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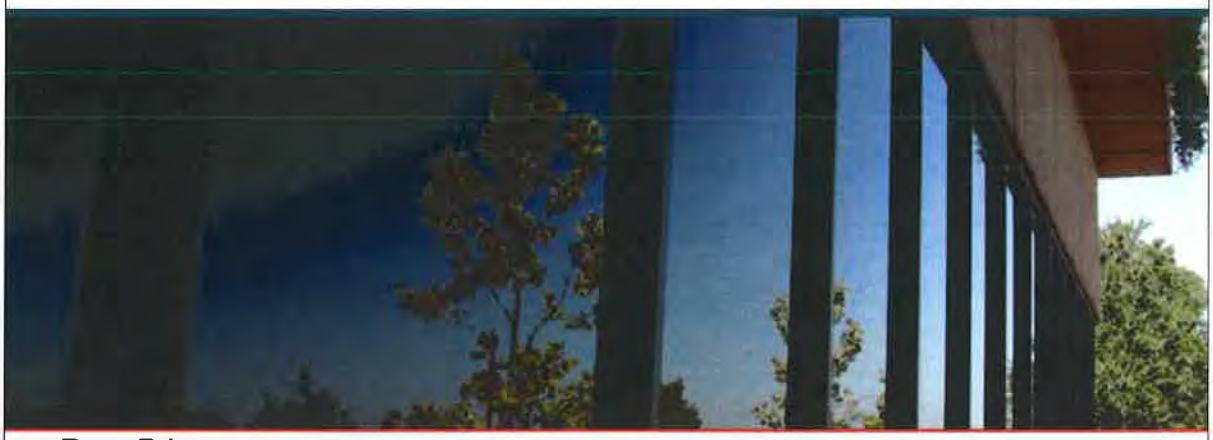
How printing technologies can change the electronics industry



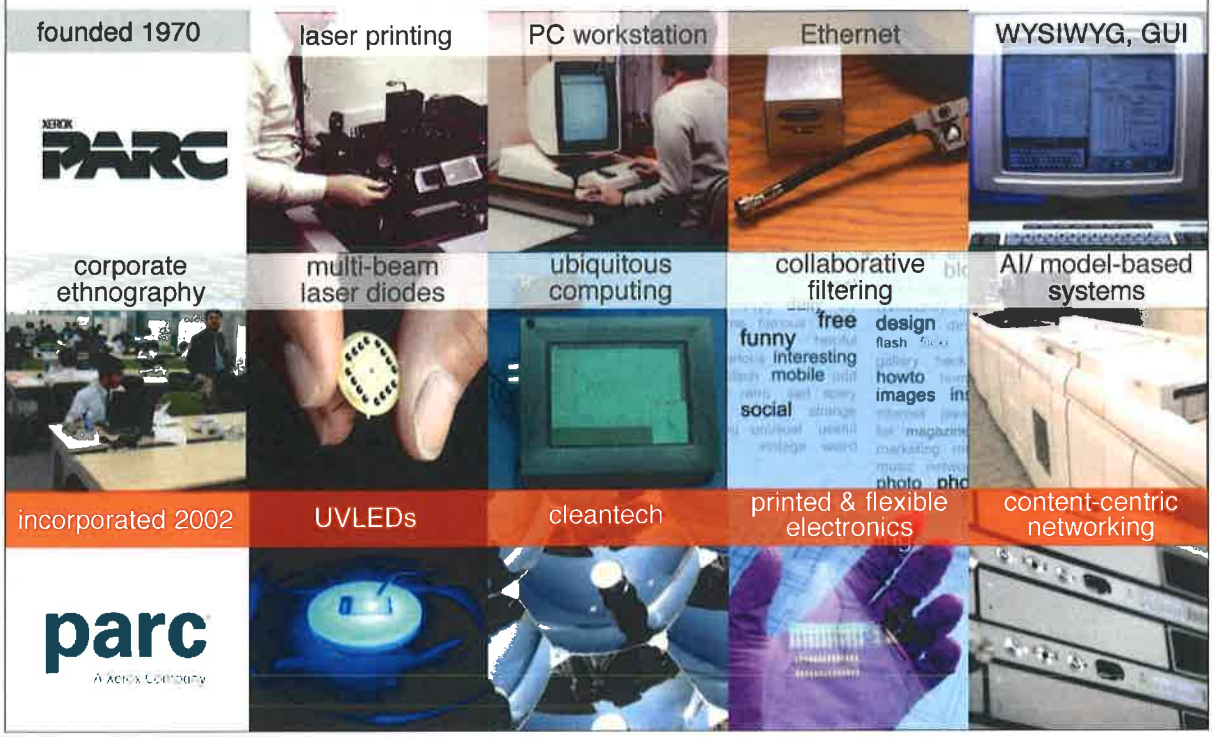
Ross Bringans
PARC, A Xerox Company
bringans@parc.com

About PARC

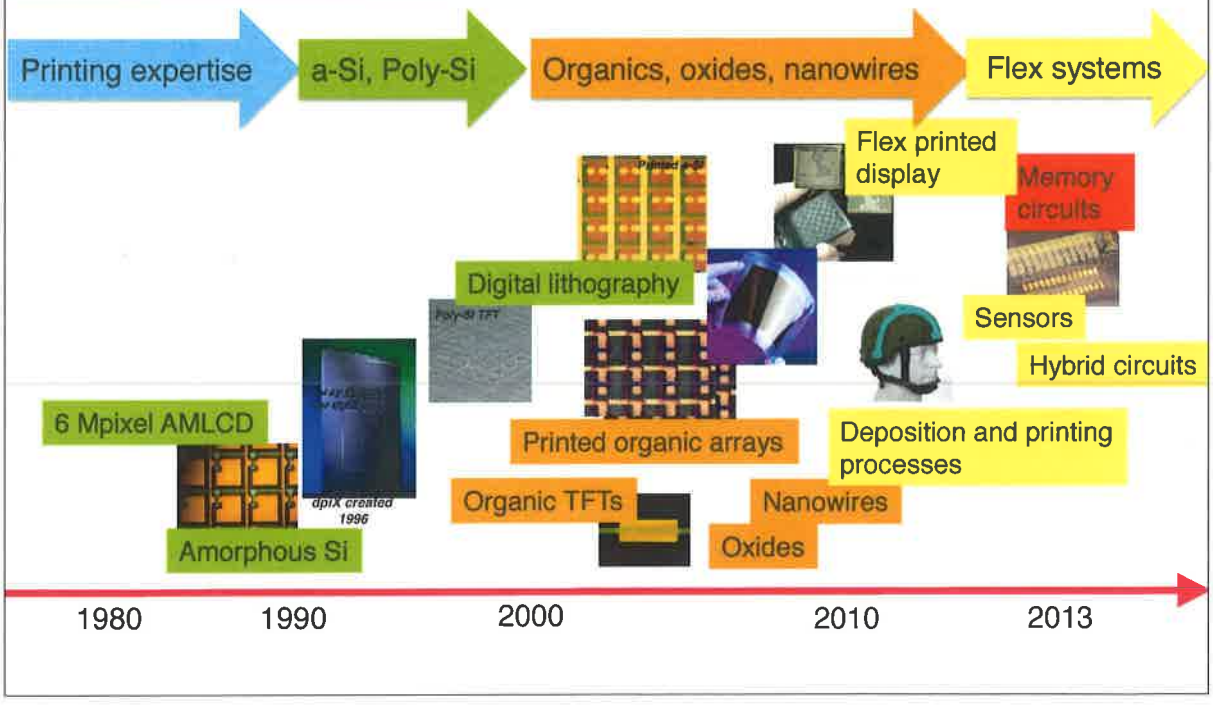
Founded in 1970 as Xerox Palo Alto Research Center

Spun out in 2002 as an independent research business.

PARC history

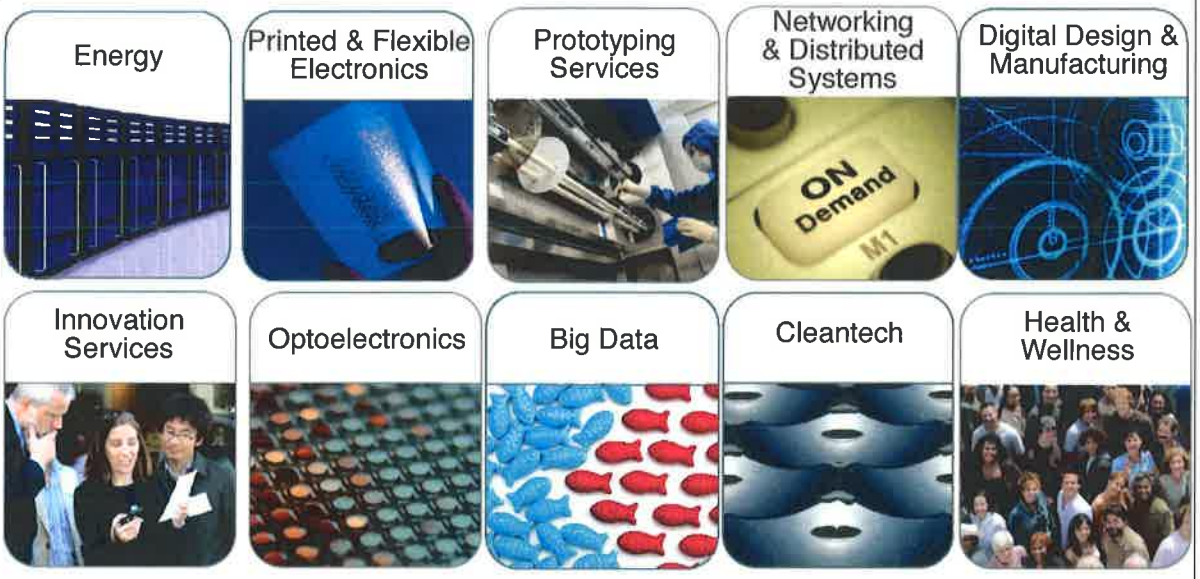


Large Area and Printed Electronics

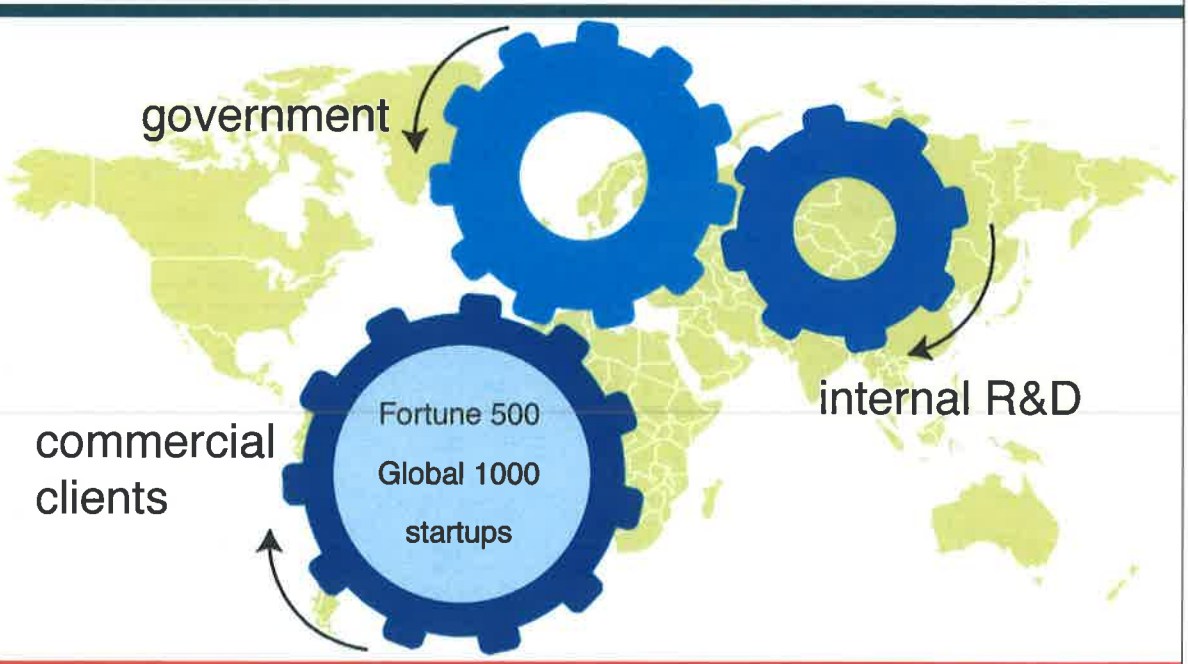


PARC now

The Business of Breakthroughs®



PARC's open innovation business model



Introduction

- How can the world of manufacturing be changed
  - Democratization of manufacturing
  - Mass customization
  - Just in time delivery
- How can the printing business be expanded
  - Higher value "prints"
  - Completely new markets

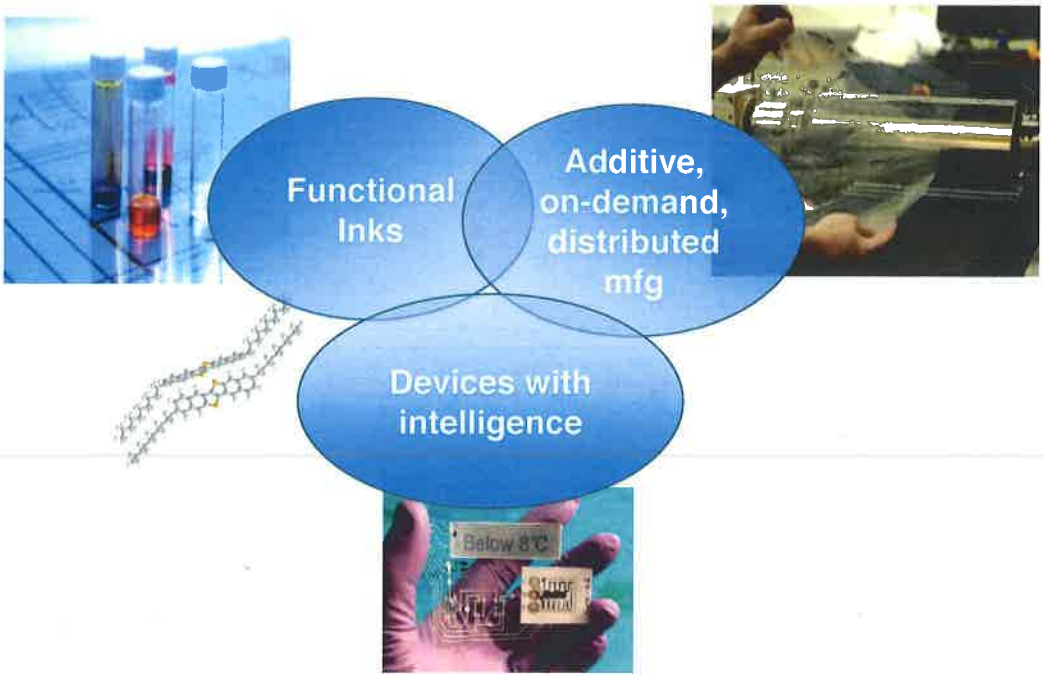
For printers, there are some familiar challenges

- Custom at the same price as traditional
- Quality that meets the requirements
- Speed
- Skills mix
- Installed base

Outline

- Printed
  - Screen
  - Inkjet
  - Gravure
  - Offset
  - Flexo
  - Aerosol
  - Extrusion
  - 3D
- Electronics
  - Conductors
  - Passives
  - Semiconductors
  - Transistors
  - Circuits
  - 2D systems
  - On 3D systems
  - In 3D systems
  - Optical devices
  - (and chips)

Printed Intelligence



Images clockwise: Functional inks used at PARC, Gravure printing at PARC, Thin Film Electronics ASA

Why are people excited?

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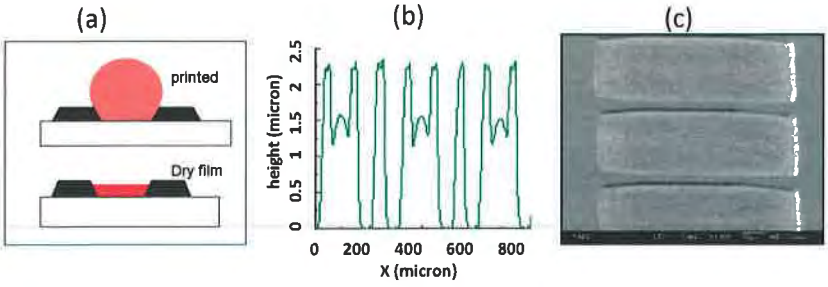
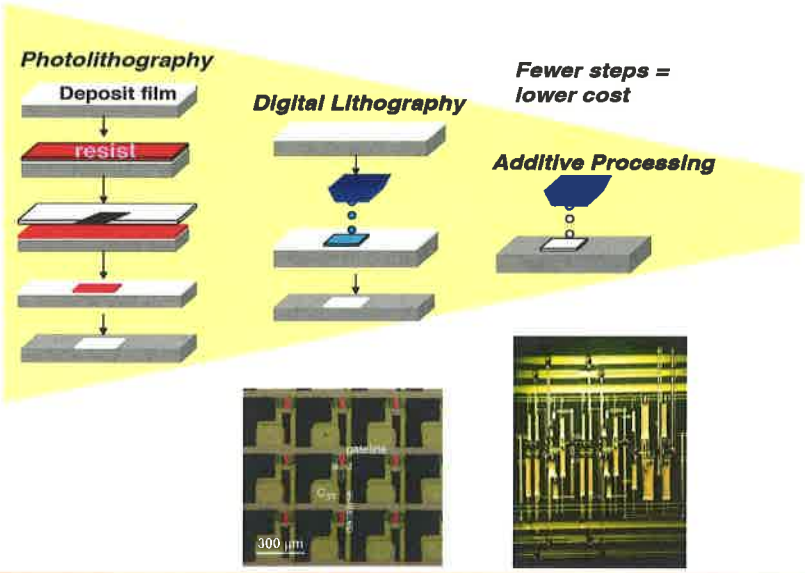
Printing can be used for:
1. Dispensing



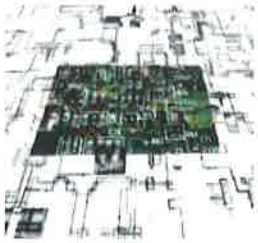
Ink deposited into wells

Printing can be used for:
2. Patterning



Printing can be used for:
3. Assembly

Expensive serial assembly



Replaced by low cost parallel automation thru printing "chips as ink"

Printing can be used for:
4. Building

3D Printing
- Plastics, metals, ...




Images: pixabay.com; commons.wikimedia.org

Printing can be used for:
5. Just-in-time manufacturing

NASA goal:
- digitally manufactured sensor systems
- On-site, on-demand, additively manufactured
- Light weight, customizable, distributed sensor systems

JPL
Jet Propulsion Laboratory
California Institute of Technology

BOEING

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And, printing promises:
6. Ability to make Really Complex Systems

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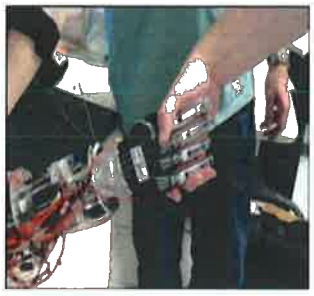
Current state of the art



- Degree of Integration
- Sensor density

European Framework SmartHand project

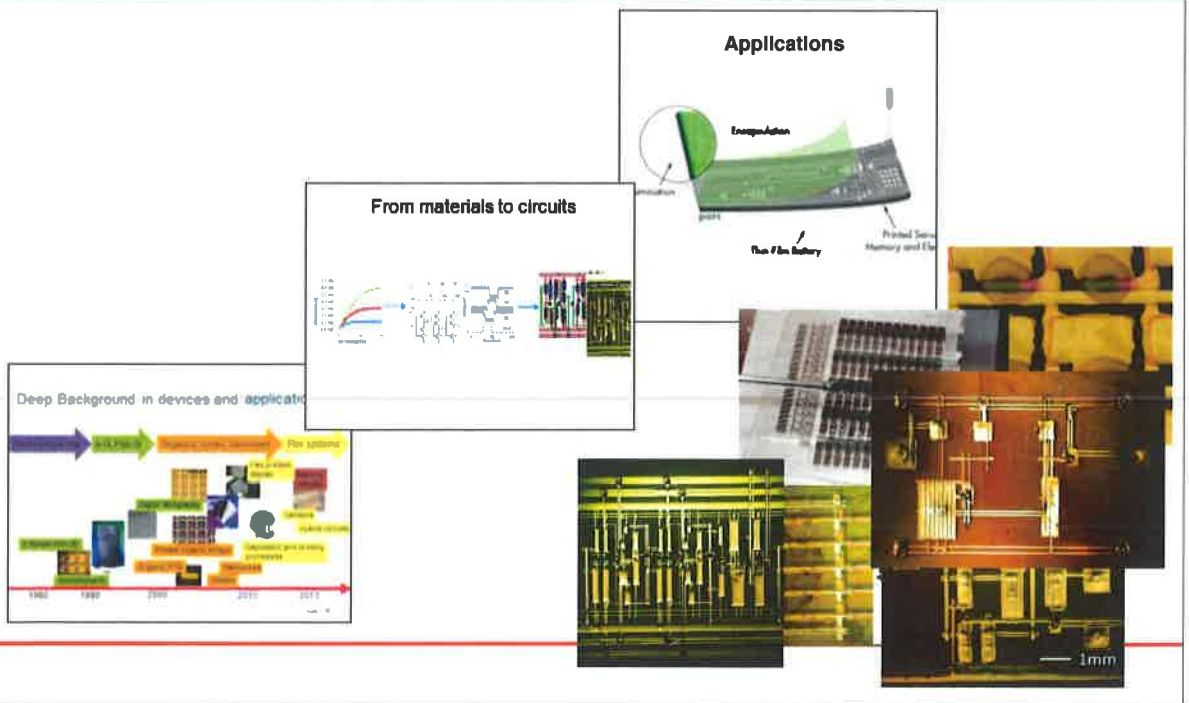
Integrated Object Printer

Integrated high density sensors

Integrated complex motor function

In nature

From Materials to Systems

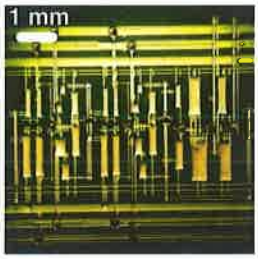


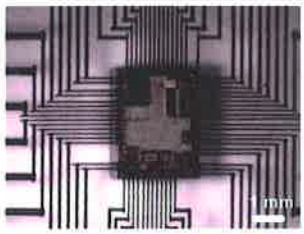
Approaches to Printing Electronics

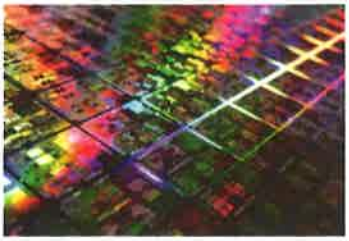
all-printed: all components printed from simple inks

hybrid: include some pre-fabricated components if needed

assembly: large scale assembly of electronic components







increasing performance, size of materials set, cost

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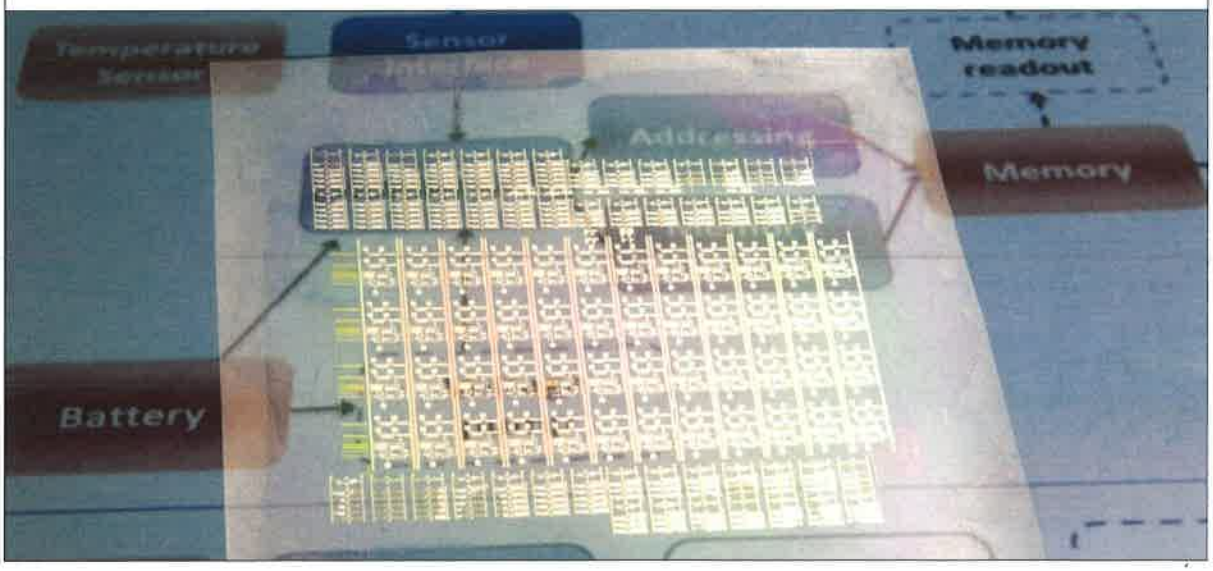
1. All-printed Electronics



Printed conductors – already here

- RFID antennae
- Membrane switches for keypads
- Touchpads
- Automotive mirror defrosters
- Medical sensors e.g. EKG, EEG.

Gravure printing of electronic structures on paper. (Wikimedia commons)

T-Ink

Copyright PolyIC

New directions in printed conductors

- Low temperature inks and high temperature papers
  - Nano particles
  - Coated paper

Xerox Research Center Canada

Arjowiggins

http://www.xrcc.external.xerox.com

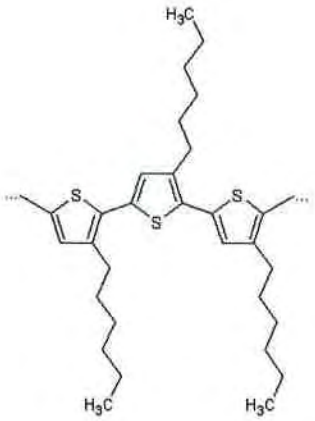
- Printing on 3D structures – Optomec examples

http://www.optomec.com

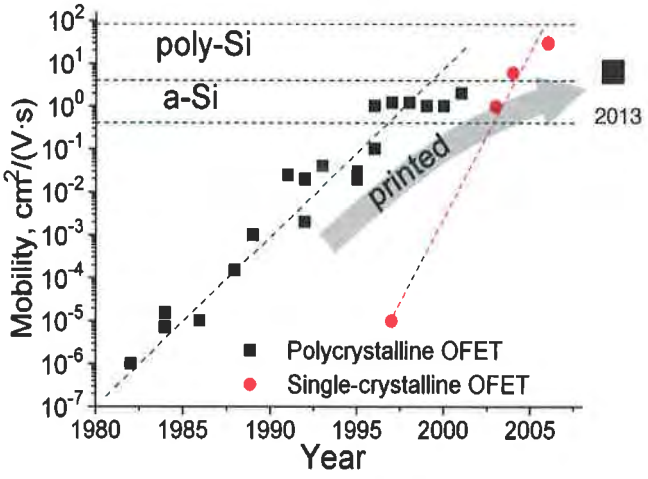
SUBSTRATE:
CERAMIC CUBE
INK:
Ag NANOPARTICLE
POST PROCESSING:
THERMAL 120C TO 180C

SUBSTRATE:
STACKED SILICON DIES AND EPOXY CIRCUIT BOARD
PRINTED INK:
Ag NANOPARTICLE
POST PROCESS:
THERMAL AT 220°C
PHOTO COURTESY OF VERTICAL CIRCUITS INC

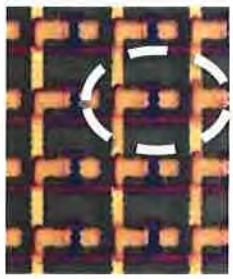
Printed semiconductors

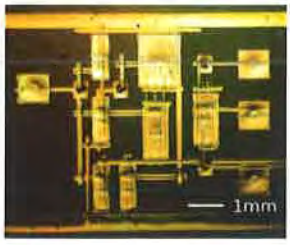


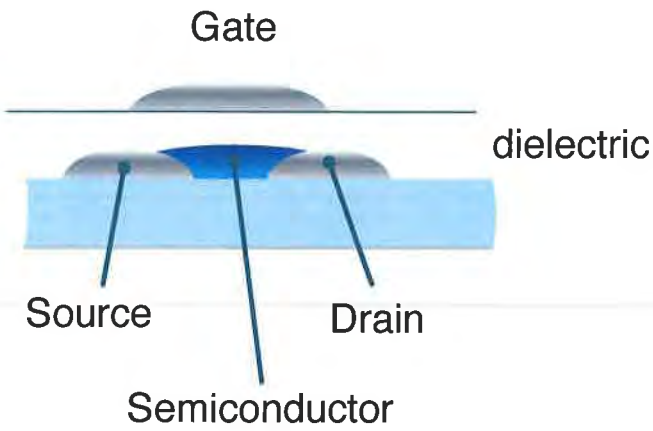
polythiophene



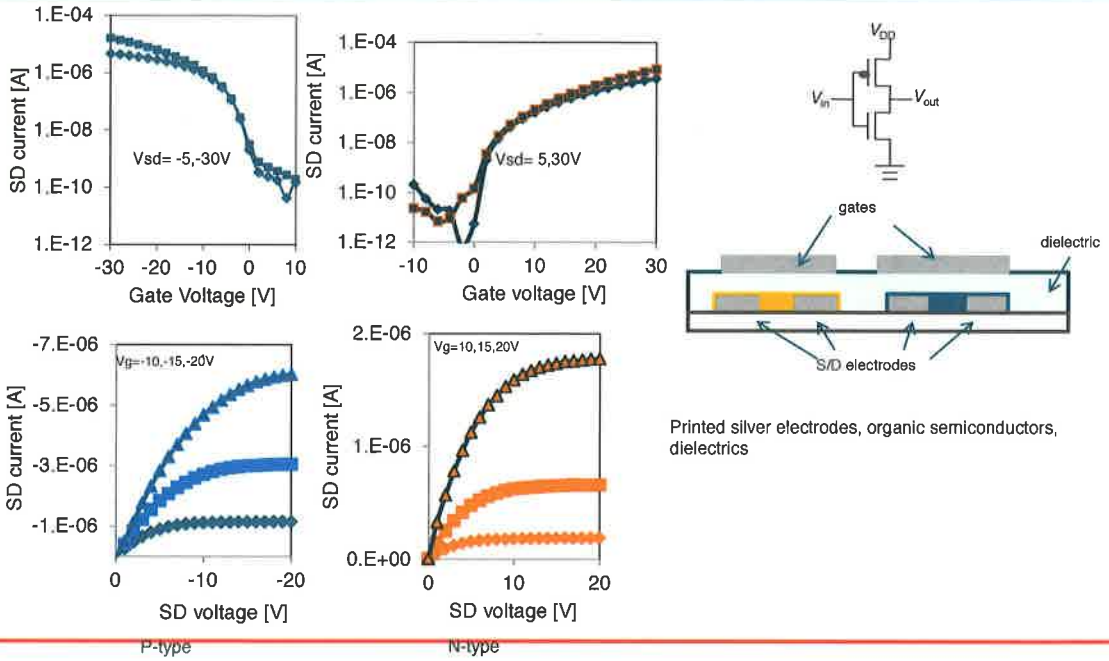
The foundational device: Printed Thin Film Transistor (TFT)





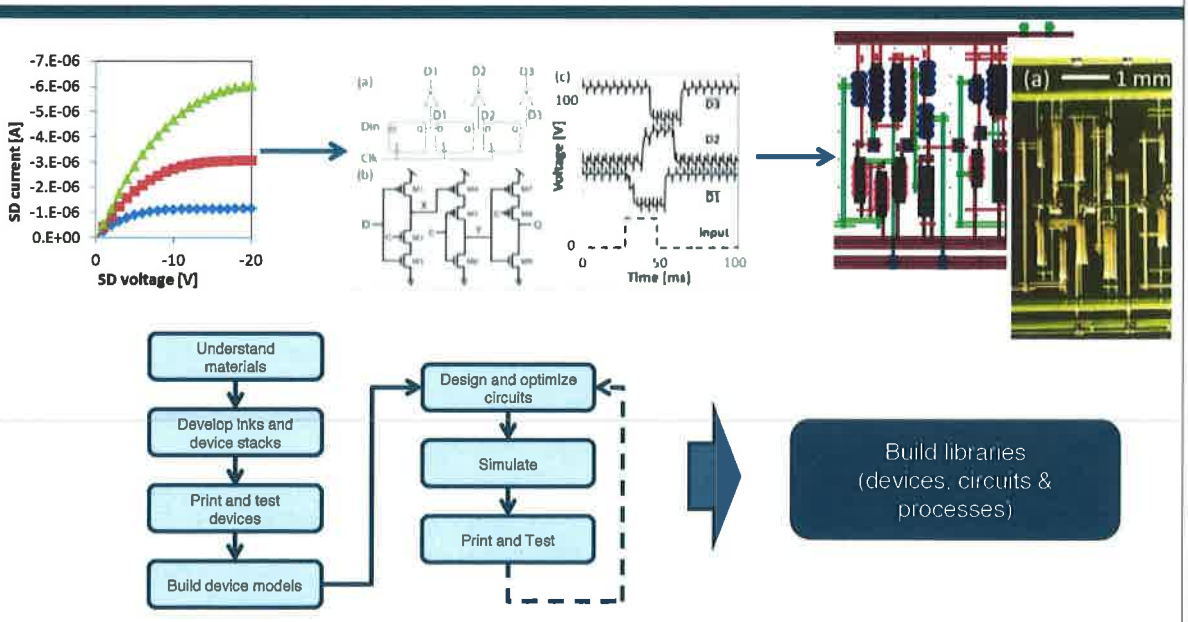


Printed complementary TFTs

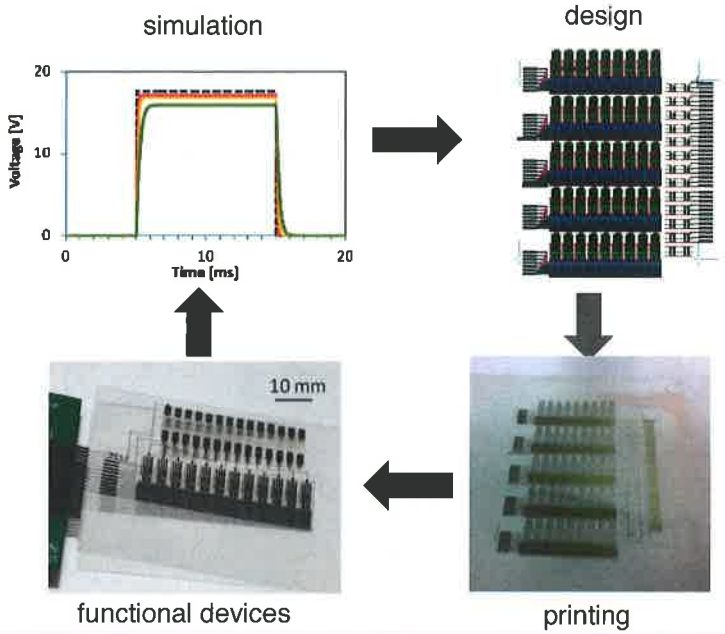


Printed silver electrodes, organic semiconductors, dielectrics

From materials to circuits

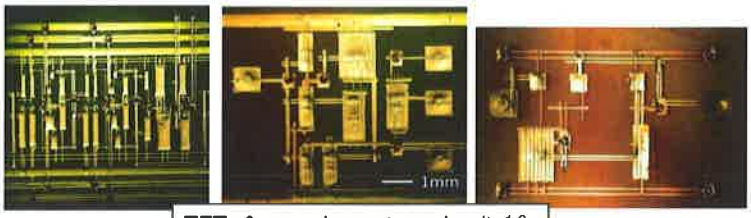


Development Cycle

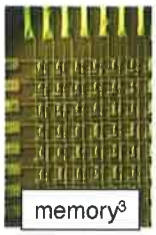


All-Printed Devices

Many device types can be printed from simple inks

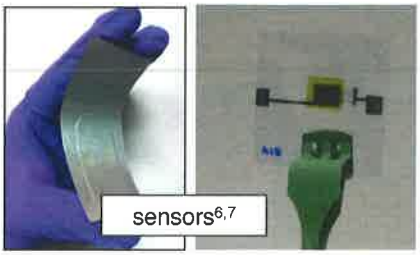


TFTs & complementary circuits[1,2]



memory[3]

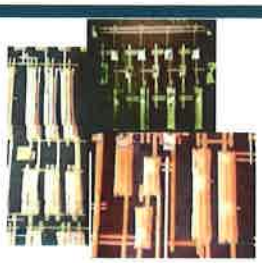
electrochemical storage[4,5]



sensors[6,7]

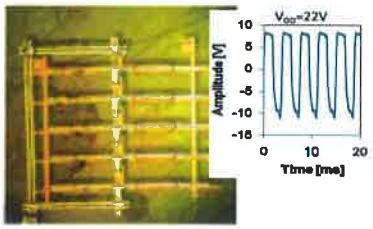
[1]*APL*, **2009**, 253302; [2]*IEEE Electron Dev. Lett., 34, 2013, 271*; [3]*JAP* **2009**, 094504; [4]*Adv. Mater.*, **2011**, 3251, [5]*APL*, **2013**, 233302; [6]*Org. Electron.* **2011**, 682; [7]*APL* **2013**, 103308

An expanding library: printed logic



AND, OR, NOT, NAND

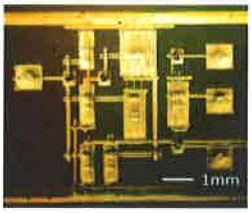
Boolean logic



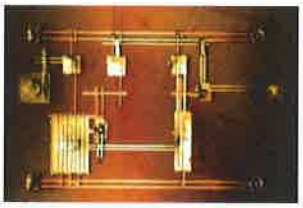
Ring oscillator

Shift register

Decoder



Pulse generator

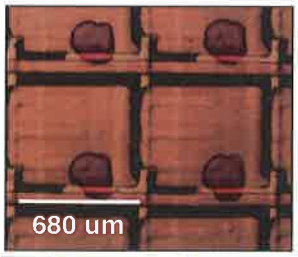


Trigger with half latch

Memristor

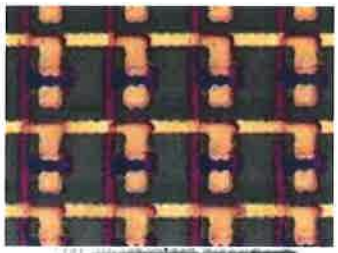
An expanding library: printed arrays

Active matrix display



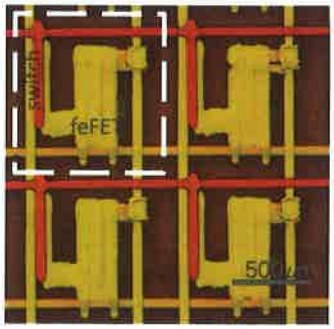
J. Soc. Info. Display 2007, 7, 485-490

Image sensor arrays



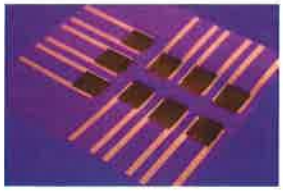
Appl. Phys. Lett. 92, 213303 (2008)

Memory arrays

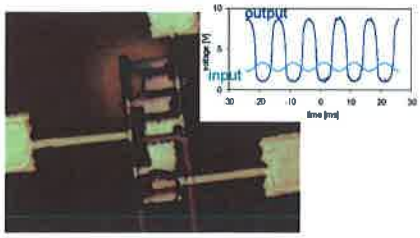


Org. Electronics 12, 2012 (2011)

An expanding library: sensors & interface



Temperature sensor

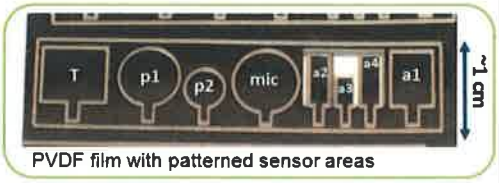


Amplifier

Flex battery

Light sensor

Pressure sensor

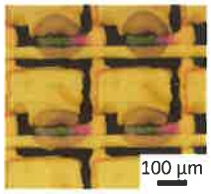


PVDF film with patterned sensor areas

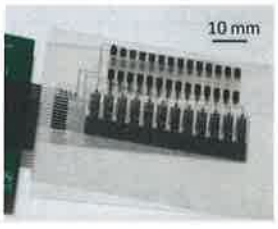
MEMS (acceleration, acoustic)

Applications for All-Printed Circuits

Many different applications



Ink-jet printed active matrix backplanes and displays[1]



addressing systems[2]
(developed with Thin Film Electronics)

[1] *J. Soc. Inf. Display* **2007**, 485; [2] *Sci. Rep.*, *2*, **2012**, 585