MEMS on Alternate Substrates: A Case Study with Biometric Sensors

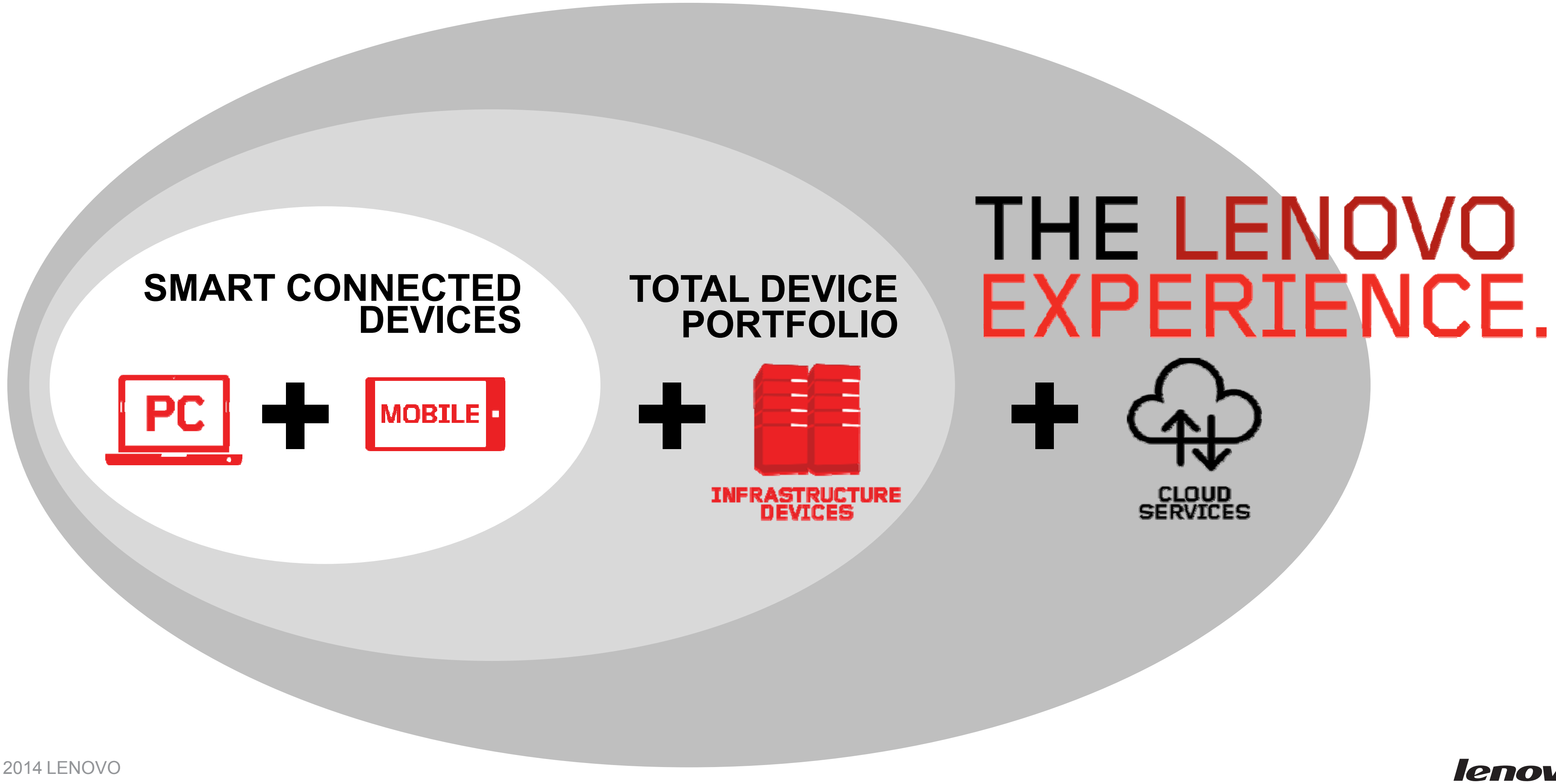
S. K. ("KG") Ganapathi – June 25, 2014

- » About Lenovo MEMS
- » Why Alternate Substrates?
- » Polymer Properties and Processes
- » Fingerprint sensors on alternate substrates

LENOVO IS...

A global technology leader approaching $39B in sales with 54,000 people and customers in 160+ countries.

Triple PLUS Strategic Roadmap



SMART CONNECTED DEVICES

PC + MOBILE

TOTAL DEVICE PORTFOLIO

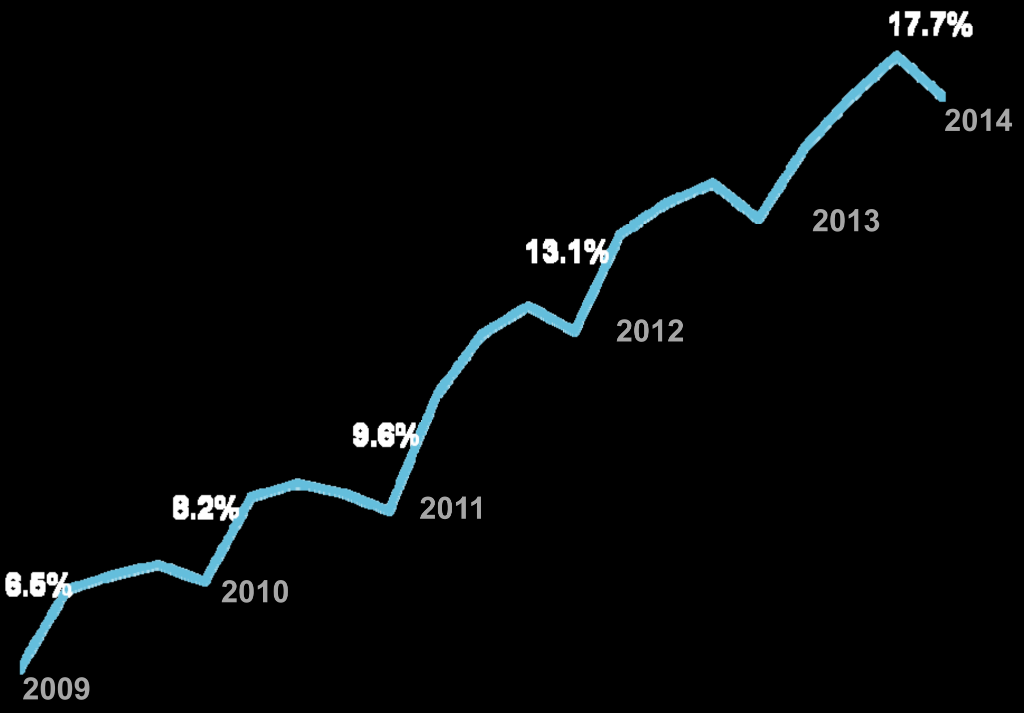
+ INFRASTRUCTURE DEVICES

THE LENOVO EXPERIENCE.

+ CLOUD SERVICES

Lenovo's Performance

Lenovo WW PC Market Share



Record Performance

#3 in PC + Smartphone + Tablet

115 Million WW

#2 in PC + Tablet

Near 65 Million WW

#1 in PC

Record 55 M sold WW, #1 in Consumer for first time

Lenovo MEMS Business Unit

What it is

Vertical integration into component / sub-system differentiated opportunities

- Based on acquisition of Fidelica Microsystems fingerprint technology
- Intended to build innovation and differentiation for Lenovo products
- Leverage Silicon Valley ecosystem and talent pool
- Gateway to technology access, investment and partnering

About Us

1. Based in San Jose, CA
2. Core competence in components, sub-systems and software based innovation
3. Teams in San Jose, China, Japan and North Carolina

YES, WE'RE HIRING!

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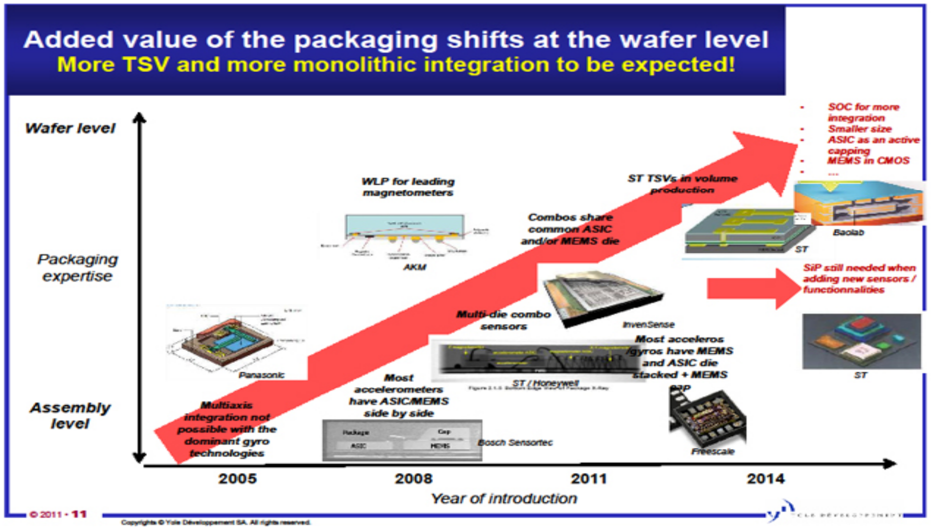
Some background for this topic

- Magnetic recording industry rich in technology of thin film based micro-devices
- Many similarities to today's MEMS sensor industry
  - Device complexity, rapid scale-up requirements
  - Process intensive; no "standard process modules"
  - Short life cycles, miniaturization, commoditization
- But…almost totally non-silicon based; little in common with CMOS infrastructure
  - Ceramic substrates - Metals / alloys / organic insulators

Ripe opportunity to leverage technologies into other device designs

In some instances, silicon IS irreplaceable…

- Widely available fabs
- Mechanical stability
  - Creep & fatigue response of SC silicon
- Well defined processability
- Monolithic MEMS/CMOS integration
- Fine geometry

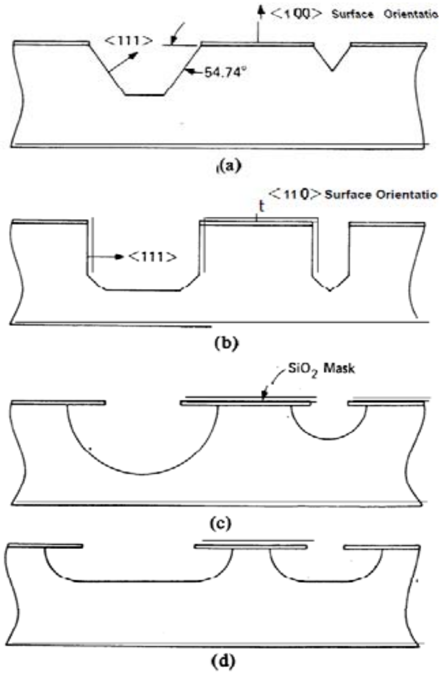


Added value of the packaging shifts at the wafer level

More TSV and more monolithic integration to be expected!

Copyrights © Yole Développement SA. All rights reserved.

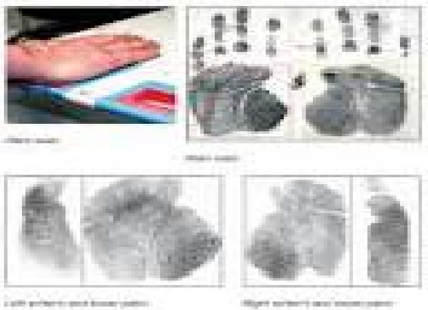
Source: Yole Developpement



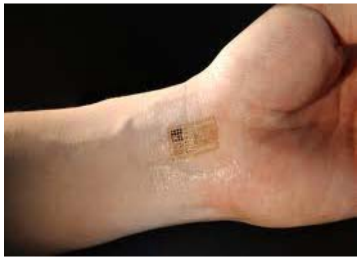
A summary of wet chemically etched hole geometries in MEMS
From Petersen, 1982

Why alternate substrate platforms?

- Device is inherently large
    - Device may not even fit on traditional silicon wafers; cost too high
    - UI devices: Touch sensors, handwriting input, fingerprint sensors
    - Energy harvesting devices: Area or mass dependent
- Transparency
    - Medical sensors; user interface sensors
- Flexibility: need to fit a “contour”
    - Health sensors; artificial “skin” / robotics
    - Contoured surfaces of consumer devices / automobiles
- Incompatibility with traditional silicon processing
    - Some metals unacceptable in CMOS fabs
    - Process may require materials such as cured polymers



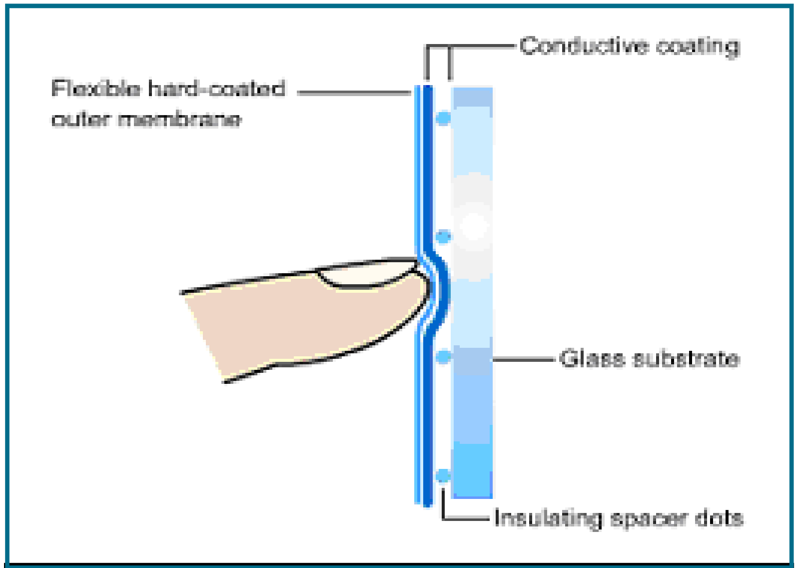
Credit: Mashable



Proofs of principle with alternate substrates

QMT IMOD Display

Fidelica Fingerprint Sensor

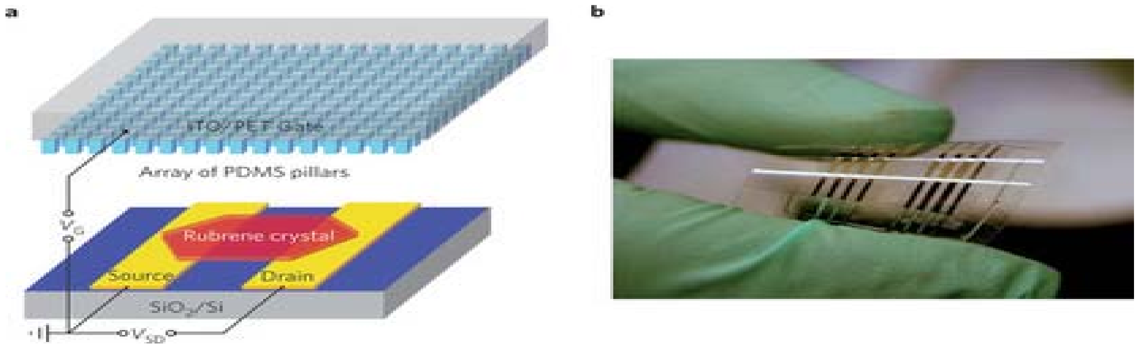


Resistive Touch Panel

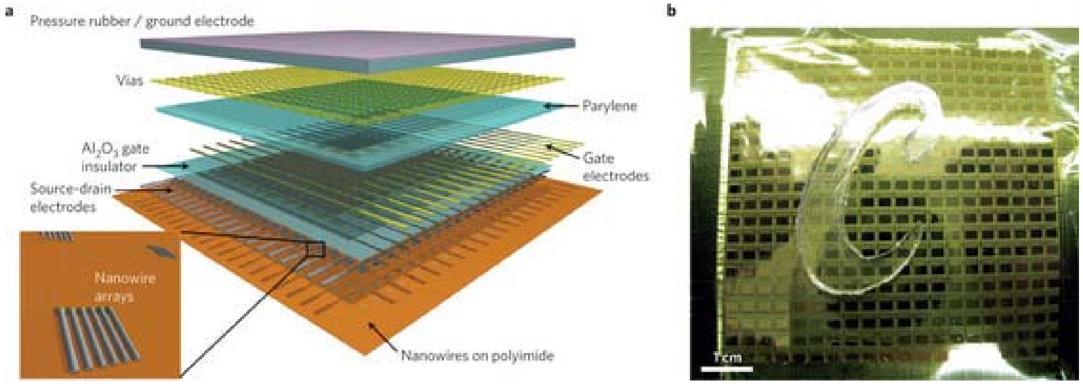
Source: www.elotouch.com

Artificial skin: another frontier

- Robotics
- Health care
- Other Applications



Flexible array of transducers on microstructured PDMS films

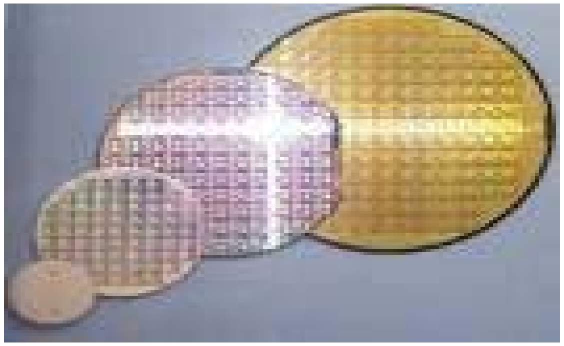


Artificial skin based on arrays of Ge/Si nanowires

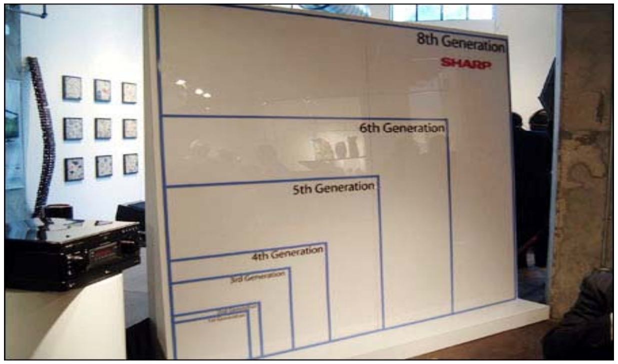
Flexible electronics: Within touch of artificial skin; John J. Boland
Nature Materials 9, 790–792 (2010) doi:10.1038/nmat2861 Published online 12 September 2010

Economies of scale vs. cost

Cannot underestimate the impact of scale!



Silicon



Glass

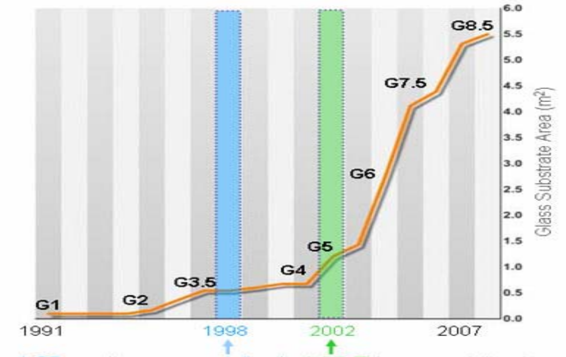
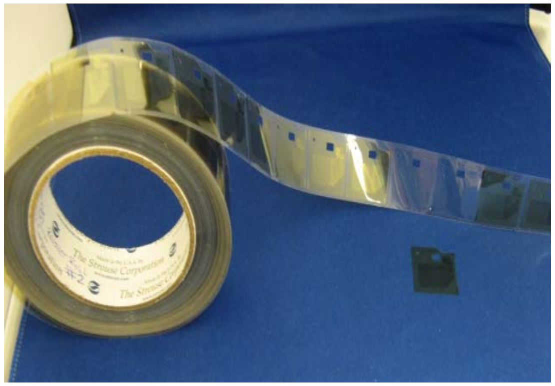


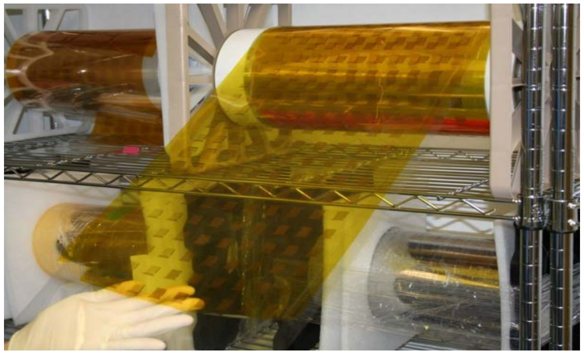
Figure 1. TFT-LCD glass substrate size and generation of display panel manufacturing fab in chronological order. (G1 stands for Generation 1 Fab.)

LCDs: Challenges and Opportunities for Lithography; http://spie.org/x27569.xml

Panel Flex



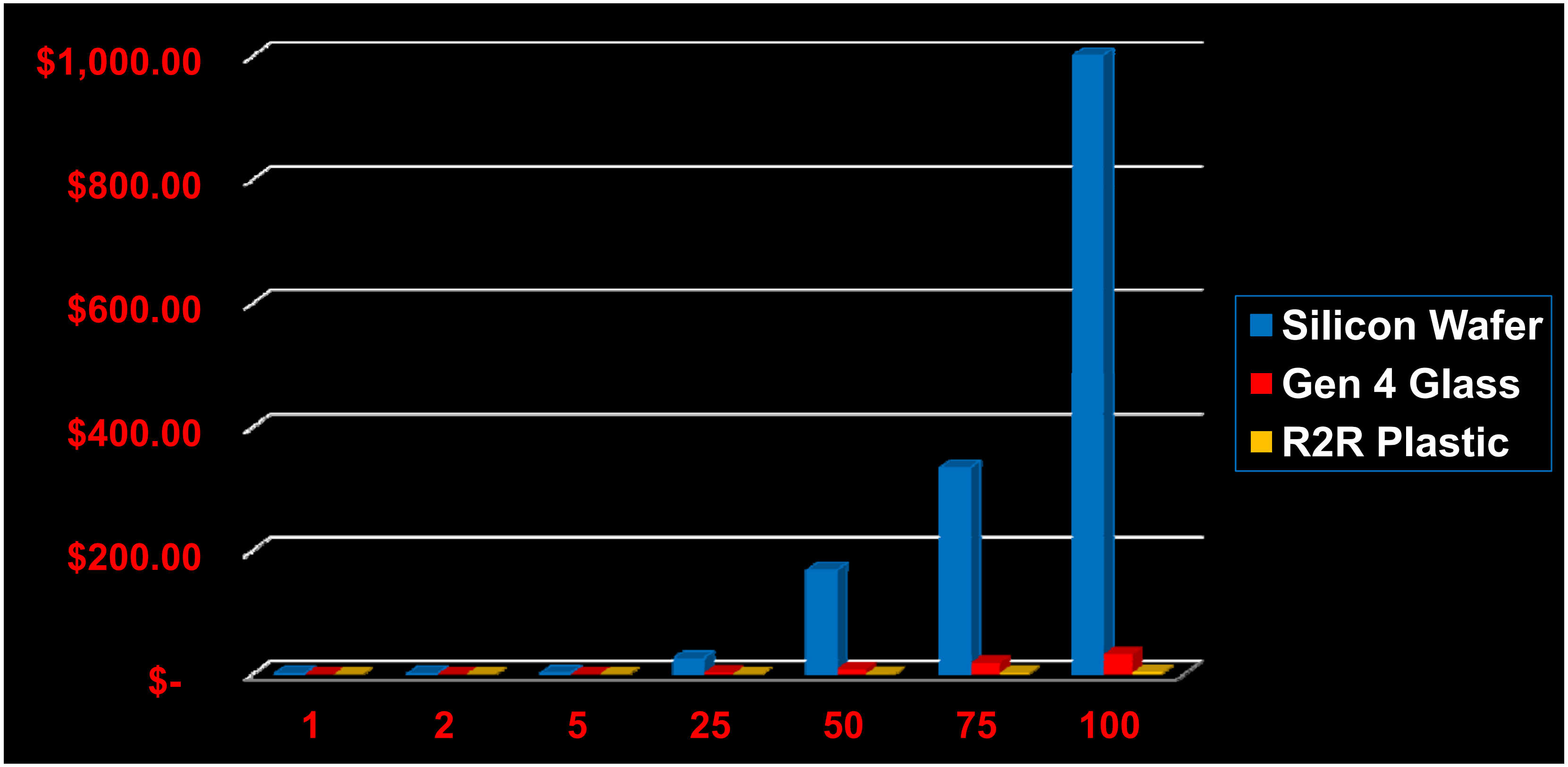
Reel-Reel Flex



Roll-Roll Flex

Cost advantage scales with device size

Cost per die



Die size – mm (square die)

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Polymer Properties

Advantages

- Light weight
- Low cost raw material
- Excellent corrosion resistance
- Flexibility

Downsides

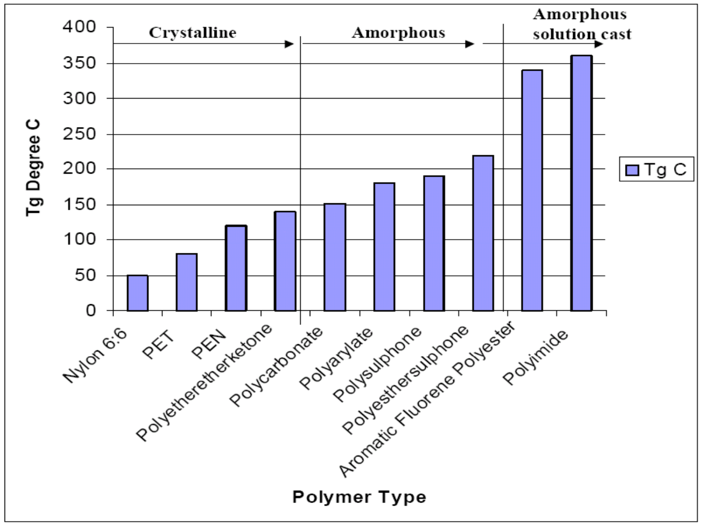
- Low processing temperature; low dimensional stability
- Not suitable for stable / reliable mechanics

Polymer Choices

- Multiple factors to consider
  - – Thermal stability and distortion: Tg vs. processing temperature required
  - – Surface roughness / inherent defect density / scratches / fill particles
  - – Moisture absorption
  - – Optical properties – Transparency, UV stability

Properties	**Unit**	**Appear™**	**AryLite™**	**Sumilite®**	**PureAce**	**Teonex**	**Melinex**
		3000	**A 100HC**	**FST-X014**		**Q65**	**ST504**
Thickness	µm	100	100	200	50-160	100-200	
Base Polymer		Cyclic olefin copolymer	Polyarylate	Polyethersulfone	Polycarbonate	PEN	PET
Thermal							
Tg	°C	330	325	223	150	121	78
Decomposition temperature (at 5 wt% loss)	°C	360	480	485			
CTE (-55 to 85 °C)	ppm/°C	74	53	54	60-70	13	15
Optical							
%Transmission (400-700 nm)	-	91.60%	90.40%	90.10%	>90%	85%	>85%
Refractive index (633 nm)	-	1.52 (base film)	1.64 (base film)	1.65 (base film)	1.58	1.75	1.66
Physical							
Young's modulus	GPa	1.9	2.9	2.2	1.7	6.1	5.3
Tensile strength	MPa	50	100	83		275	225
Elongation to break	-	10%	17%	7%	170%	90%	120%
Specific gravity	-	1.16	1.22	1.37	1.2	1.36	1.4
Water absorption	-	0.03%	0.40%	1.40%	0.40%	0.14	0.14

Bill MacDonald , Plastic Films and R2R Processing, DuPont Teijin Films



Tg for commercial films

Bill A MacDonald , K. Rollins, R. Eveson, K. Rakos, B. A. Rustin, M. Handa, **Mat. Res. Soc. Symp. Proc. Vol. 769 2003,** and DuPont Teijin Films

Conductors on Plastic Substrates

- Thin films
  - Low resistance: Metals and Alloys
  - High Resistance
    - CERMET (e.g., co-sputtered SiO and Cr)
    - Tantalum oxide
- Conducting polymer composites
  - Polymer thick film (PTF) resistors
  - Composite plastics (polycarbonate) or elastomers (silicones)
  - Carbon nanotube composites
- Intrinsically conducting polymer (ICP) resistors

Range of process options

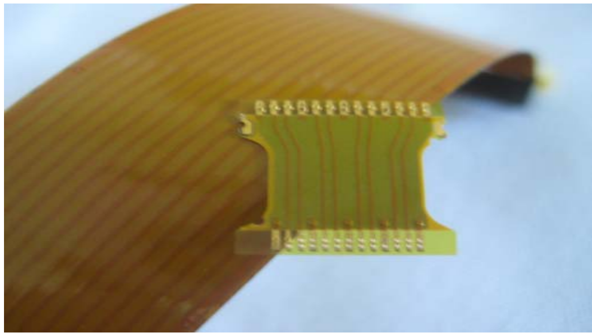
- Impressive high volume capabilities in large area glass and plastic fabs
  - <5 micron geometries on large form factor; even smaller for glass
  - Thin film metallurgies (gold, chromium, TiW, Al, Mo, Cu…)
  - Conducting metal oxides (ITO, rare earth transition metals)
  - Insulators (Alumina, Silicon Oxides…)
  - Thin Film Resistors (Controlled metal oxides)
  - Patterned Polyimides (insulators, release layers, planarizers, gap fillers…)
  - Sacrificial etch technologies (metal release, photoresist sacrificial layers…)
  - Multi-layer overlays

Leveraging alternate substrates…

- What does it take to make it work??
  - Design Challenges
  - Process Integration and Development Challenges
  - Foundry and Business Model Challenges
  - The foundry’s “What’s in it for me?” Questions
  - Manufacturing / Inventory / Yield Challenges

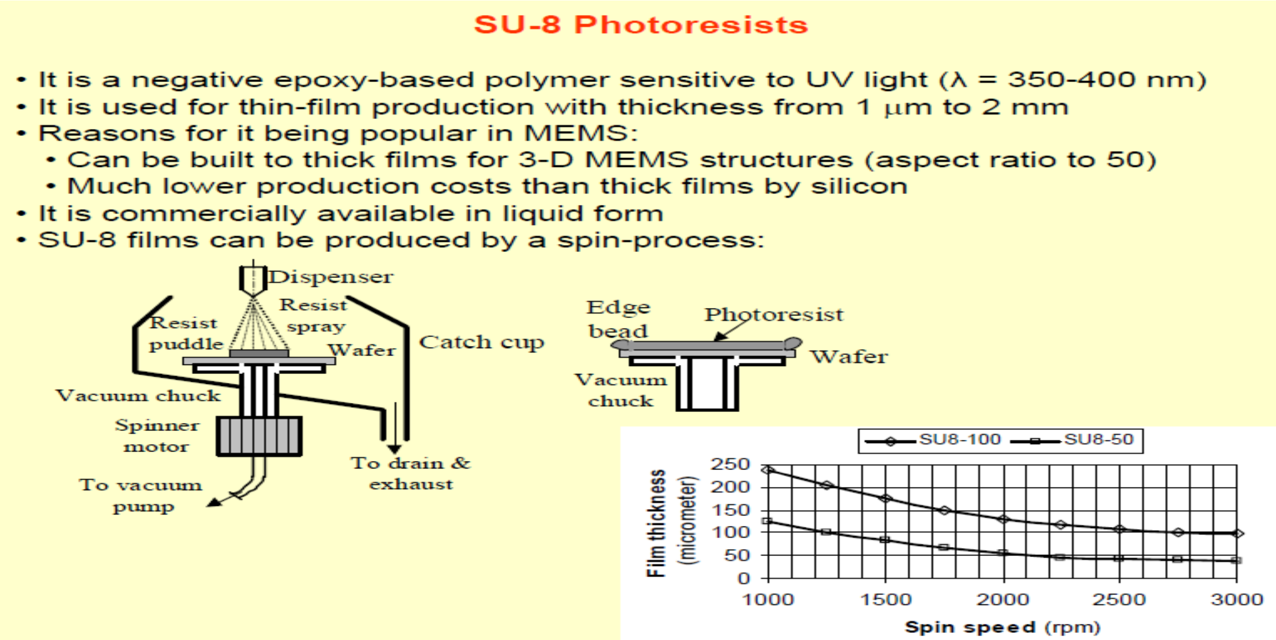
Process will be different…

- Multi-layer vias / interconnects with flex-flex interconnect…
  - <10µm layer-layer alignment and interconnect



Source: www.dupont.com

- High Aspect Ratio Structures: Accomplished in a variety of ways



SU-8 Photoresists

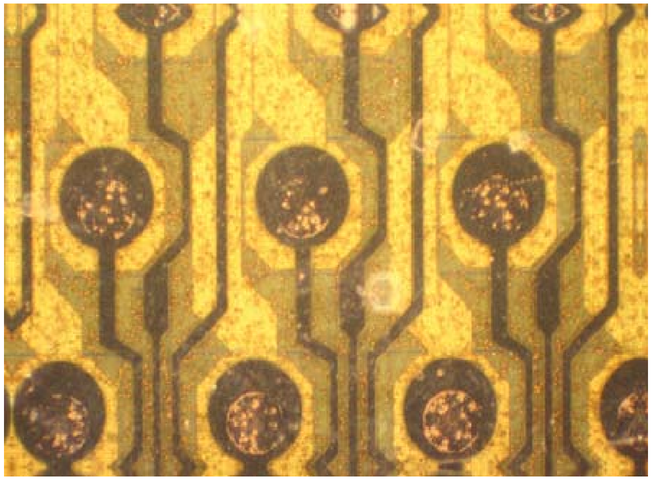
- It is a negative epoxy-based polymer sensitive to UV light (λ = 350-400 nm)
- It is used for thin-film production with thickness from 1 µm to 2 mm
- Reasons for it being popular in MEMS:
  - Can be built to thick films for 3-D MEMS structures (aspect ratio to 50)
  - Much lower production costs than thick films by silicon
- It is commercially available in liquid form
- SU-8 films can be produced by a spin-process:

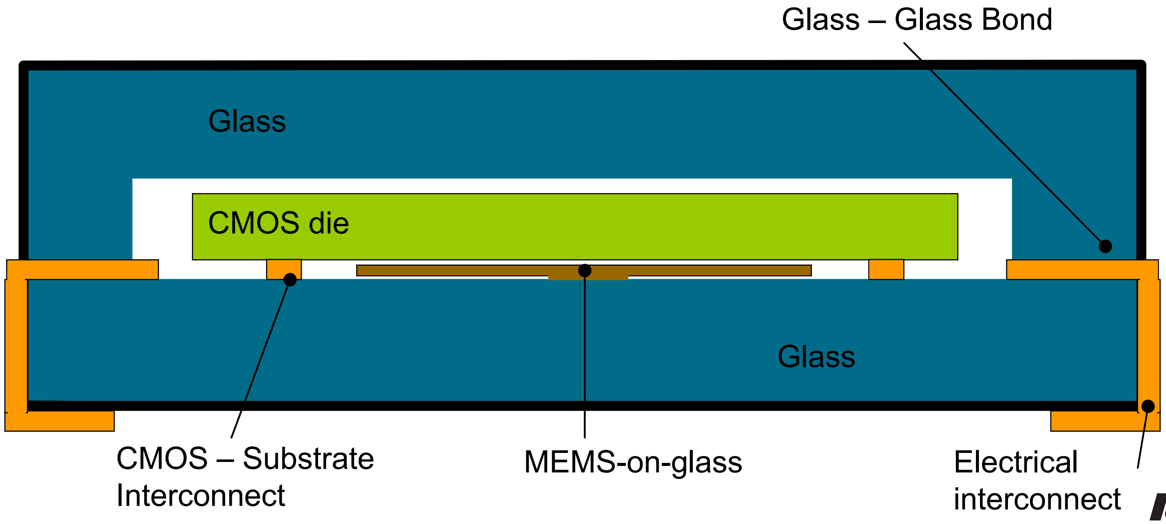
From Lectures on MEMS and Microsystems Design and Manufacture
http://www.engr.sjsu.edu/trhsu/ME189_Chapter%207.pdf

Package will be different…

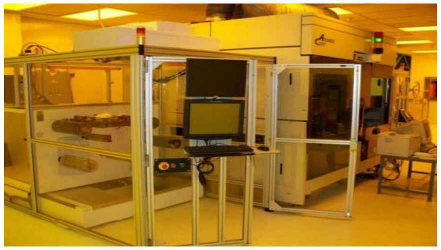
Packaging / MEMS Integration

- Chip-on-flex & chip-on-glass are now standard…
  - <30μm pitch; flip chip; ultra-low profile; high pin count
- Re-engineer substrate for package…
  - <10μm layer-layer alignment and interconnect





Processes and Providers

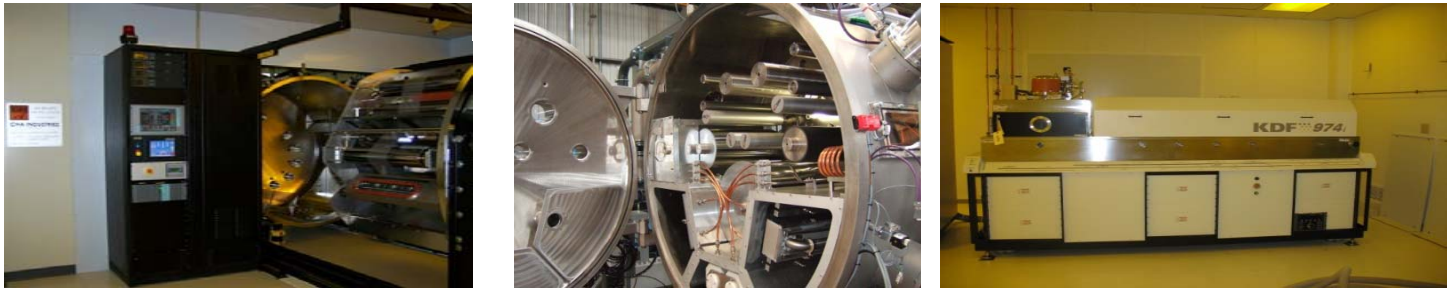


Exposure (resolution: L/S = 4/4 μm) (Azores)

Coating and Exposure (resolution: L/S = 10/10 μm) (Toray)

Photolithography

- Toray, Azores
- <4μm line width
- <1μm overlay
- 24” wide webs



Vacuum Deposition

- CHA; KDF; General Vacuum
- Multiple sources and sputter guns
- Metal, Si, ITO deposition
- 20+” wide webs

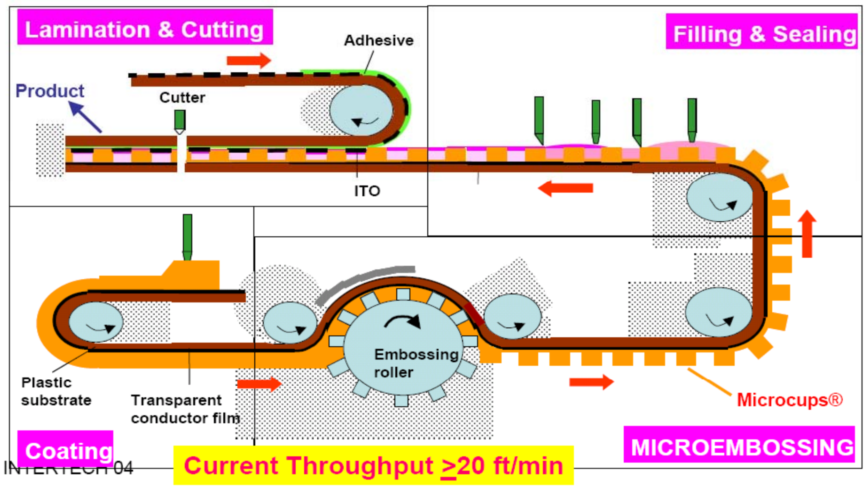
In-Line Defect Inspection

- ECD Corp.
- Defects < 1μm
- Scratches <1 x 10μm
- 24” wide webs

The Center for Advanced Microelectronics Manufacturing; Binghamton University; State Univ. of New York; http://www2.binghamton.edu/camm/facilities/index.html

Micromolding as a Process Tool

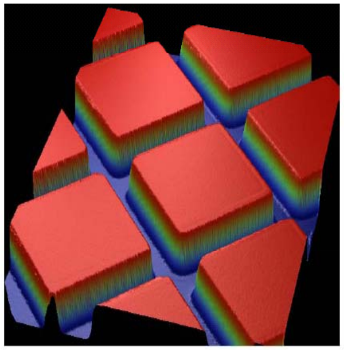
Roll-to-Roll Process



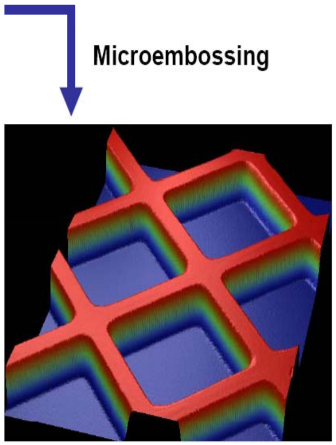
Current Throughput ≥20 ft/min

R. C. Liang et al., (SiPix), Intertech Flexible Display Conference, 2004

Microcups®



Profilometer picture of Mold from Microembossing roller



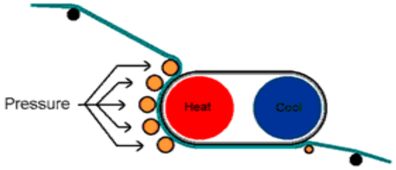
Embossed microcups

Microcup size: 40-200um
Street width: 5-25um
Depth: 12-40um
Microcup shape: rectangular, square, hexagonal

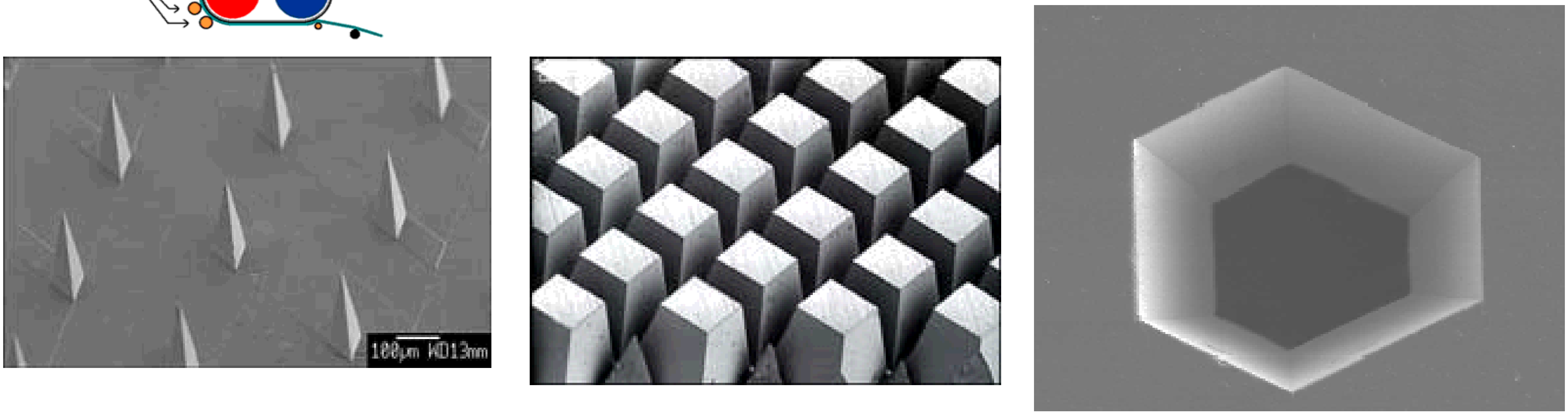
Microreplication / Embossing

AVERY DENNISON

Microreplication



- Roll-to-roll processing compatible
- Resolution of better than 1mm
- \$30 to \$210 m^{-2}



Avery Dennison Microreplication (http://www.microreplication.averydennison.com/)

Micro-Imprinting Process

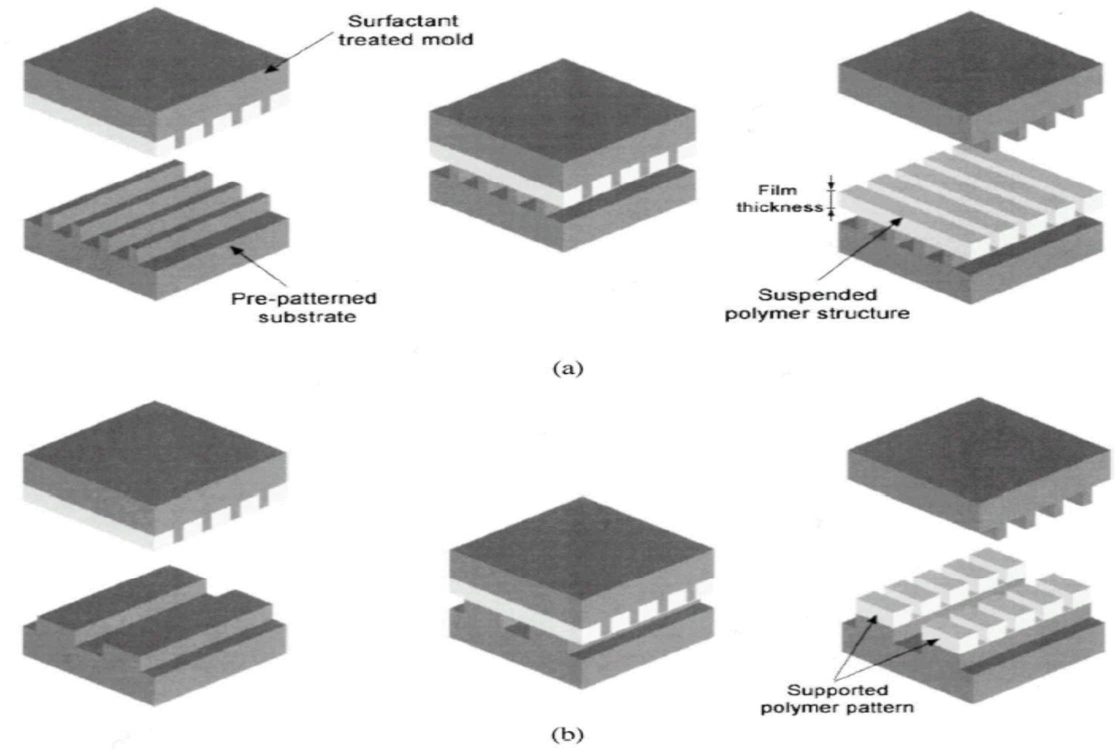


FIG. 1. Schematics of imprinting over topography. Two situations can occur depending on the pattern spacing on the substrate: (a) polymer pattern is imprinted across the raised features on the substrate; (b) polymer pattern is only transferred over the protruded surfaces.

Bao, L.-R., X. Cheng, X.D. Huang, L.M. Guo and S.W. Pang., J. Vac. Sci. Technol. B 20N60, Nov/Dec 2012, p2881

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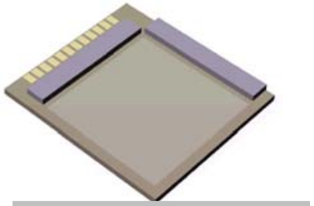
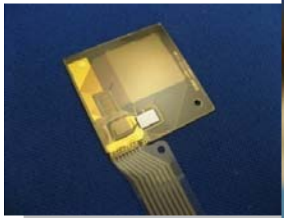
Fidelica Microsystems background

- **Founded in 2000 to pursue unique fingerprint sensor technology**
  - Developed and shipped on glass and flexible substrates
  - Transferred to manufacturing partners
  - Full solution with algorithms/applications
- **Now part of Lenovo**

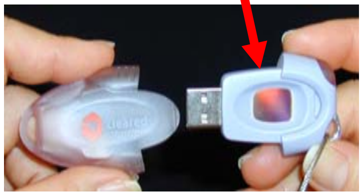
- **Just like a postage stamp…**
  - As large…
  - As thin…
  - As flexible…
  - As (in)expensive…?



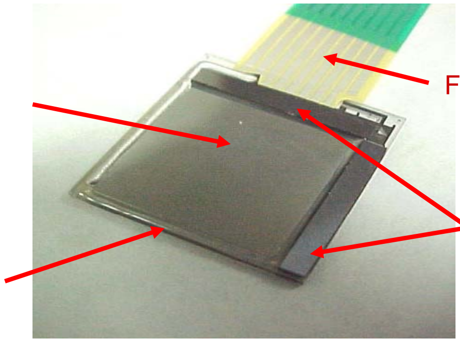
Glass sensor



Plastic sensor



Fidelica Sensor Assembly



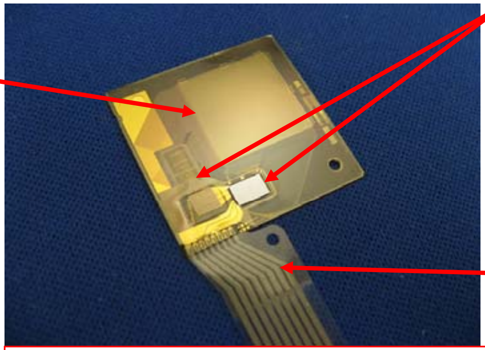
Polymer films

Flex cable

Glass sensor substrate

ASICS (2), flip-chip bonded with ACF

Glass based sensor

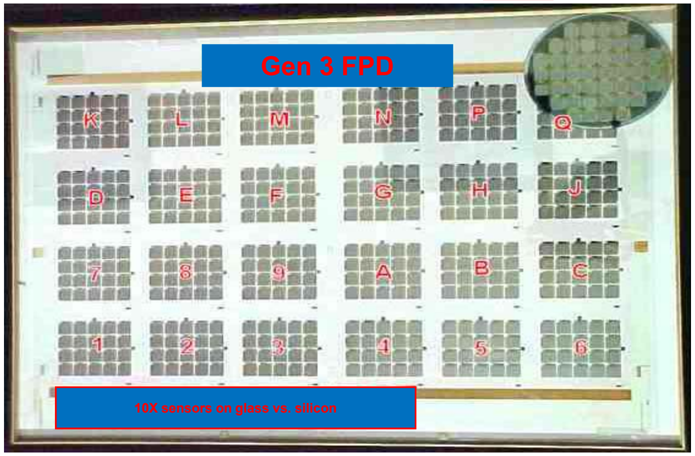


Plastic sensor substrate

ASICS (2), flip-chip bonded with ACF

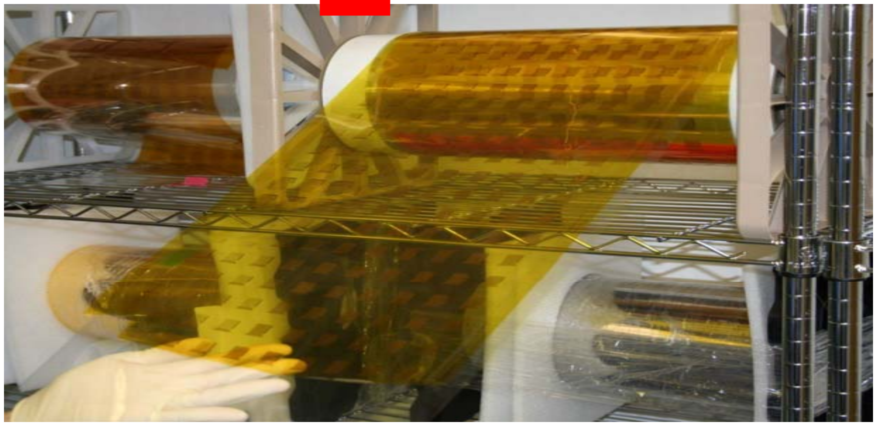
Flex cable

Plastics based sensor

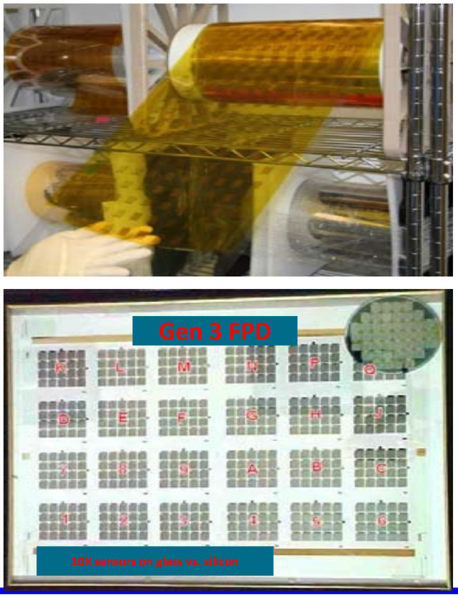


Gen 3 FPD

10X sensors on glass vs. silicon

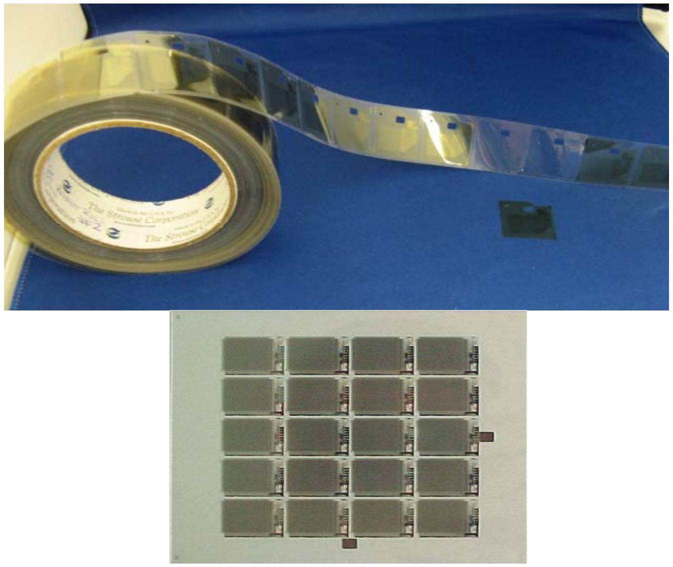


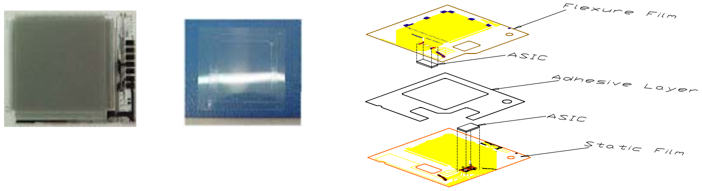
Manufacturing Flow



Gen 3 FPD

10X sensors on glass vs. silicon





Assembly

The challenges they don't teach you about…

- Picking a manufacturing partner
- Process development at remote foundries
- Business challenges for the foundry
  - Operating as a foundry
  - Product mix and filling the fab…
  - Reacting to business and market cycles
- Assembly, Packaging and Test

THANK YOU GRAZIE MERCI DANKE GRAZIAS 謝謝 СПАСИБО

GRACIAS OBRIGADO ありがとう DANK TAKK BEDANKT DAKUJEM