Flexible and Printed Electronics – A Korean Initiative

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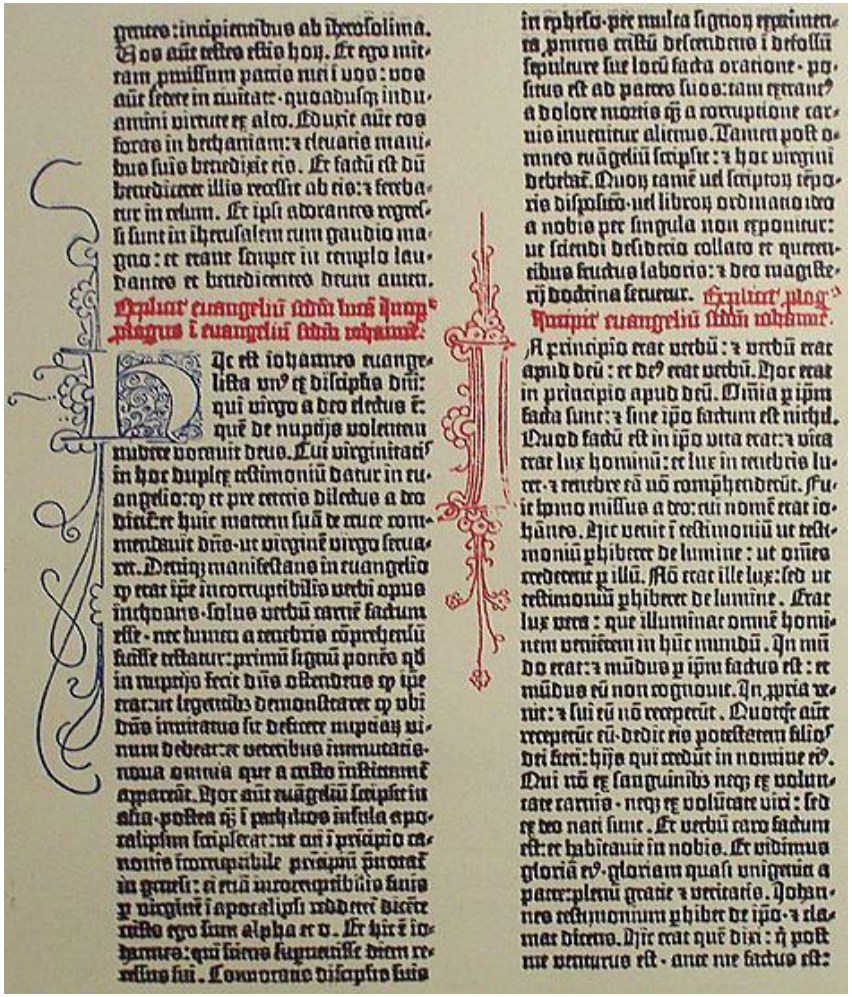
Contents

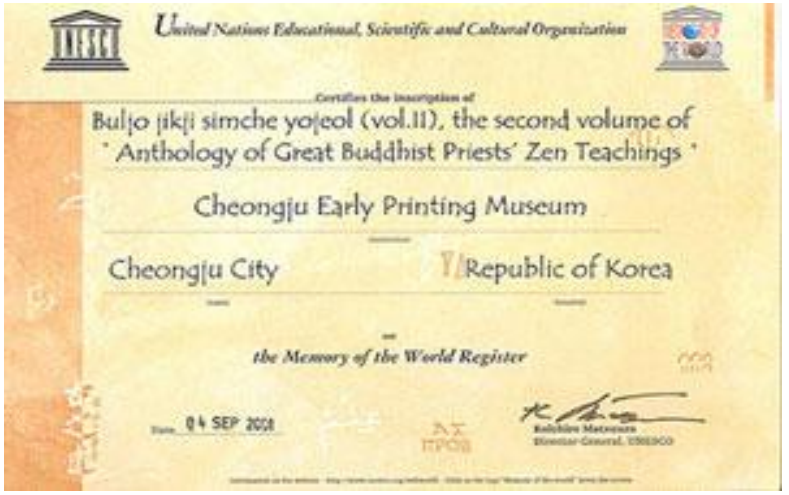
The Printing Revolution

Gutenberg Printing Press & Bible

Printing press from 1811, exhibited in Munich, Germany
Wikipedia

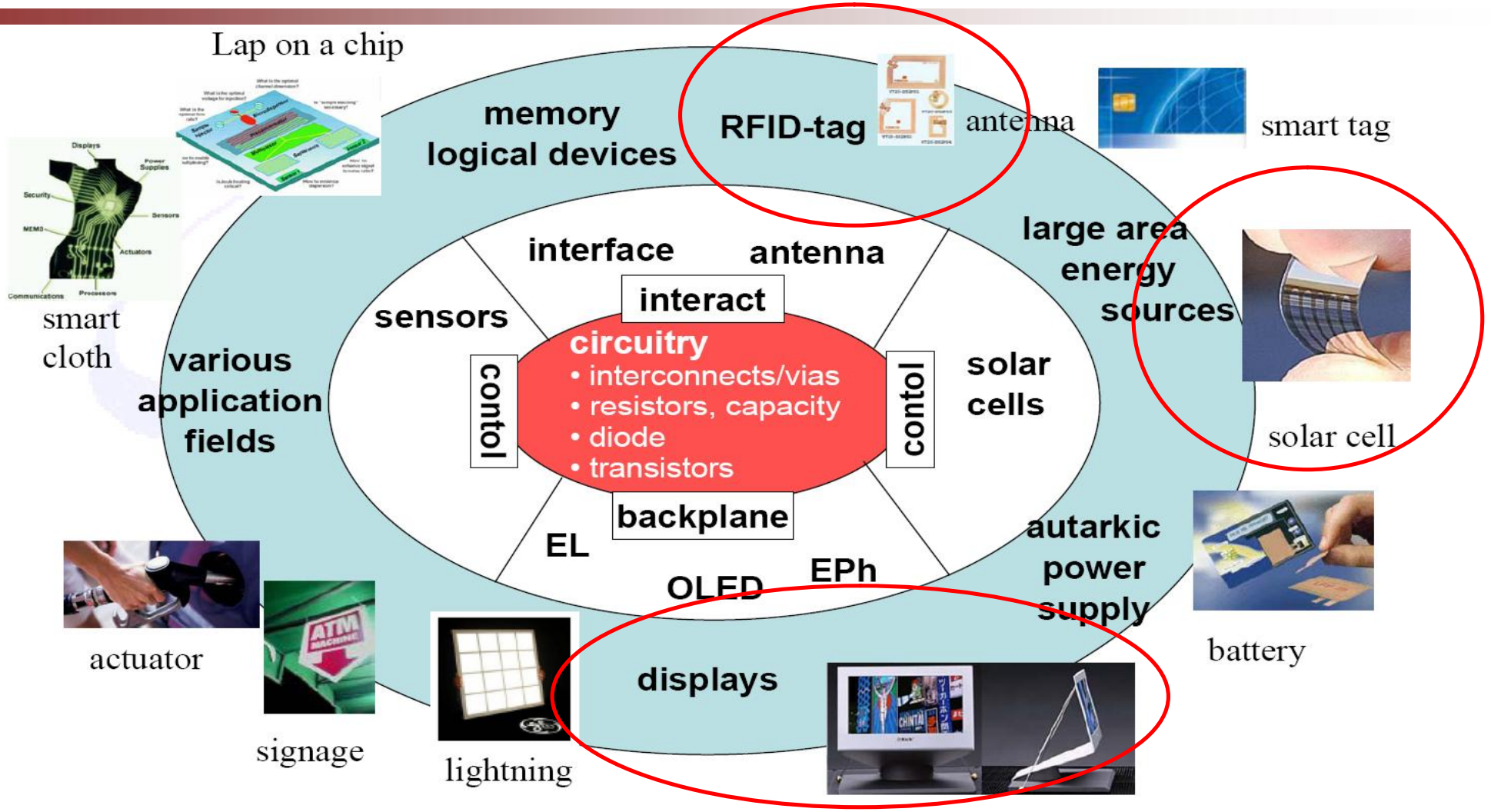


World 1st printed book by metal movable types (1377)



1377

Active research areas in Korea



- *Everything that can benefit from being flexible will be flexible and printed.*
- *Low-cost manufacturing; Reduce material waste and energy consumption, etc.*
- *Paradigm shift: Disruptive technology may be a threat to the existing industries*

Korean PE Univ. & Institutes

Seoul
- KDIA
- KoPEA
- 21C Frontier Program: Next-gen. displays
- SNU
  - ISRC/Display Center
  - OLED Center
- FDRC (Konkuk Univ.)
- ADRC (Kyunghee Univ.)

Daejeon-city
- ETRI
- KRICT
- KIMM
- KAIST: FDRC

Jeonbuk-Province & Jeonju-city
- IWFPE at Mooju
- KETI-KPEC (Korea Printed Electronics Center)

Pohang-City
- Nanocenter (POSTEC)

Sunchon-City
- RIC & WCU (Sunchon

Korean PE Companies

Paju-City
- LG Display (LCDs, OLEDs)

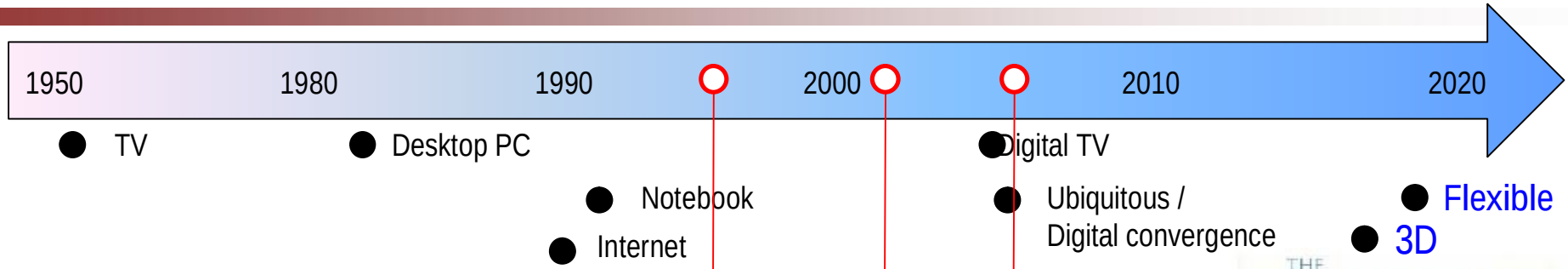
Suwon-City & Kiheung
- Samsung Electronics (Semiconductors, LCDs, Si-Solar cells: R&D)
- Samsung SMD (OLED R&D)
- Samsung SDI (DSSC R&D)
- Small companies:
  - Inktec, Uniject, etc.

Cheonan-City (Tangjeong) & neighborhoods
- Samsung Electronics (LCDs)
- Samsung SMD (OLEDs)
- Equipment, materials companies

Sunchon-City
- Paru (RFID), etc.

Kumi-City
- LG Display (LCDs)
- Small companies

Roadmap of displays and Government support



Bulky & heavy **à** Thin & light **à** conformable, flexible & rollable

- "G7" Project for displays ('95-'01): R&D money, Set up 5 display tech. centers, etc.
  - Catch up Japan and eventually become world No. 1.

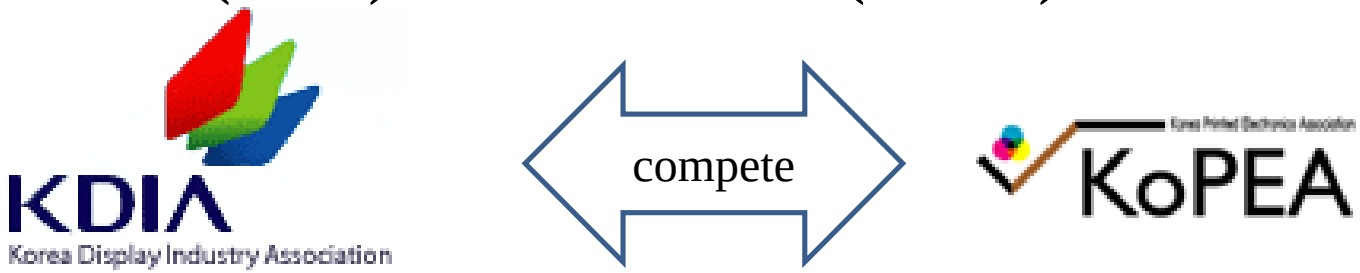
- "21C Frontier Program" Development of Next-Gen Displays (''02-'' 12): 9 years, $10M/yr - All-organic displays (OTFTs, e-papers, etc.)
- "SystemIC 2010" Project ('01-'11)

- Industrial Core Research Projects ('05~): ~ US$ 3-5 M per project
  - e.g., Development of 40" AMOLEDs, Soluble OLED materials, 5.5-Gen ((1320×1500mm) AMOLED Equipments, OLED lightings, etc.

PE & Flexible Display Associations

Korea Display Industry Association (KDIA)

Korea Printed Electronics Association (KoPEA)



- **Industry networks**
- **R&D planning**
- **Conference & Exhibition**
  - **IMID**
  - **IWFPE**

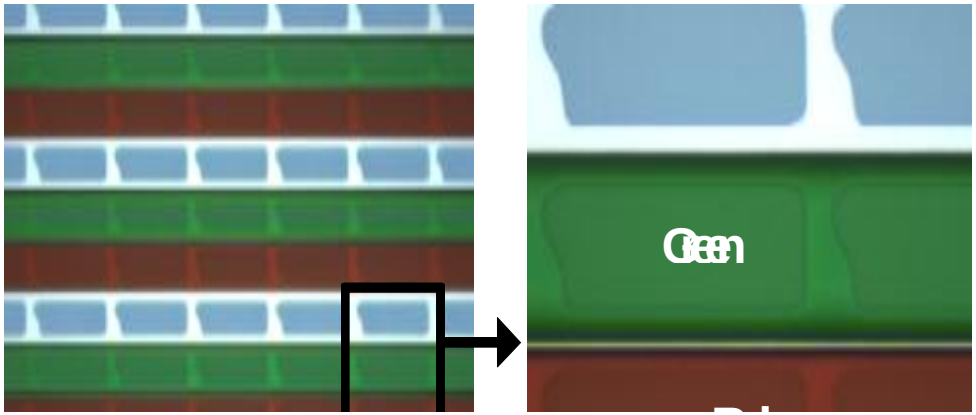
- **Industry networks**
- **R&D planning**
- **Conference & Exhibition**
  - **ICPE**

Printed Electronics Roadmap

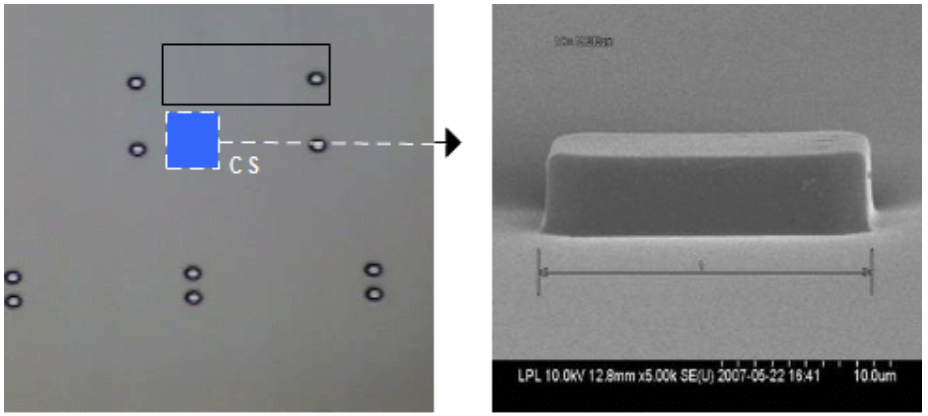
		1st Phase				2nd Phase			3rd Phase		
Year		'11	'12	'13	'14	'15	'16	'17	'18	'19	'20
Applications	All-printed, large-area OLEDs	Development of core tech. for printable OLEDs • Soluble OLED materials • Printable OLED backplanes				Long-lifetime printable OLEDs • Large-area OLED printing • Uniformity, Stability			All-printed AMOLED • Gen 11 • Flexible R2R AMOLED		
	Green Display Tech. & Process	Development of core tech. for printable LCDs/PDPs • Pritable Color Filters • Pritable Cell Barriers, etc				Eco – Display tech. • Printable TFTs • New materials & Processes			All-printed LCD/PDP		
	Disposable Displays	Low-cost e-papers				Large-area e-paper			All-printed Disposable E-paper		
	Interactive Smart Displays	Printable Touch and haptic sensors				Printable Touch Panels			All-Printable Touch and haptic Displays		

KDIA, Vison and strategy for the development of Korean display industry (2010. 6)

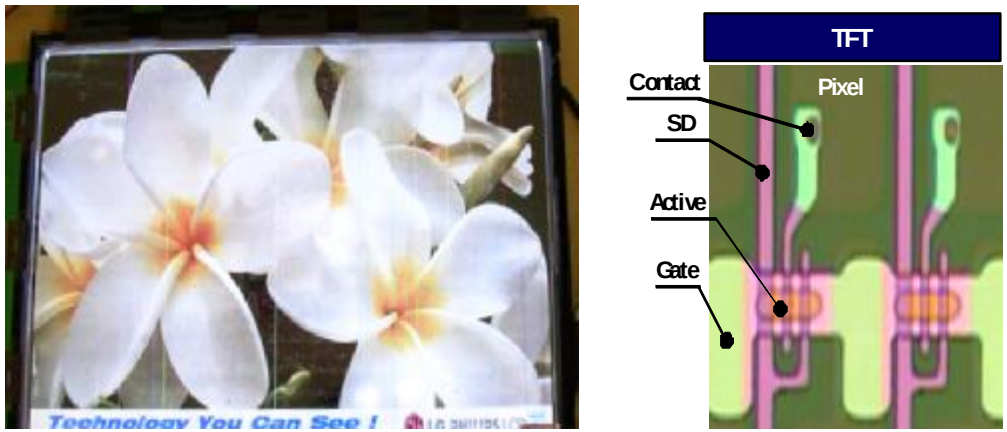
Printing tech. for displays



Reverse offset printing CF pattern image
(LG Display)



Imprinting column spacer
(LG Display)



All layer resist printing TFT panel and printed TFT structure image, LG Display (2009)

A4-size color EPD, LG Display

PE & Flexible Display Infrastructure

KETI – KPEC in Jeonju-city

- ~US $70 million (2004.8~2009.12)
- MKE, Jeonbuk-do & Jeonju-city
- Supervising Organization : KETI
- Participating Organization : 59 institutions

- **Company** : ADP, NPP, Jusung, ANS etc. (49)

- **University** : Chonbuk National Univ, KunSan National Univ, Wonkwang Univ, Jeonju Univ, Woosuk Univ (5)

- **Institute** : KIMM, KBSI, JMRC (3)

- **Local Government** : Jeollabukdo, Jeonju City (2)

SNU Display Technology Research Center

Director : Prof. Ki Woong Whang

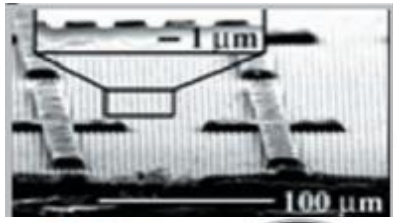
Objective :

- Fundamental research in display technology
- Education of graduate students in display area
- Activation of collaboration and technology exchange with display industry

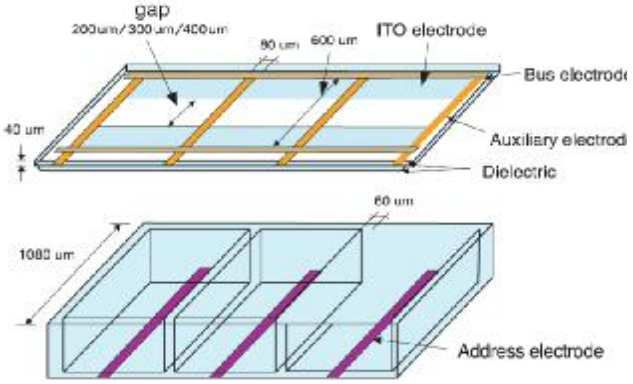
Research Areas :

- Basic Display Technologies
- Liquid Crystal Display (LCD)
- Plasma Display Panel (PDP)
- Field Emission Display (FED)
- 3-Dimensional (3D) Display
- Organic light-emitting diode (OELD) Display
- Flexible Display Technologies

Flexible LCD

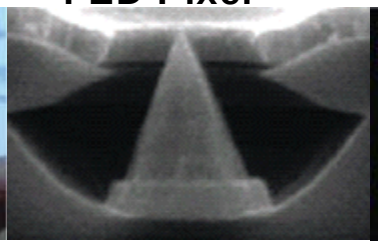


Advanced PDP DIDE Cell

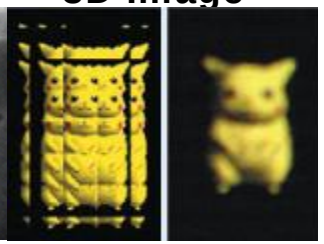


White OLED

FED Pixel



3D Image



Development of high-performance PE circuits – SystemIC 2010 Project (SNU)

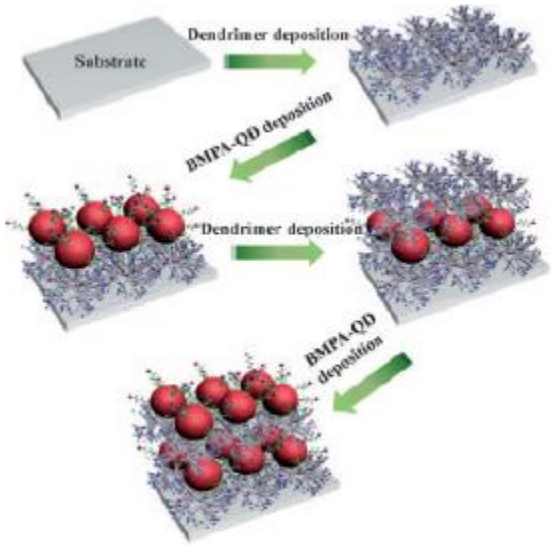
- 2007-2011 (~US$ 1.3 millon per year
- 20 Professors and 105 graduate students
- 6 companies

	2007	2008	2009	2010	2011
Printed TR	• frequency > 0.5 MHz • I_{on}/I_{off} ratio > 10^2 • operation voltage < 20 V • lifetime > 0.25 year	• frequency > 13.56 MHz • I_{on}/I_{off} ratio > 10^3 • operation voltage < 15 V • lifetime > 0.5 year	• frequency > 500 MHz • I_{on}/I_{off} ratio > 10^4 • operation voltage < 13 V • lifetime > 1 year	• frequency > 1 GHz • I_{on}/I_{off} ratio > 10^5 • operation voltage < 10 V • lifetime > 3 years	
Printed memory	• data retention > 1 hour • endurance > 50 cycles • operation voltage < 10 V • cell size < 100 μm	• data retention > 1 day • endurance > 100 cycles • operation voltage < 8 V • cell size < 10 μm	• data retention > 1 month • endurance > 500 cycles • operation voltage < 6 V • cell size < 1 μm	• data retention > 1 year • endurance > 1000 cycles • operation voltage < 5 V • cell size < 0.5 μm	
Printed diode	• rectification ratio > 10^2 • 3dB Frequency > 0.5 MHz	• rectification ratio > 10^3 •3dB Frequency > 13.56 MHz	• rectification ratio > $5x10^3$ •3dB Frequency > 500 MHz	• rectification ratio > 10^4 •3dB Frequency > 1 GHz	
Printed interconnection	• sheet resistance < 100 Ω/**o**	• sheet resistance < 10 Ω/**o**	• sheet resistance < 5 Ω/**o**	• sheet resistance < 1 Ω/**o**	
Printed ine width	• inkjet < 100 μm • nano imprint < 1 μm	• inkjet < 80 μm • nano imprint < 0.5 μm	• inkjet < 50 μm • nano imprint < 0.2 μm	• inkjet < 20 μm • nano imprint < 0.1 μm	
Test vehicle	• TR, memory	• inverter, memory array	• ring oscillator, memory array	• ring oscillator, RFID	

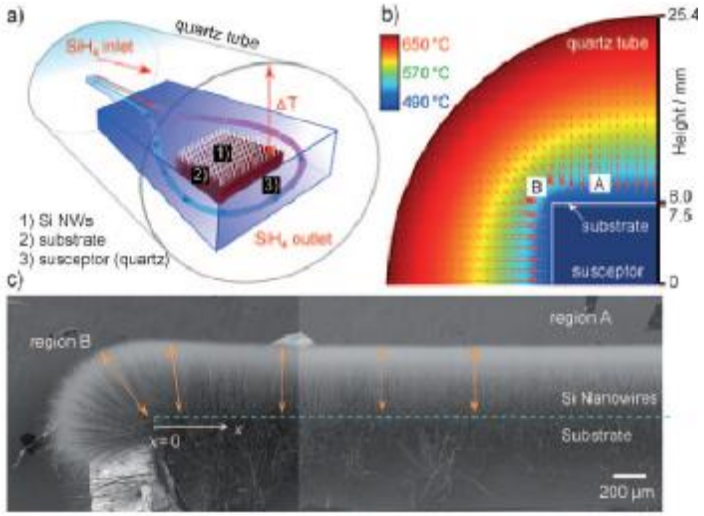
SystemIC 2010 Project (SNU) – Recent results

Molecular Orbital Gating in Molecule Transistor
-published in Nature

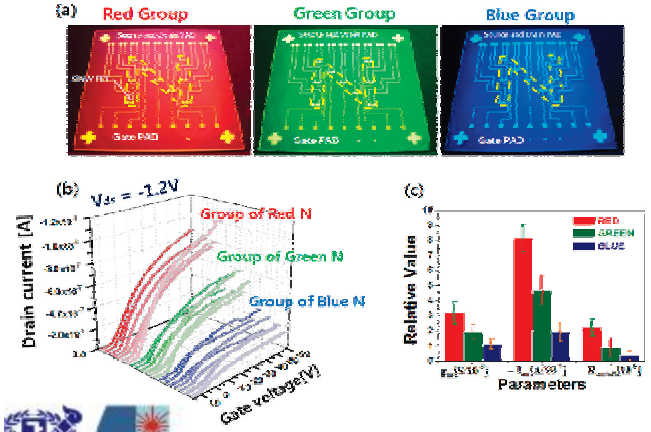
LBL self-assembly layers in non-polar solvent
-published in Angew. Chem. Int. Ed.



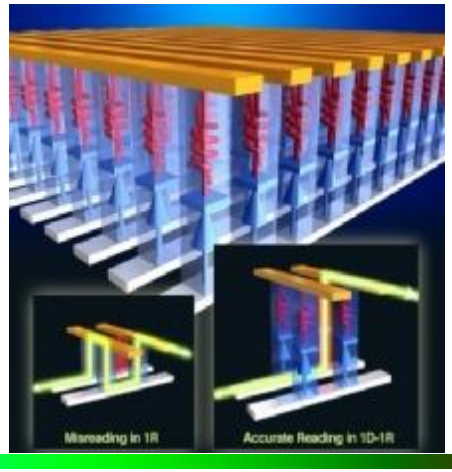
Nanowire Growth in a Local Temperature Gradient
-published in Angew. Chem. Int. Ed.



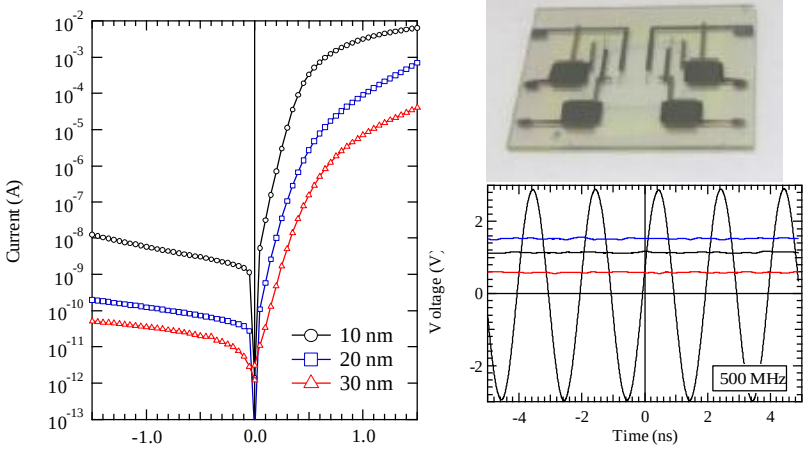
Programmable Direct-Printing Nanowire
-published in Nano Lett.



1D-1R type memory (inside cover)
-published in Adv. Mater.



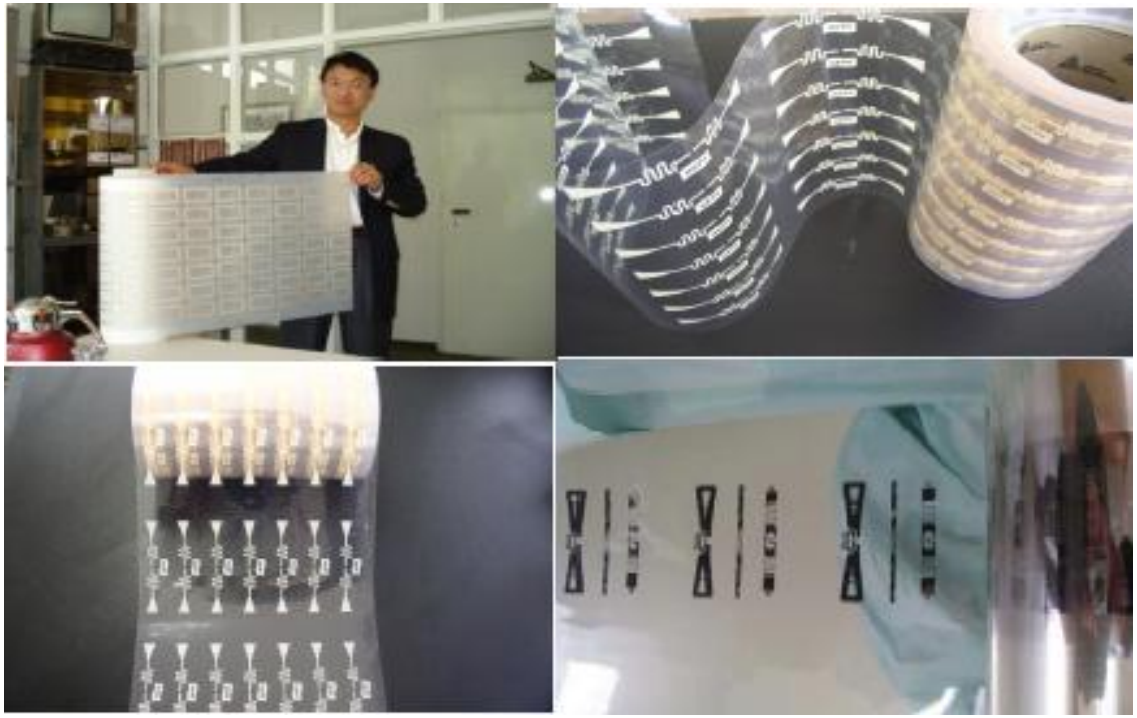
Flexible 500 MHz Rectifier

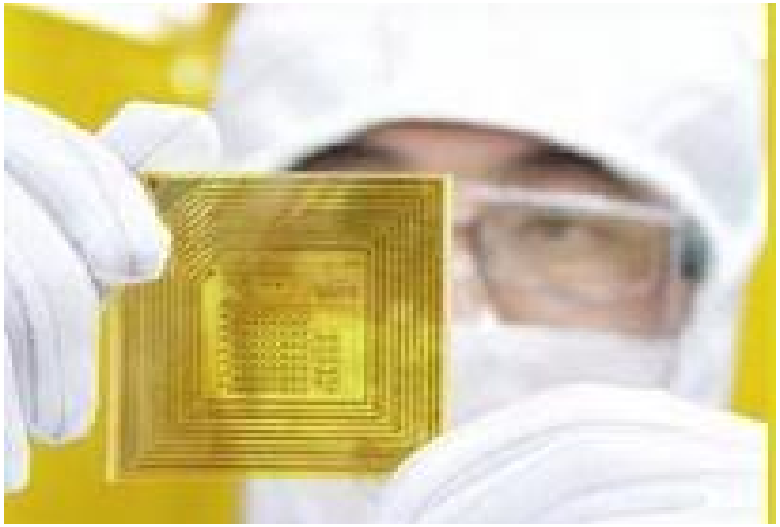


RFID: Sunchon National Univ.

Sunchon Univ.

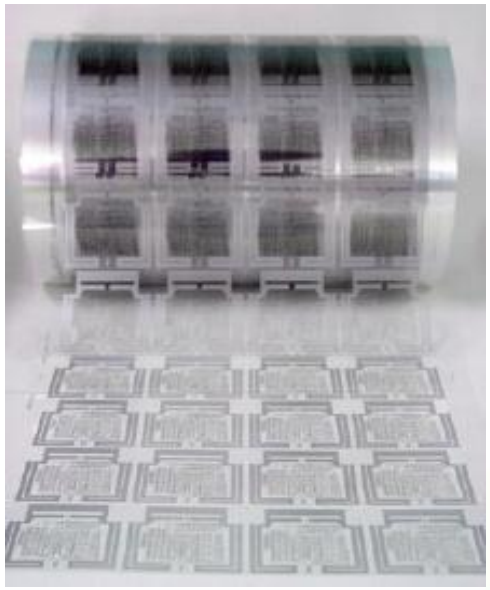
- Regional Innovation Center
- World-Class Univ. Program (MEST) – PE Department
- ~ US$10 millions per year.



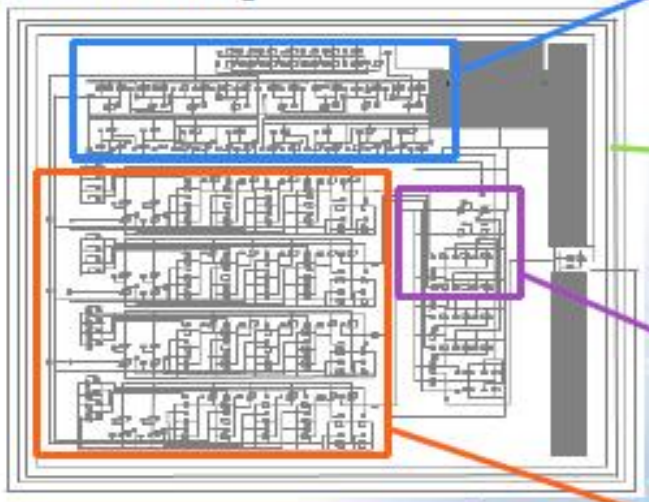


Development of Roll-to-Roll Printed 13.56 MHz RFID Tags

Replacing the current barcode to low-cost RFID Tags



[13.56 MHz]



Digital Processor
(R2R printed TFT with variation 5 % under 10 V and 120 KHz -13.56 MHz)

Antenna
(Surface resistance, Cost)

Rectifier
(Rectfied 10V @ 13.56 MHz)

96 bit
Read and Write Memory
(Stability: 1yr)
10 V and 10 KHz speed

R2R Printing process
100 um resolution
R2R: 7 color units with 20 m/min
Registration Accuracy: 10 um

Summary

Printed Electronics in Korea

• Very active for developing printing technology for displays
  - Large-area, low-cost, eco-displays, flexible displays, …
• Infant stage for other PE technologies

Korea's advantages: Strong manufacturers and good supply chains

• Samsung Electronics & LG Displays, etc.

Korea's weakness: Lack of fundamental research and core IPs, Materials

Strategy of Korean Government

• Support research on core technologies (printing technologies and materials) and strategic application areas (LCDs, OLEDs, e-papers, Touch panels, Flexible PCBs, Organic solar cells, RFIDs)
• Strengthen equipments and materials industries: Next-gen. display test-beds, R&D tax exemption, support small companies, etc.
• Build infrastructure and enhance international collaboration: Support international conferences: IWFPE, IMID, etc.; International R&D programs, etc.
• Education of R&D manpower: Research centers, BK21, WCU programs, etc.

Thank you very much for your attention.

PLEXTRONICS

Light. Power. Circuitry.™

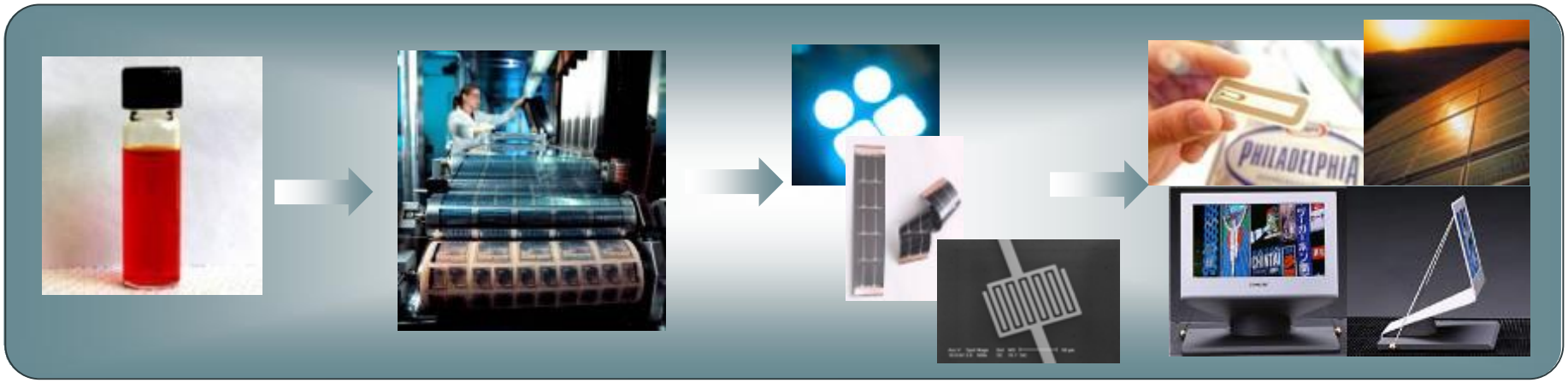
The Global View of Printed Electronics and What it Could Mean to the U.S.

Andrew Hannah, CEO

September 24, 2010

Advantages of Printed/Flexible Electronics

Organic Printed Devices



Polymer Inks → Printing → Thin Films → Devices

< $$ + < $$ + Any Surface = Electronics Anywhere

Printed Electronics Market Applications

Building Blocks

Building Block Products

Integrated Products

Light → **OLED**
- Backlights
- Small-Area FPDs
- White Light Panels

Power → **OPV**
- Energy Harvesting
- Off-Grid Power
- BIPV (Building Integrated PV)

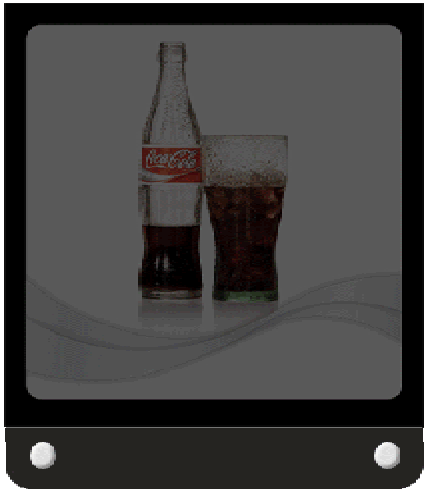
Circuitry → **OFET**
- RFID Tags
- Backplanes
- Sensors

- Smart Shelving
- Item-Level RFID
- E-Paper
- Smart Textiles
- Toys & Entertainment
- Promotional Displays
- Next generation TVs/displays – 3D
- Cell phone displays
- Sensors
- Wearable Electronics
- …….

New Product Opportunities for Emerging Market Needs

OPV powers EPD Displays under indoor lighting

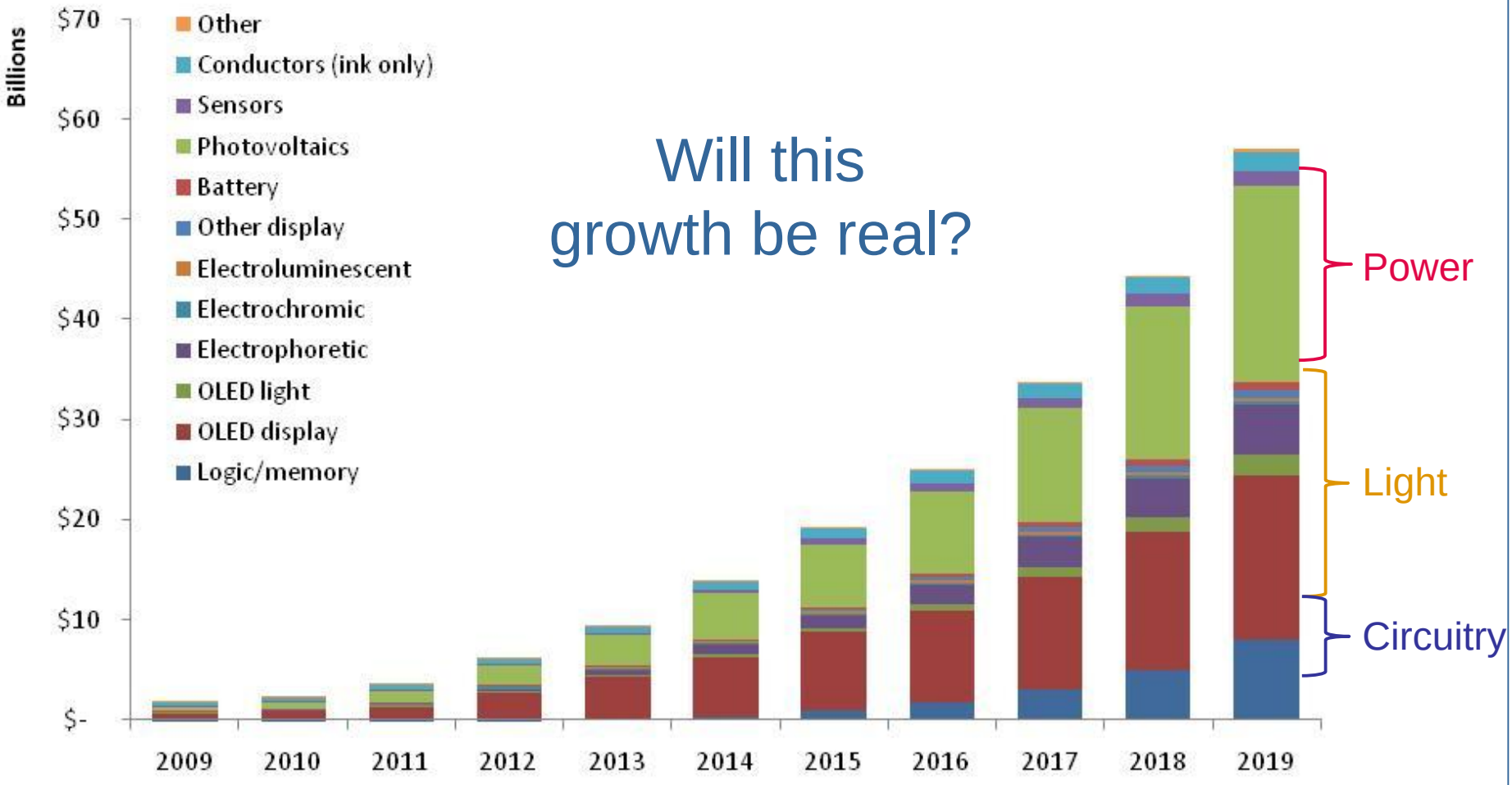
Replace shelf labels for efficient, dynamic pricing



Interactive advertising to drive consumer purchase decisions

Printed Electronics: An Emerging Market

The PE market in 2010 is about $2B, about 20% of that is flexible.
By 2020, that rises to almost $60B, 75% of that is flexible.



Source: IDTechEx 2009-2029 Market Report

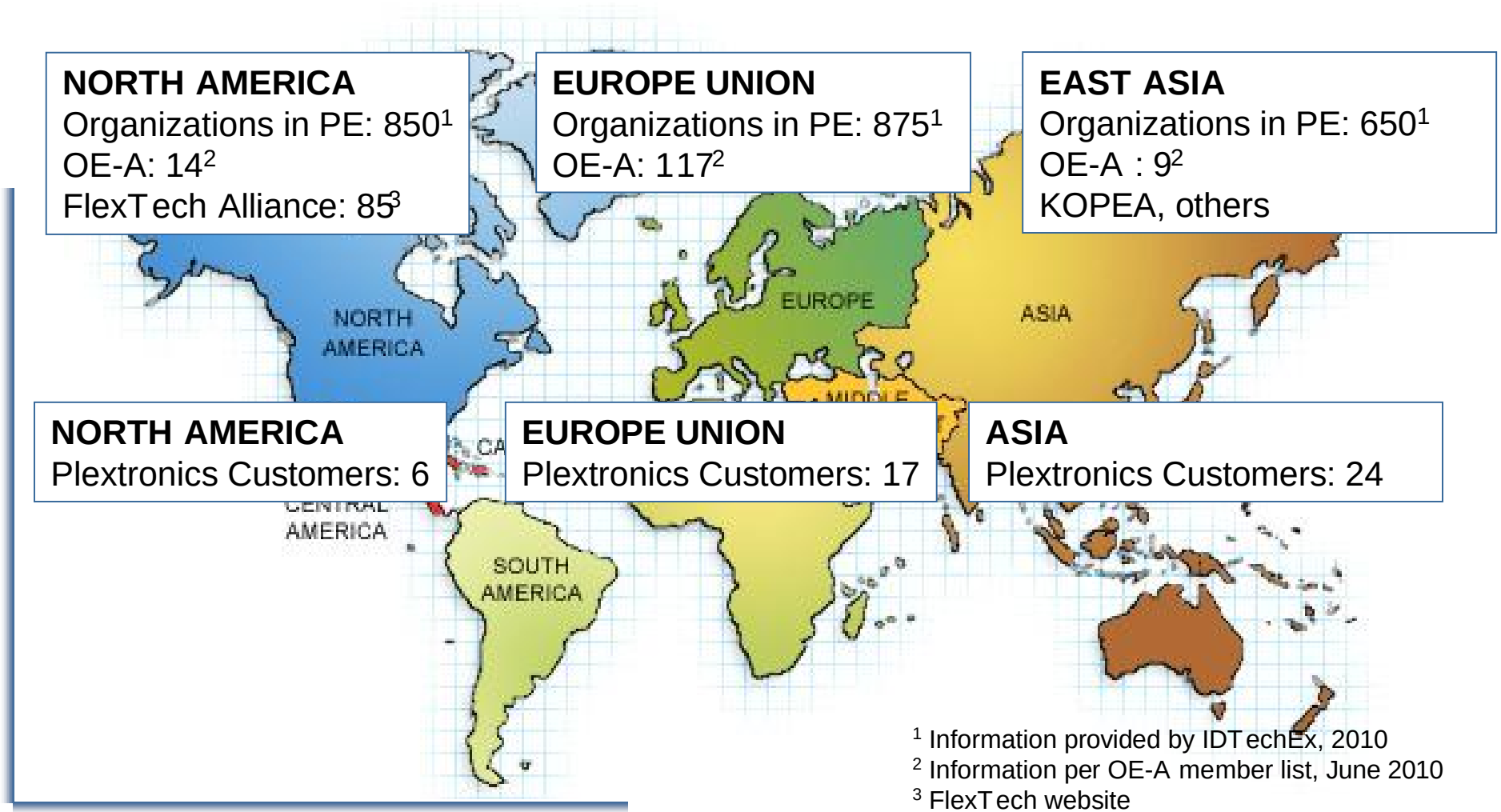
Printed Electronics is Growing Globally…

2500 organizations developing printed electronics globally [1]

NORTH AMERICA
Organizations in PE: 850[1]
OE-A: 14[2]
FlexTech Alliance: 85[3]

EUROPE UNION
Organizations in PE: 875[1]
OE-A: 117[2]

EAST ASIA
Organizations in PE: 650[1]
OE-A : 9[2]
KOPEA, others



NORTH AMERICA
Plextronics Customers: 6

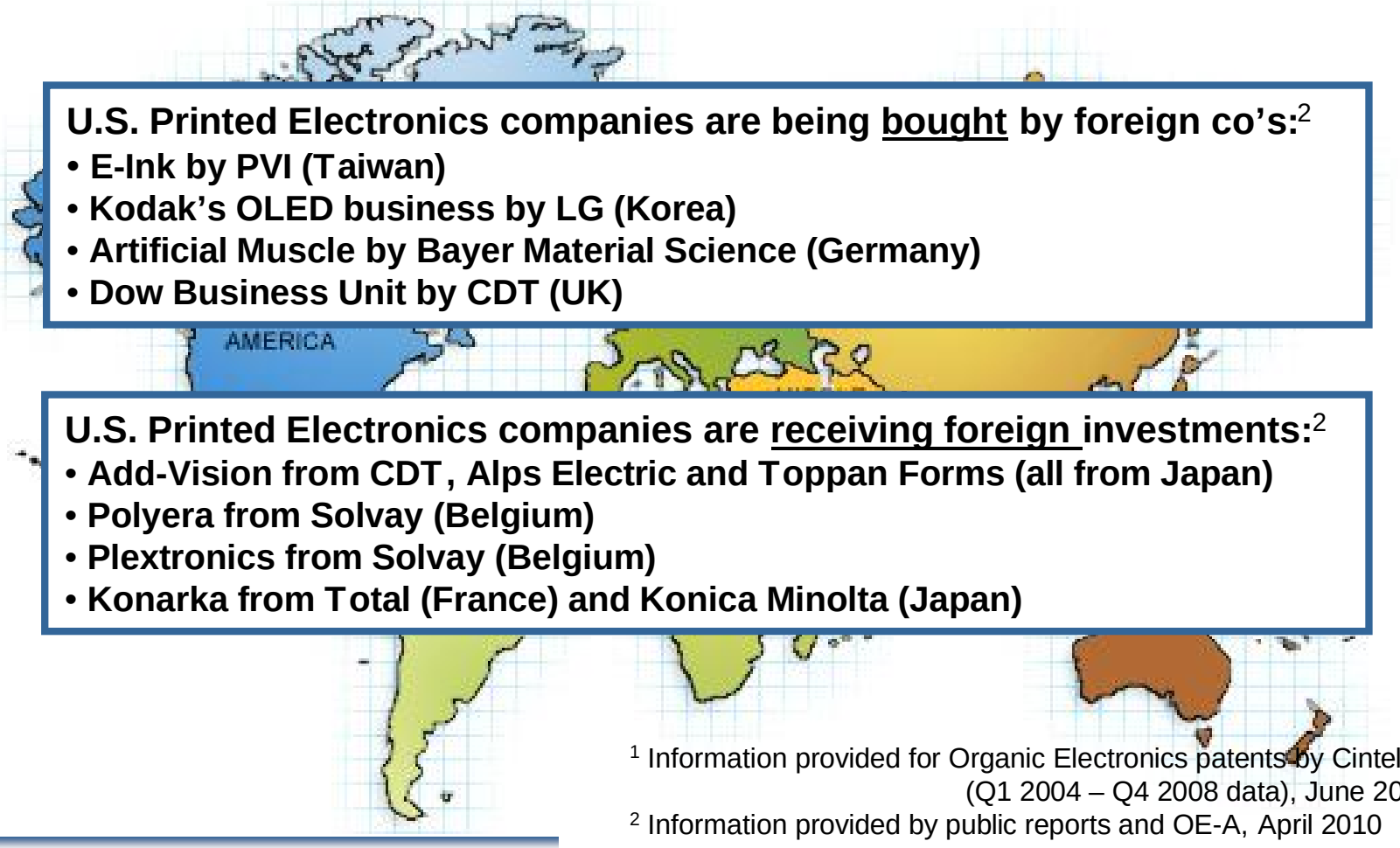
EUROPE UNION
Plextronics Customers: 17

ASIA
Plextronics Customers: 24

[1] Information provided by IDTechEx, 2010
[2] Information per OE-A member list, June 2010
[3] FlexTech website

But US-based PE Companies Are Becoming Scarce

NORTH AMERICA	EUROPE UNION	ASIA
OE Patents Filed: 5,406[1]	OE Patents Filed: 3,737[1]	OE Patents Filed: 25,077[1]



U.S. Printed Electronics companies are being <u>bought</u> by foreign co's:[2]
- **E-Ink by PVI (Taiwan)**
- **Kodak's OLED business by LG (Korea)**
- **Artificial Muscle by Bayer Material Science (Germany)**
- **Dow Business Unit by CDT (UK)**

U.S. Printed Electronics companies are <u>receiving foreign</u> investments:[2]
- **Add-Vision from CDT, Alps Electric and Toppan Forms (all from Japan)**
- **Polyera from Solvay (Belgium)**
- **Plextronics from Solvay (Belgium)**
- **Konarka from Total (France) and Konica Minolta (Japan)**

[1] Information provided for Organic Electronics patents by Cintelliq (Q1 2004 – Q4 2008 data), June 2010

[2] Information provided by public reports and OE-A, April 2010

And the U.S. is being Outspent

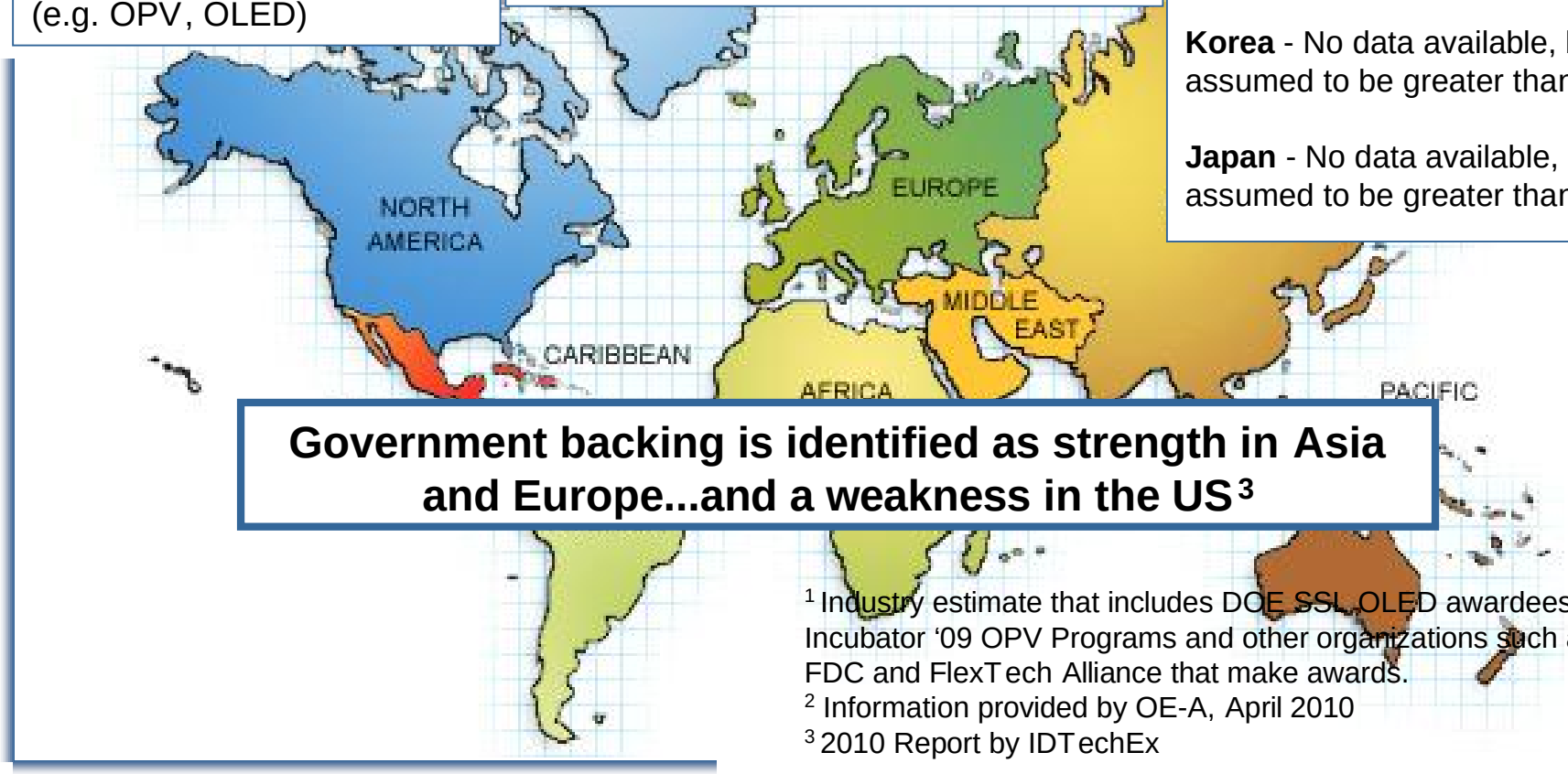
UNITED STATES:
Less than **$50 Million spent in 2009**[1] in government funding specifically for Printed Electronics programs (e.g. OPV, OLED)

EUROPE :
In the last few years, the European government has invested **$500 Million** and has committed another **$500 Million** for Printed Electronics programs.[2]

EAST ASIA:
Taiwan - From 2006-2013, it is projected that Taiwanese government will invest about **$200 Million** in Printed Electronics.[2]

Korea - No data available, but assumed to be greater than Taiwan.

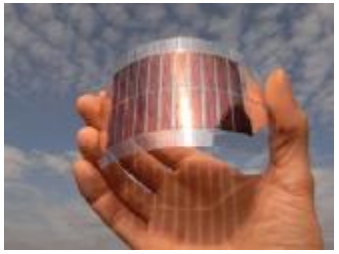
Japan - No data available, but assumed to be greater than Korea.



Government backing is identified as strength in Asia and Europe...and a weakness in the US[3]

[1] Industry estimate that includes DOE SSL, OLED awardees & PV Incubator '09 OPV Programs and other organizations such as FDC and FlexTech Alliance that make awards.
[2] Information provided by OE-A, April 2010
[3] 2010 Report by IDTechEx

OE-A Roadmap, Applications



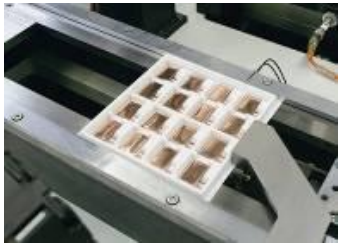
Organic Photovoltaic

Flexible Displays

OLED / EL Lighting

Printed Memory

Organic Sensor



Flexible Batteries

Smart Textiles

Printed RFID

Smart Objects

Source: FhG ISE, Plastic Logic, Novaled AG, PolyIC, Thin Film Electronics, Plastic Electronic, VARTA, Francital

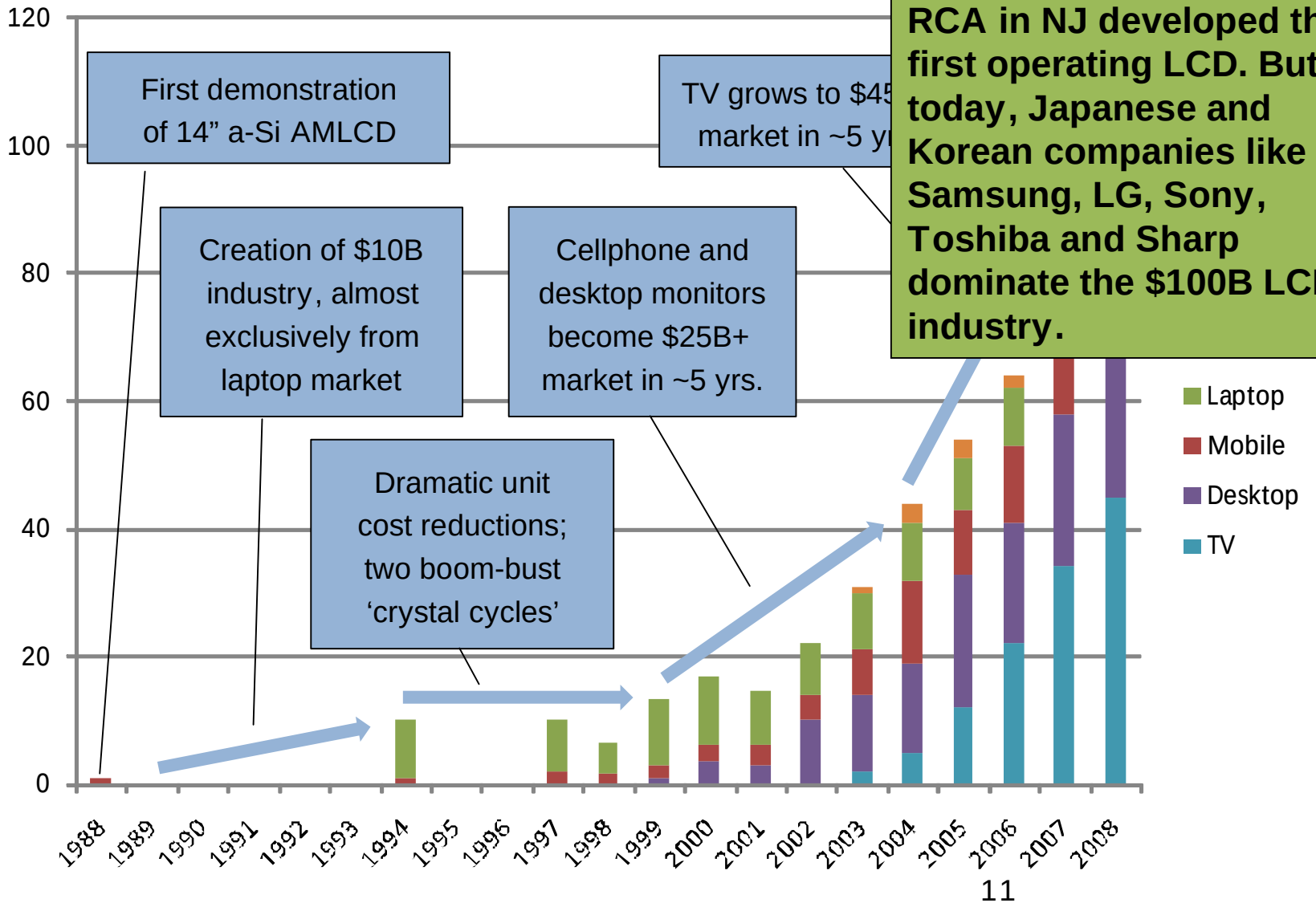
State of Global PE Industry Today

1. Asia leads in Intellectual Property
2. Foreign purchase and/or investment in U.S. businesses is accelerating
3. U.S. is being outspent in Printed Electronics, especially from a government perspective

So....is it too late?

How LCD Became a $100B Industry

In 1968, researchers at RCA in NJ developed the first operating LCD. But today, Japanese and Korean companies like Samsung, LG, Sony, Toshiba and Sharp dominate the $100B LCD industry.



Source: DisplaySearch, iSuppli, Press releases, Plextronics analysis

It's Not Too Late: What the U.S. Should be Doing

Create Centers of Excellence for advanced manufacturing and application development.

- Case in Point: Taiwan Science Parks and growth of OLED industry
- Case in Point: Holst Centre, The Netherlands, and open innovation model
- Case in Point: PETEC, UK, a design, development and prototyping facility

Presentation by Jwo-Huei Jou, National Tsing Hua University, at ISFOE10 in Greece, July 2010

petec ...the future inspired

It's Not Too Late: What the U.S. Should be Doing

• Government support is critical. Fundamental technology and science is good enough, what's missing is support for application development.

• Need programs that focus on:

Technology Integration – testing, validating and improving technology through prototypes and demonstrators to help overcome technological hurdles and begin to anticipate manufacturing challenges.

Manufacturing – shared infrastructure, especially for prototyping and pilot-scale manufacturing, where companies can experiment with printing electronic devices such that they can establish state-of-the-art manufacturing facilities in the U.S.

Innovation – working with researchers and universities to constantly improve technology and discover ground-breaking technology.

• Incentivize companies to use U.S. raw materials, products and manufacturing

• Take a patient view of your investment

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Thank You

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If you would like a white paper to learn more about a Printed Electronics initiative in the U.S., please contact me at ahannah@plextronics.com.

PLEXTRONICS
Light. Power. Circuitry.™

National Science Foundation (NSF)

Flexible/Hybrid Electronics Research Opportunities

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National Academies Meeting
Friday, September 24, 2010

Global Perspectives Session

- Andrew Hanna, Plextronics
- Christian May, Fraunhofer, Dresden
- John Chen, ITRI, Taiwan
- Changhee Lee, Seoul National University S. Korea

NSF: Flexible/electronics Research support and Opportunities

- Current NSF Supported Research Areas for Flex/Printed Electronics
- WTEC Study
  - Purpose, Findings, Future Directions
- How NSF may be of help to you and the flex electronics community?

Applications of Flexible Hybrid Electronics

- **Energy**
  - Organic Photovoltaics (OPV)
  - Solid-State Lighting based on OLEDs
  - Batteries
- Electronics
  - Displays
  - E-Paper
  - Sensors and Actuators
- Biomedical and Healthcare
  - Sensors, system on a foil
- Communications
  - RFID
- Defense
  - Various Applications e.g. flexible displays

NSF Supported Flexible Hybrid Electronics Research

- **Organic and Polymer Electronics and Optoelectronics**
  - OLEDs
  - OFETs
  - Solar Cells-organic, inorganic
  - Sensors and Actuators

- **Inorganic thin-film devices**
  - Transistors and circuits
  - Light emission
  - Photovoltaic
  - Displays
  - Batteries
- **Hybrid devices**
  - Utilizing inorganic and organic materials
- **Hybrid circuits and systems**
  - Hybrid organic/inorganic CMOS etc.
- **Fabrication and Manufacturing Issues**
  - Low-cost, High throughput
  - Print-Compatibility generally desired

NSF: Flexible/electronics Research support and Opportunities

- Flex/printed – an area of emphasis for ECCS
- Current NSF Wide Support for Flex/Printed electronics-
  - ü about 195 projects
  - ü Each project ~ 300 K/3 years
  - ü Includes ERC's (e.g. RPI), MRI etc.
  - ü Supported across many programs in NSF
    - Ø Engineering (ECCS, CBET , CMMI, IIP , EEC)
    - Ø MPS (Physics, Chemistry , DMR etc.)
    - Ø Many projects are in collaboration with industry (e.g. CMU-Plextronics, Michigan, UT-Austin, Northwestern, also SBIR)

EPMD Topics of Interest

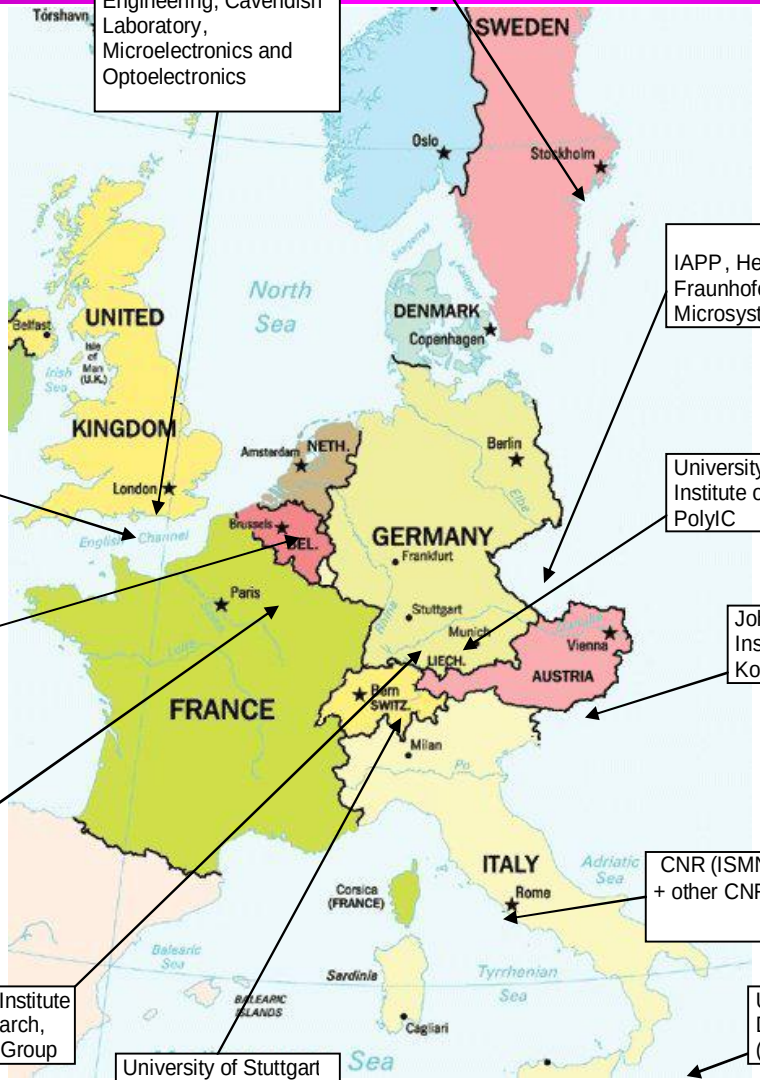
- **Micro/Nanoelectronics**
- **Sensors and Actuators**
- **Carbon-based electronics**
  - **Graphene, Carbon nanotubes etc.**
- **Flexible/printed electronics**
- **Solar Cells/photovoltaics**
  - **Inorganic and Organic**
- **Beyond Moore's Law (BML)**
- **Wide band gap semiconductors (GaN, SiC etc.)**
- **Multiferroic Devices**

Flex Electronics Study-May 2009

- Prepare a summary presentation on US position in the area
- Visit leading laboratories (Industrial, University, Innovation Centers) in Europe
- Learn what are the successful strategies that are being pursued there in the field
- Prepare a report on the visit
- Create recommendations that will help enhance US competitiveness

University of Linköping,
Biomolecular and Organic Electronics,
Centre for Organic Informatics

CDT, Plastic Logic,
University of Cambridge:
CAPE, Department of
Engineering, Cavendish
Laboratory,
Microelectronics and
Optoelectronics



IAPP, Heliatek, Novaled,
Fraunhofer Institute for Photonic
Microsystems (IPMS)

Imperial College London:
Blackett Laboratory,
Department of Chemistry,
Department of Materials,
Centre for Nanotechnology

University of Erlangen-Nürnberg,
Institute of Polymer Materials,
PolyIC

Holst Centre,
Philipps Research,
Polymer Vision

Johannes Kepler University (Linz
Institute for Organic Solar Cells),
Konarka, Plastic Electronic

IMEC

CNR (ISMN)
+ other CNR guest hosts

BASF, Max Planck Institute
for Solid State Research,
Organic Electronics Group

University of Stuttgart

University of Bari,
Department of Chemistry
(virtual visit)

Principal Strengths of Europe

- EU-level priority area for about a decade
- Long term view of the field
- Strong research groups which have existed for many years
- Close Industry-University-Innovation center co-operation in pre-competitive research
- Access to specialized fabrication/prototyping facilities
- Multi-organization centers

USA Strengths as Perceived by European Scientists

- Strong research universities with well-regarded PhD programs
- A well-developed venture capital infrastructure that is more advanced than what exists in most other countries
- Practical knowledge in creating start-up companies
- Ability to attract talent from everywhere
- Strong support from organizations such as NSF, DoD (e.g. ARL-Flex Display Center at ASU), DOE, etc.

Panel Suggestions

- Establish NSF-NNIN like facilities dedicated to flexible hybrid electronics
- Allow universities access to fabrication equipment and expertise
- Incubate small companies
- Implement successful NSF models for microelectronics/nanotechnology

Summary of Panel Suggestions

- Establish a SEMATECH-like organization for hybrid flexible electronics for pre-competitive research involving multiple companies and universities
- Nurture technologies till they are ripe for commercialization
- Create models for support involving government agencies and industry

Panel Suggestions

- Establish new funding streams that include researchers from multiple organizations
- Create focused centers that span the range from fundamental to applied research
- Enhance funding mechanisms for groups of companies to develop high-risk technologies

- Report is available at: http://www.wtec.org/flex/HybridFlexibleElectronics-final-July2010.pdf

What may be helpful for advancing flex/printed electronics?

- Breakthrough concepts - something like an iphone would be great!
- Most apps currently are evolutionary. Need a compelling app.
- Need pilot scale research facilities for prototype manufacturing.
- Need collaborations between agencies to leverage resources to support research in this highly interdisciplinary to create technology.

Thanks !

do jeh ! xie xie ! grazie ! merci !
arigato ! obrigado ! gracias !
takk ! tack ! arigato ! Dhanyawad!
spasibo ! toda ! asante ! danke !

Global Perspectives Session

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