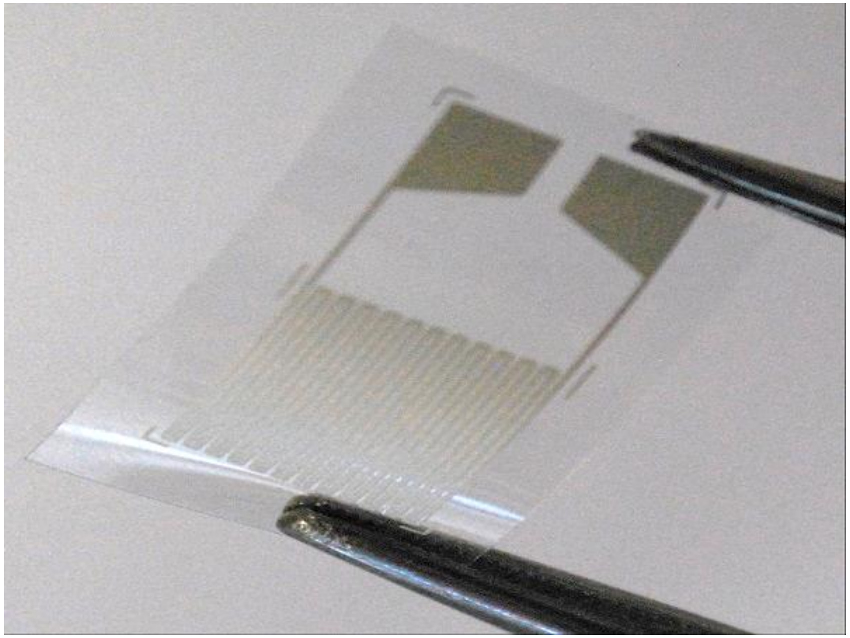
http://www.konicaminolta.com/about/research/inkjet head/new_inkjet.html

M. Prudenziati and J. Hormadaly, "Technologies for printed films", in Printed films, Elsevier, 2012.

Brief History of Printing Electronics (cont.)

End of 1980s – Development of polymer thick-films (PTF), composites consisting of a polymer matrix filled with conductive, resistive and dielectric powders to be screen printed and cured at modest temperatures (<200 °C), for passive components such as potentiometers, low-cost strain gauges and membrane switches.

1990s - Development of new versions of printing technologies to printing fine lines and/or on large areas. The approaches comprise offset printing, gravure, pen writing, ink-jetting, thermal spraying, laser sintering, etc.



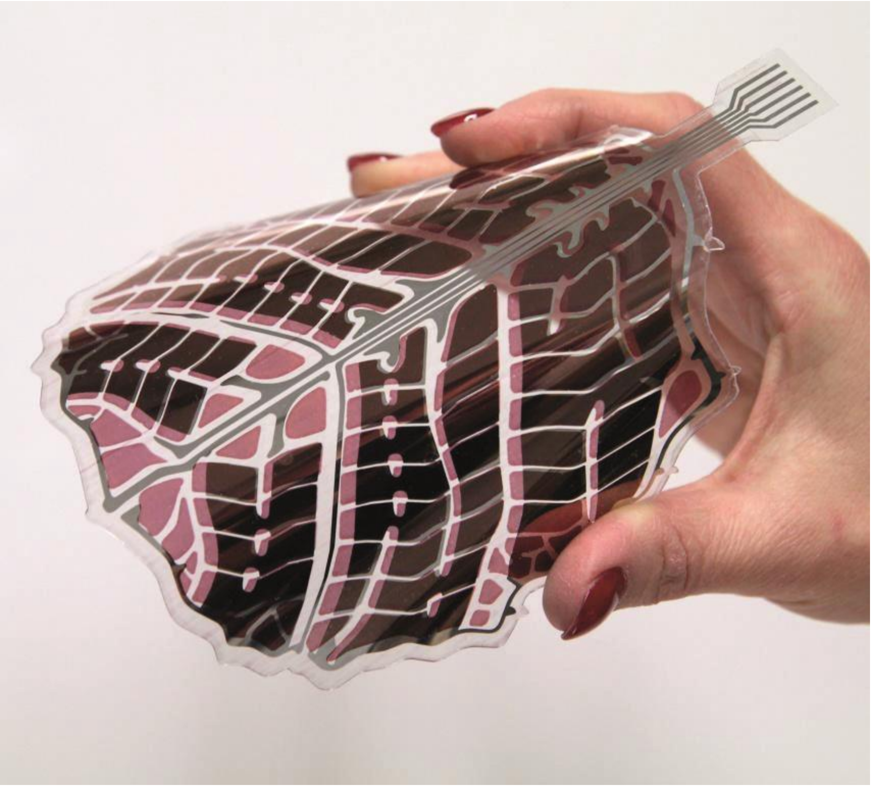
Flexible screen-printed strain gauge

http://homepages.wmich.edu/~zandim/CASSS/CASSS.htm

Brief History of Printing Electronics (cont.)

2000s - Development of printed electronics technologies to increase resolution capabilities, be easier, more cost-effective or increase areas of application.

- Printing of organic materials, including intrinsically organic conductors and semiconductors for new devices and applications, towards creating flexible electronics.



Flexible printed organic solar cell developed by VTT.

http://www.vttresearch.com/media/news/decorative-and-flexible-solar-panels-become-part-of-interior-design-and-the-appearance-of-objects

Introduction

Conventional Electronics *vs.* Printed Electronics

Made in batches on wafers in cleanroom

Produced by lithography, micromachining, ablation, etc.

Devices run fast

Layers added in furnace, vacuum or crystal growth

High resolution

Expensive processing

Rigid silicon wafers or glass

Devices are small

Not transparent

Established

A cohesive industry

Can be printed on a roll (or batch processed) non-cleanroom

Produced by printing techniques such screen-printing, inkjet, rotogravure, etc.

Devices run slowly

Layers added by printing (or vacuum)

Lower resolution

Cheap processing

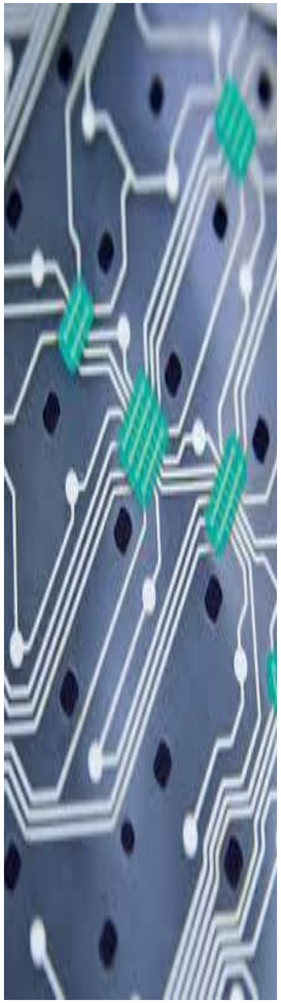
Flexible films (e.g. paper or plastic), or rigid (e.g. glass)

Devices small or large

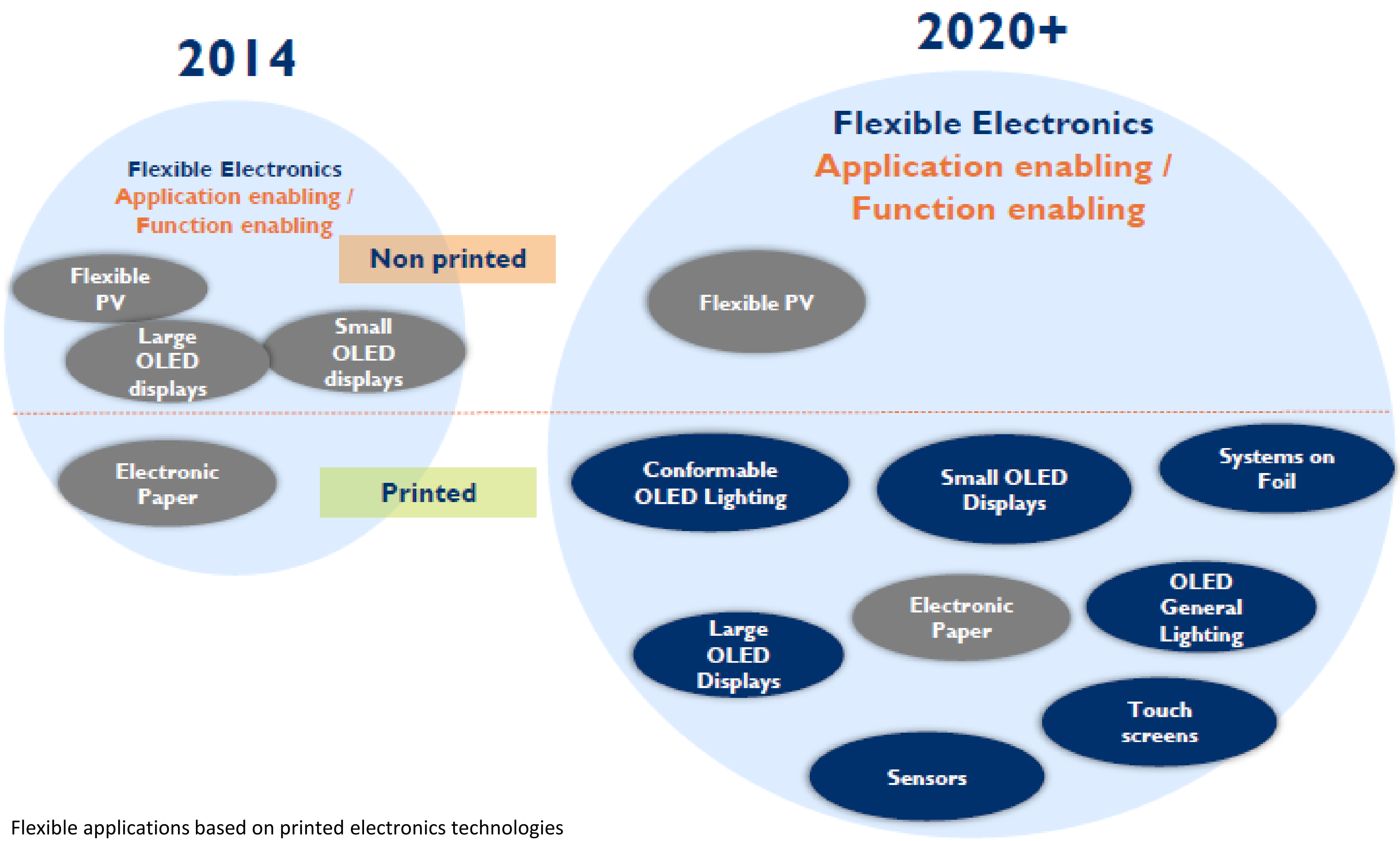
Can be transparent

Early Stage Technology

Diverse industry



APPLICATION LANDSCAPE 2014 - 2020+ / FROM TECHNOLOGIES TO MARKET



Flexible applications based on printed electronics technologies
Source: YoleDeveloppement SA. (2013)

MAIN FLEXIBLE / PRINTED ELECTRONICS APPLICATIONS

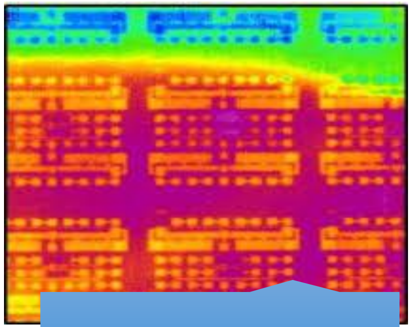
Photovoltaics

Displaying

MEMS & sensors

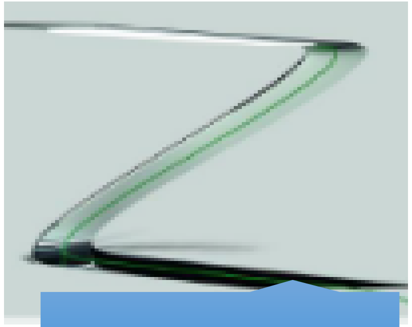
Advanced packaging

Photonics



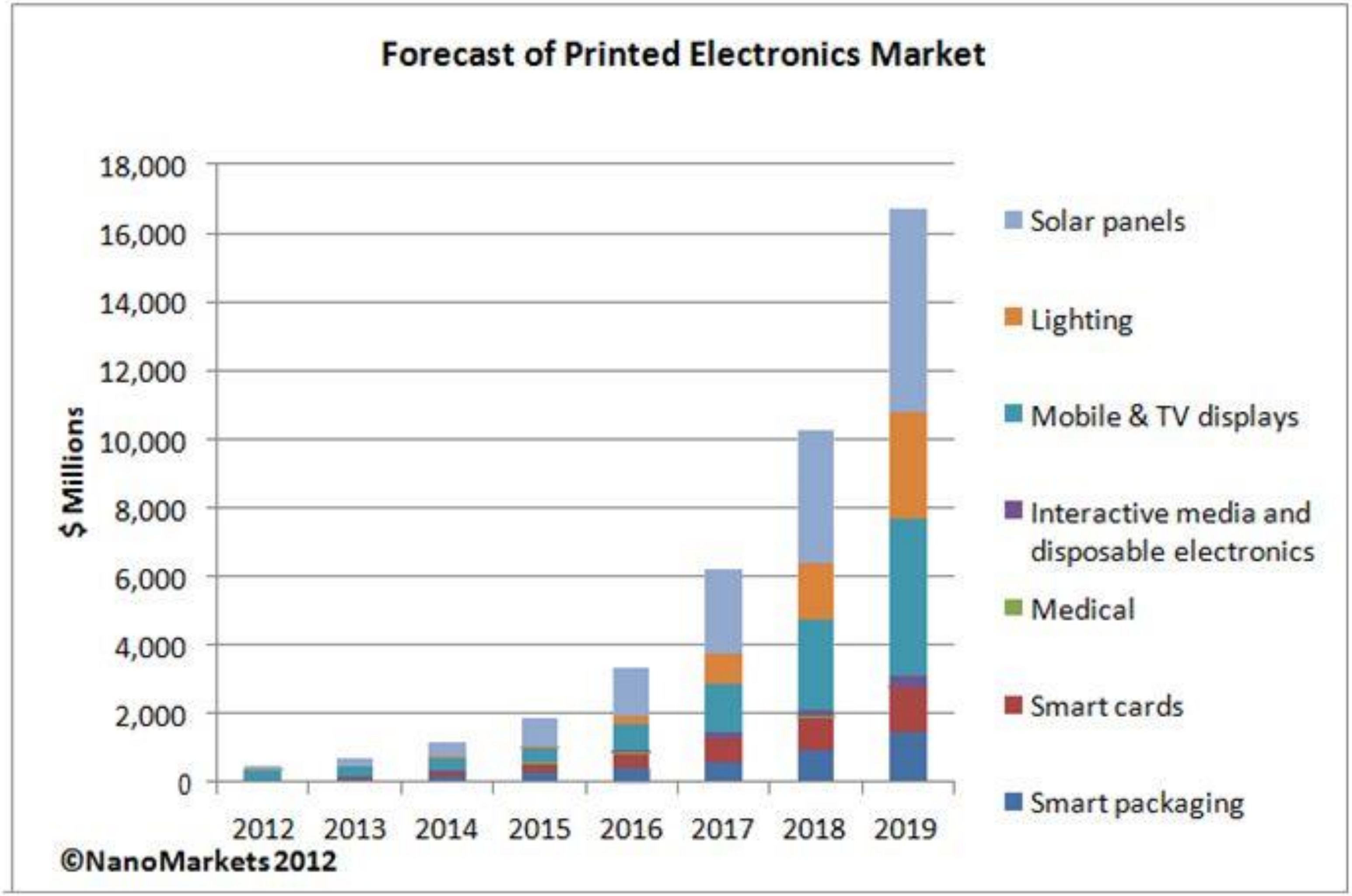
Imaging

Power electronics



Lighting

Introduction

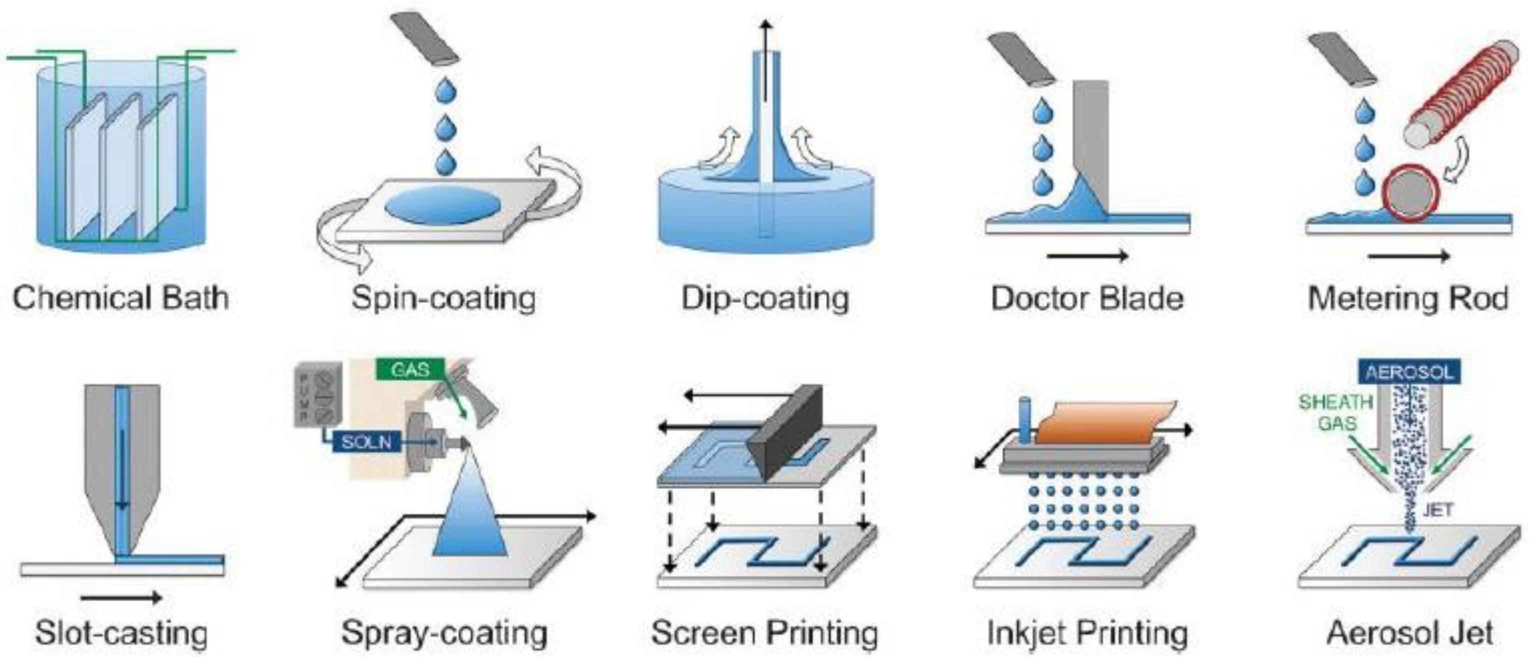


Printing technologies

Printing technologies

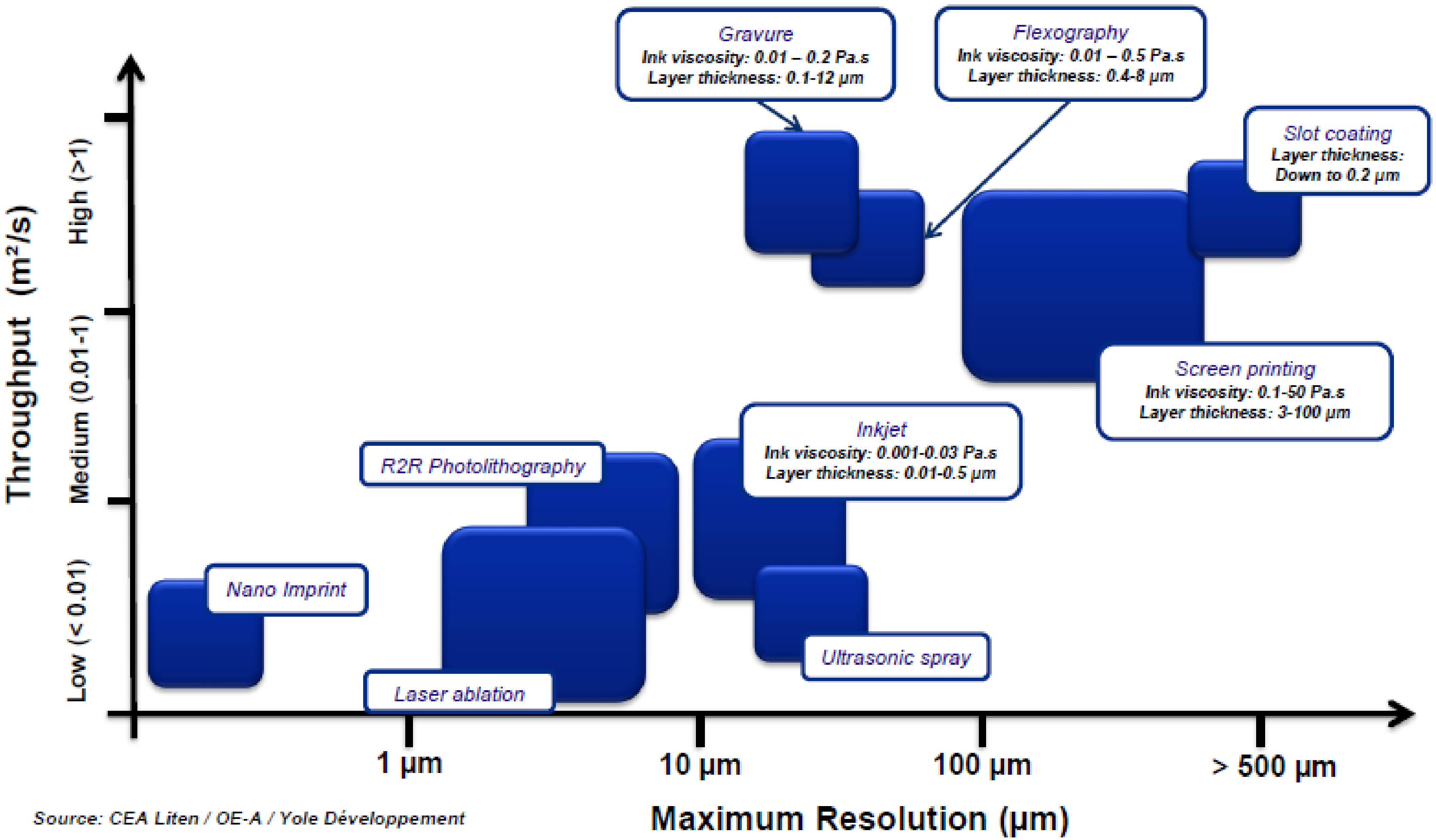
Most common deposition techniques are available at laboratory or semi-industrial scale… but none yet fits low-cost large volume production

Equipment dedicated to large volume printed electronics is still expensive and not completely adapted (nozzle clogging in inkjet, low resolution in screen printing etc.).



Description of various solution deposition methods
Source: Chem. Soc. Rev., 2011, 40, 5406–5441

PRODUCTION PROCESS THROUGHPUT & RESOLUTION



Source: CEA Liten / OE-A / Yole Développement

PRODUCTION PROCESS THROUGHPUT & RESOLUTION

	Flexography	Offset lithography	Gravure printing	Screen printing	Inkjet printing
Printing form	Relief (polymer plate)	Flat (Al plate)	Engraved cylinder	Stencil and mesh	Digital
Typical resolution (lines/cm)	60	100-200	100	50	60-250
Ink viscosity (Pas)	0.05-0.5	30-100	0.01-0.2	0.1-50	0.002-0.1
Substrates	Paper, boards, polymers	Paper, boards, polymers	Coated paper and boards, polymers	All	All, 3D possible
Film thickness (µm)	0.5-2	0.5-2	0.5-2	5-25	0.1-3
Line width (µm)	20-50	10-15	10-50	50-150	1-20
Registration (µm)	<200	>10	>10	>25	<5
Throughput (m^2 /sec)	10	20	10	<10	0.01-0.1
Printing speed (m/min)	100-500	200-800	100-1000	10-15	15-500

Source: Caglar,U. Doctor of Technology thesis, Tampere University of Technology. Publication 863.2009

Materials: Inks and substrates

Materials: Inks and substrates

FUNCTONAL INKS

Conductive
- Silver
- Carbon
- Copper

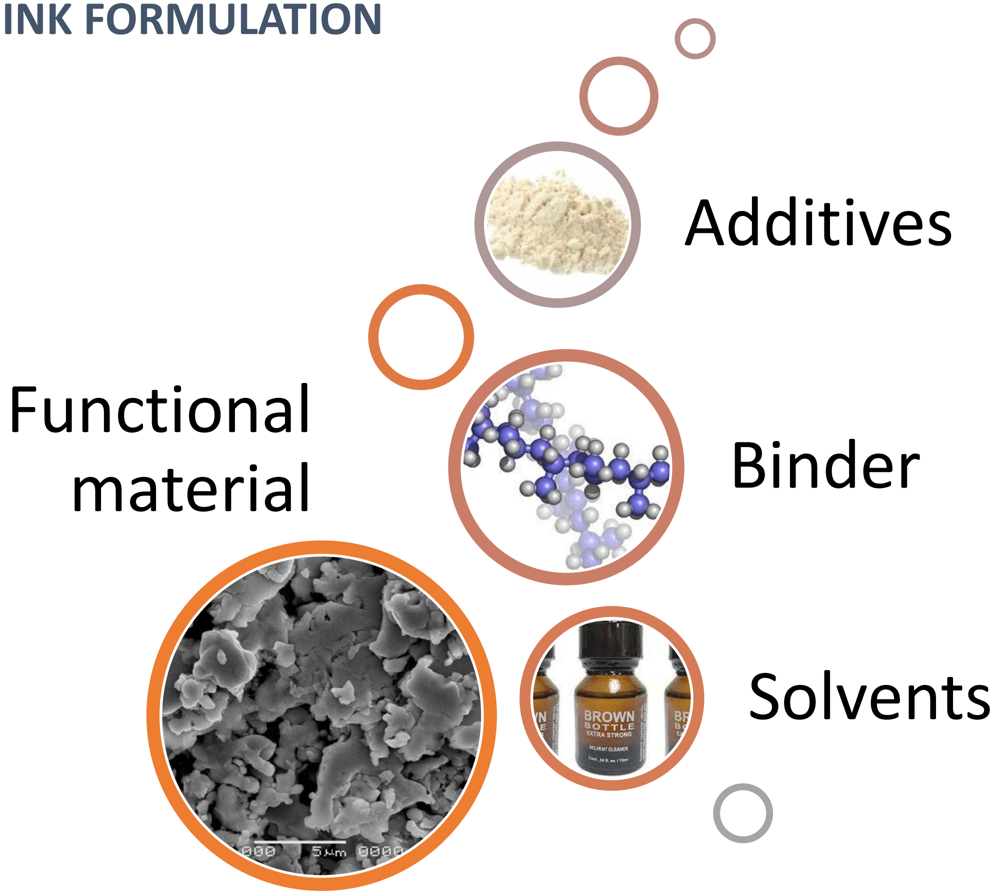
Semiconductors
- PEDOT:PSS

Dielectric

Others

Materials: Inks and substrates

FUNCTIONAL INK FORMULATION



Materials: Inks and substrates

Printed electronics could be applied directly in a great variety of substrates
Rigid/Flexible, non conventional, transparent, …

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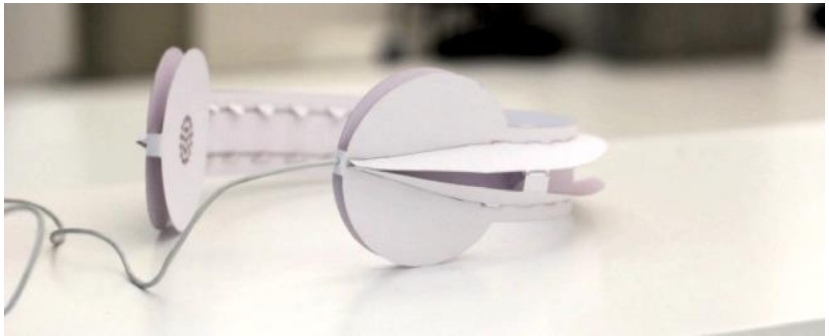
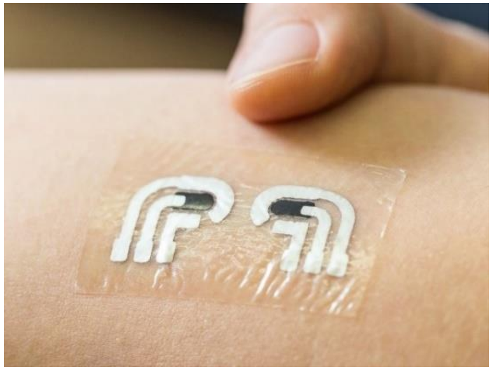
http://science-wired.blogspot.pt/2010/03/nanotube-rfid-better-barcodes.html



http://thenextweb.com/media/2012/03/13/apps-embedded-in-paper-could-give-humble-flyers-and-posters-an-interactive-future/



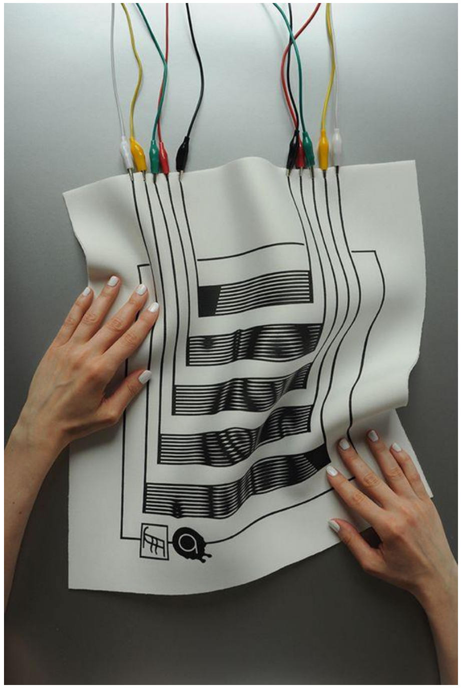
http://www.electronicproducts.com/Sensors_and_Transducers/Sensors/P_F_Sensors_their_future_and_challenges.aspx

https://gigaom.com/2014/04/07/how-thin-flexible-electronics-will-revolutionize-everything-from-user-interfaces-to-packaging/

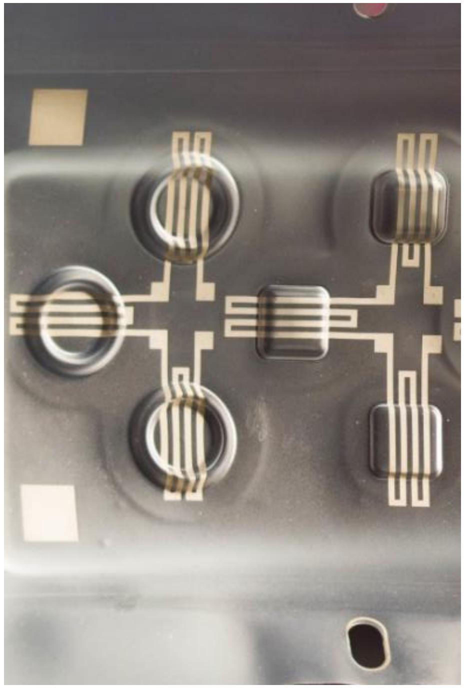
http://www.osadirect.com/news/article/1462/university-of-tokyo-reseachers-develop-novel-conductive-thread/

Materials: Inks and substrates

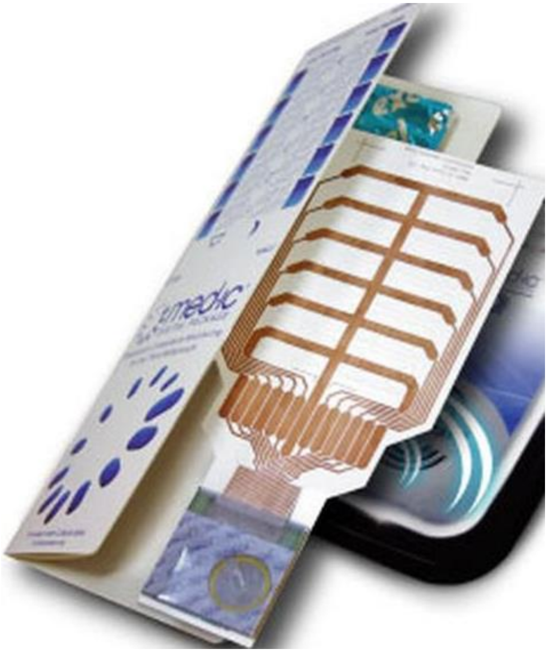
Printed electronics could be applied directly in a great variety of substrates
Rigid/Flexible, non conventional, transparent, …



http://www.designboom.com/technology/ejtech-liquid-midi-07-20-2015/



http://www.dupont.com/products-and-services/electronic-electrical-materials/printed-electronics.html



http://www.printmediacentr.com/2014/06/04/don-carli-on-printed-electronics-and-the-future-of-packaging-and-design/

Main technical / economical challenges

Main technical and economical challenges

Raw material costs

- Economies of scale
- ink cost

Process environment

- Moisture stability
- Air stability

Test standards/certification

Curing processes

Durability/stability

- Application requirements
- Barrier development

http://www.coatema.de/en/maerkte/gedruckte-elektronik.html

Main technical and economical challenges

Flexible and streachable substrates

- Alignment issues
- Geometrical distortion
- Brittle materials

Still some vacuum steps…

Batch vs. Continuous Production

- Move from sheet-to-sheet processes to roll-to-roll (R2R) processes

Full automation

http://www.coatema.de/en/maerkte/gedruckte-elektronik.html

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Thank you for you attention

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