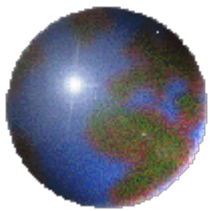


Large-Area Electronics to Facilitate a New Generation of Warfighter Health Care

Dr. Robert Reuss
DARPA Consultant
Fountain Hills, AZ
480-544-5409

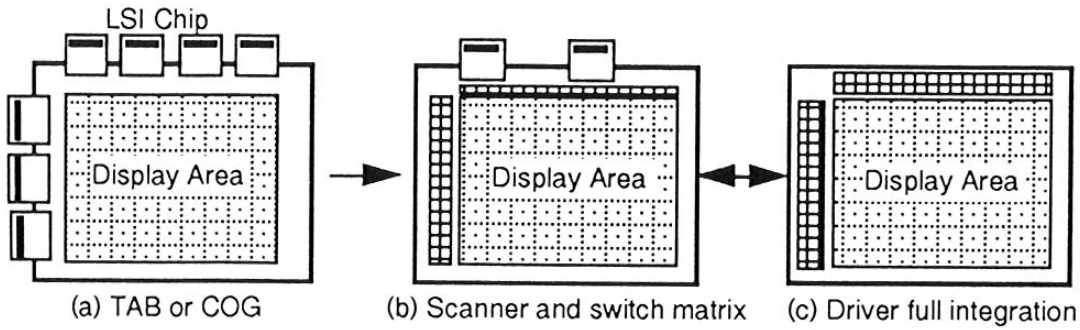
Outline

- Macroelectronics Technology Drivers
- Electronics Performance -- TFT Challenges
- Recent TFT Results
- Fabrication Tools and Technology
- Potential Collaborators

System On a Flexible Panel

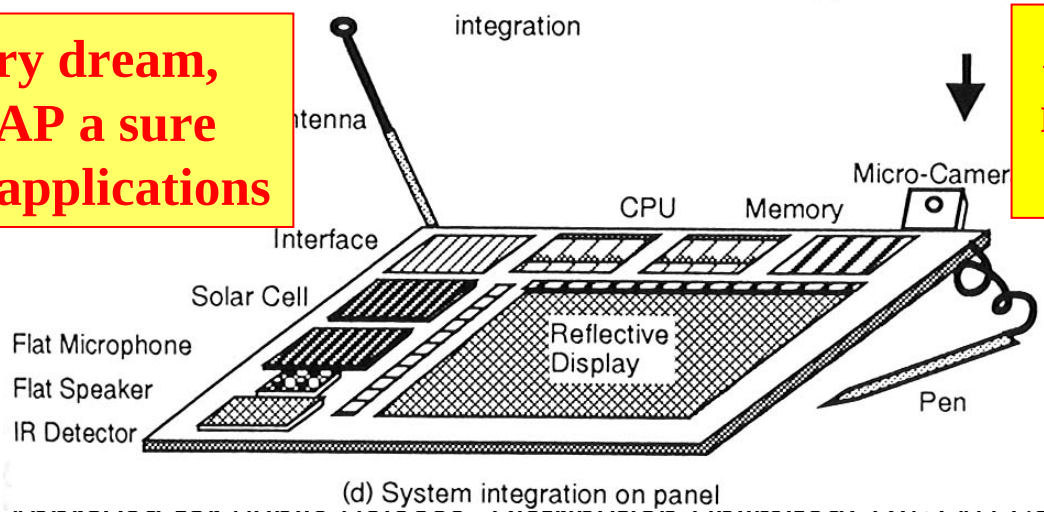
Performance of Thin Film Transistors enables display drivers and other system components to be integrated on a flexible metal foil.

High Reliability, Low Cost, Light Weight



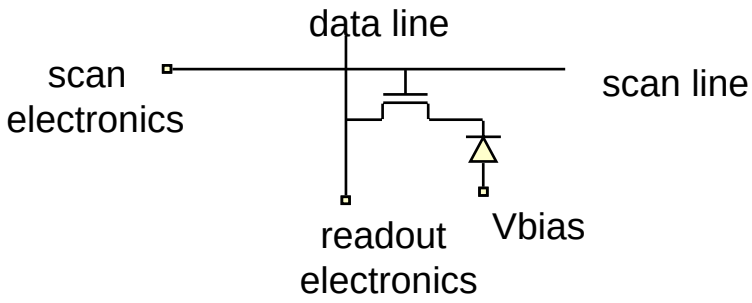
A display industry dream, but reduced SWAP a sure winner for DoD applications

Aggressive development by USDC and Army's FDC

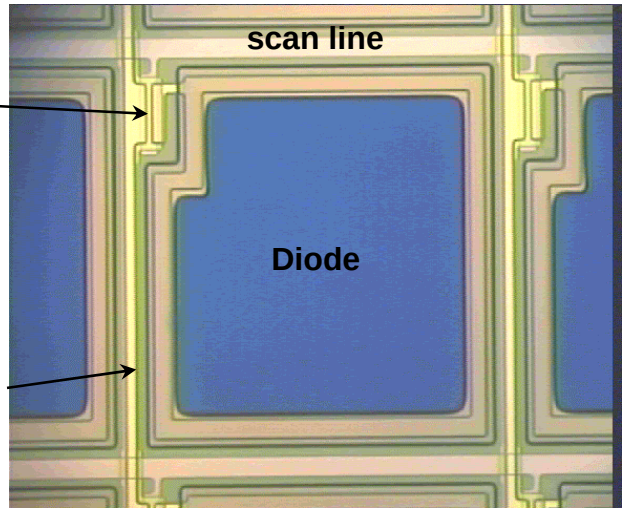


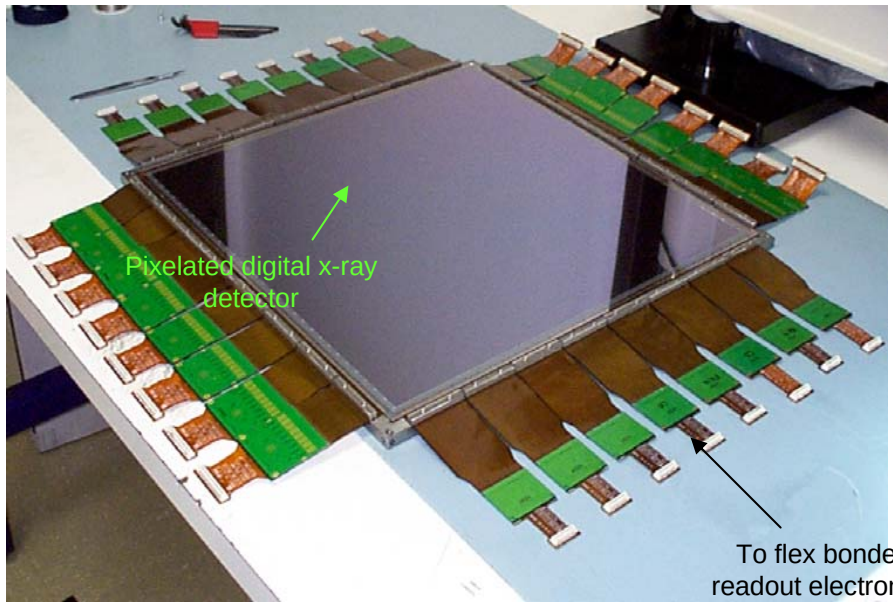
From Displays to Digital X-ray Detectors

- X-ray readout via. scintillator/α-Si photodiode.
- Readout control via. α-Si TFT.
- Readout electronics are flex bonded to panel.
  - Charge to analog voltage conversion.
  - Analog to digital conversion
  - Parallel to serial readout



Digital XRD pixel top view





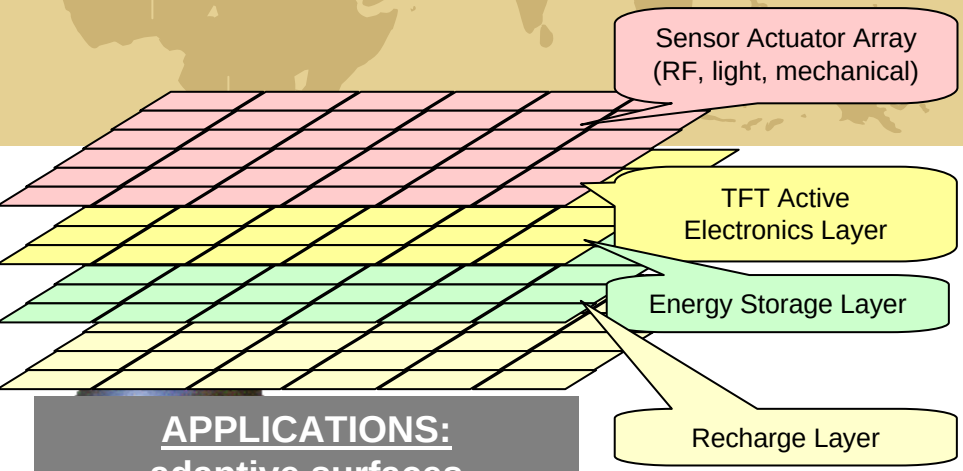
Digital Radiography will revolutionize medical imaging for diagnostic and therapeutic applications. Rugged, portable x-ray detectors for battlefield hospitals to enable rapid diagnosis of injuries from/to remote locations.

Power? Flexible PV Solutions

- Flexible – bend around ½ ” radius
- Lightweight - < 0.1 kg/m2
- Efficiency – 15-20%
- Rugged - ?
- Low Cost – $2-5/m2

Many potential vendors including Global Solar, Nanosolar, Power Films

Large Area, Distributed Flexible Electronics Technology



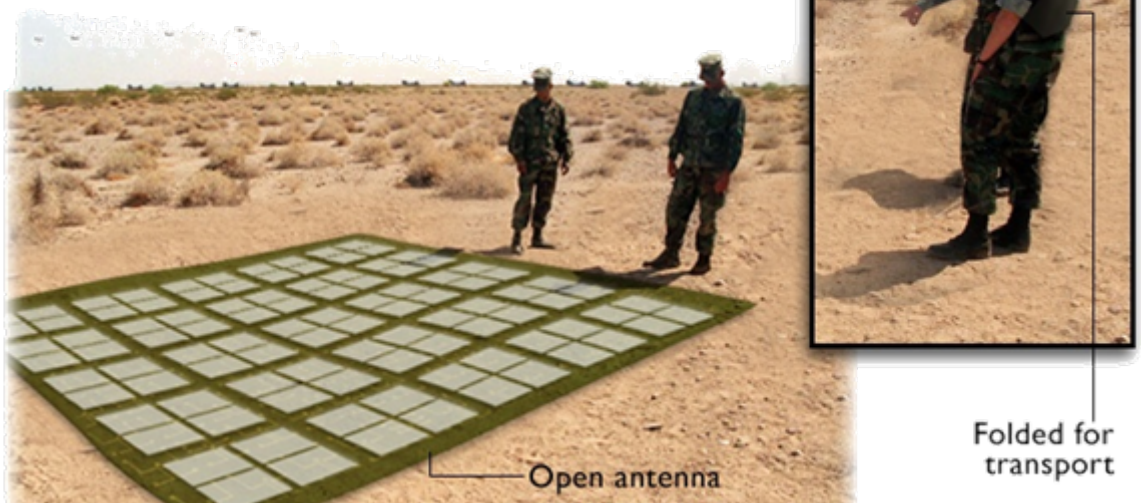
APPLICATIONS:
adaptive surfaces
sensor arrays
displays
distributed diagnostics

Goal
- Integrated electronics distributed sensor arrays that interact/respond to environment.
- Reduce weight and cost.
- Increase reliability and flexibility.

Challenges
- Thin film transistors/circuits with adequate mixed signal performance.
- Cost effective fabrication methods.

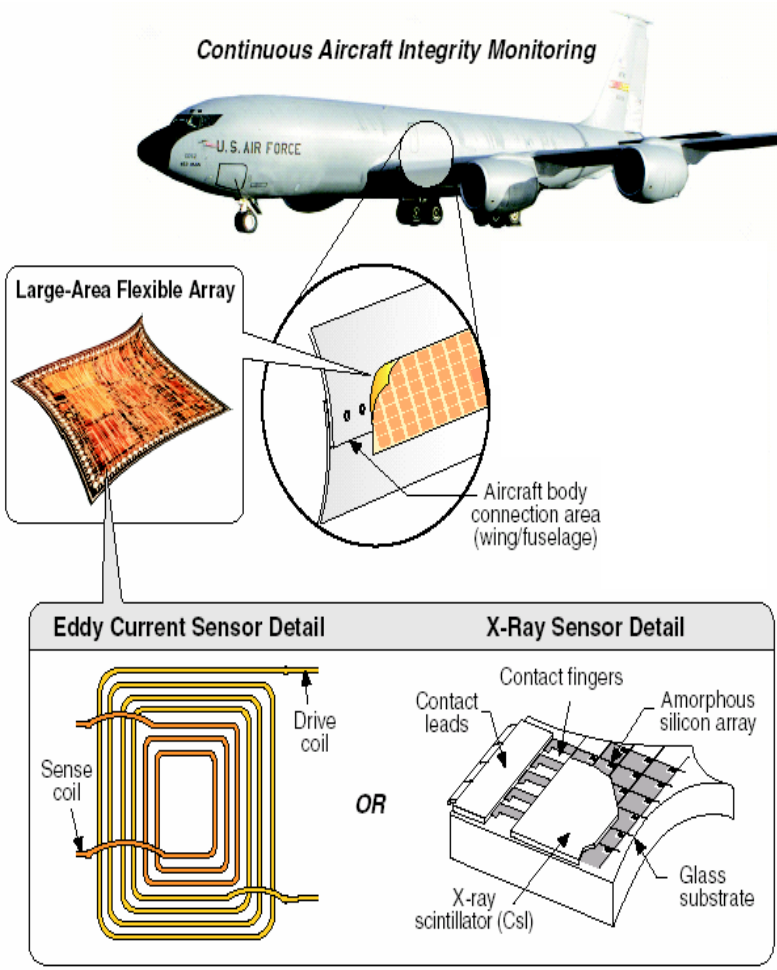
TFT devices/process candidates for >100 MHz operation in development.

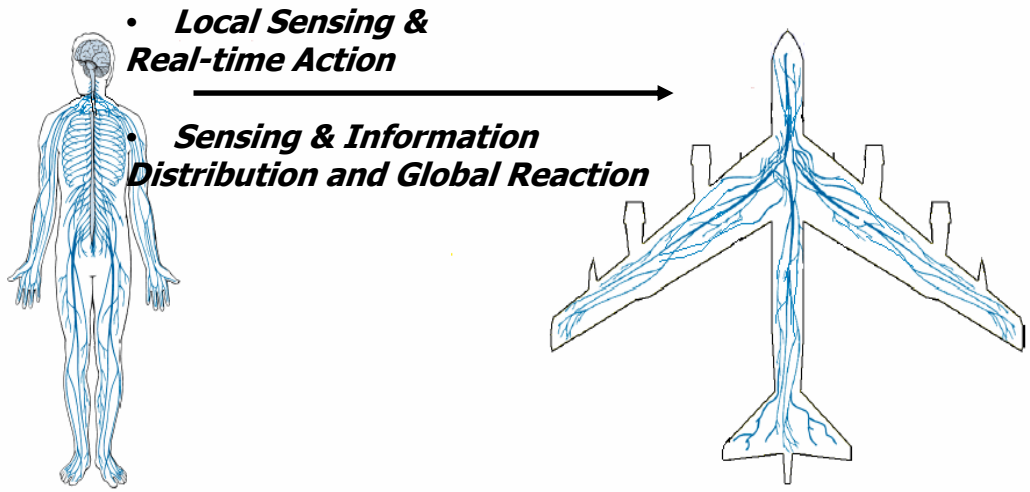
Initial application drivers identified.



Large Area, Embedded Flexible Control Electronics

Creating a totally autonomous sensing and responding system with an awareness of internal and environmental stimuli and the ability to dynamically react to them





- Structural integrity of critical components in aircraft or other equipment.
- Monitor and control **while in operation**
- Cargo monitoring.

Warfighter Health

Ideal Personal Health Monitoring System:

- Blood Pressure - 1-channel electrocardiogram with a laser-Doppler flow-sensor for the application at the finger
- Glucose - Optical measurement by analyzing reflected light from aqueous humor to calculate blood sugar level
- Respiration - Analysis of breath sounds acquired via ambient sound recording or via an electronic stethoscope
- Body Area Network covers the communication between the wearable sensors.
- Personal Area Network - covers the communication between sensors and the base station

Georgia Tech Wearable Motherboard

Heart rate, temperature, respiration rate, etc.. measured with

- Sensors integrated into the shirt
- Sensors on the soldier's body

Data from sensors sent to Personal Status Monitor in both cases

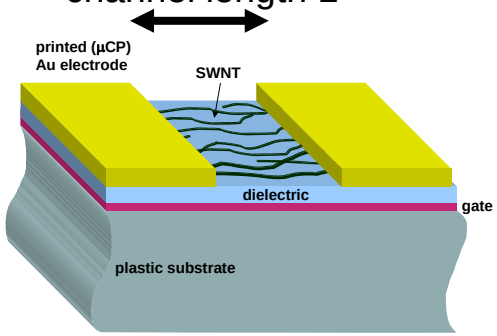
Question: Could Macroelectronics improve functionality?
Answer: Yes, form factor & *in-situ* treatment capability.
More?

f_T Considerations

- **Suppose Macroelectronic TFTs could reach transition frequencies of f_T ~ 10 GHz.**
- **RF circuits can operate at 1/3 - 1/4 of f_T.**

⇒ Well-designed Macroelectronic RF circuits should be able to operate up to 2-3 GHz.

⇒ Digital circuits should be able to operate at several hundred MHz



$$f_T = v_{sat}/(2\pi L^2_g)$$

High mobility TFT

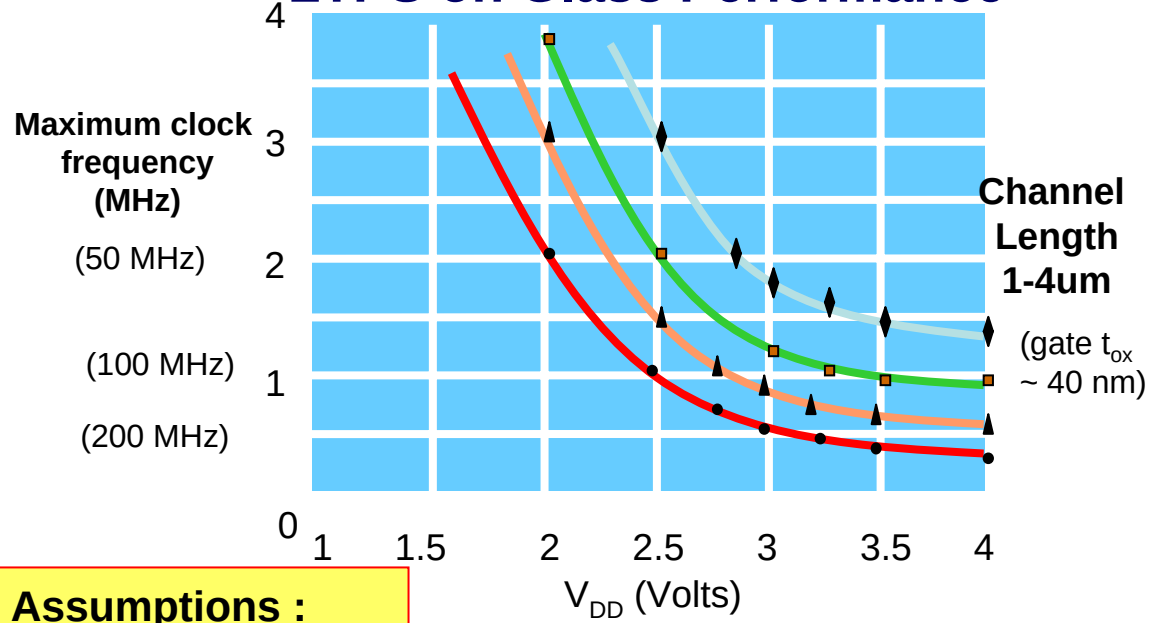
$$f_T = \frac{\mu_{FE}(V_{gs} - V_T)}{2\pi L^2}$$

Material/process lever

Moore's Law Lever

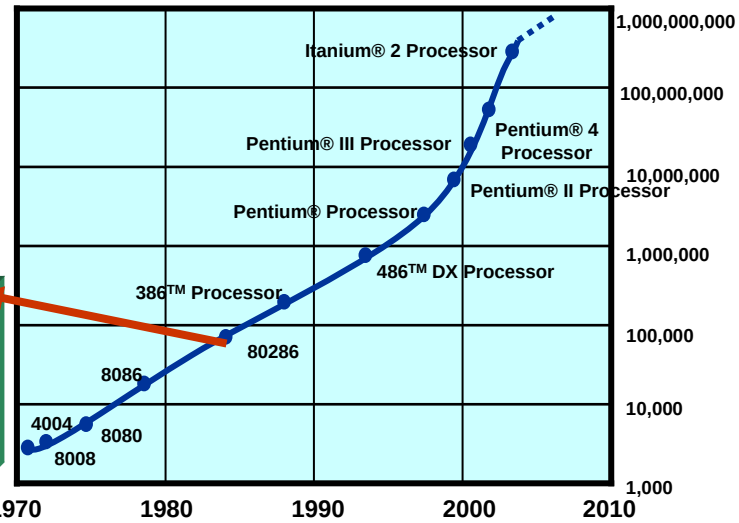
Questionable Economics for Large Areas

LTPS on Glass Performance



Assumptions :

- μ_{FE} = 300 cm²/V-s
- $V_{gs} - V_T$ = 2V
- L = 1 μm, 10 μm
- F_T = 10^{10} Hz, 10^8 Hz

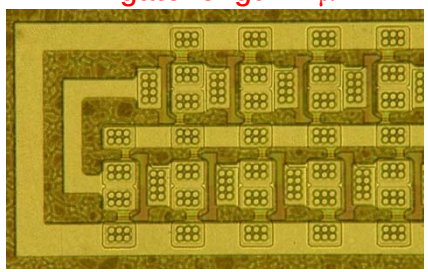


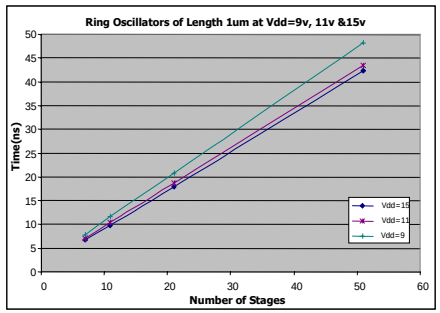
80286
- 100,000 Transistors
- 1.5 micron Technology
- Speeds from 6MHz to 20 MHz
- Capable of addressing 16 MB

Older, slower technology. But cheap!!

LTPS TFT on Stainless Steel Results

11 stage ring oscillator
TFT gate length 1 μm





Extracted Time Delay per stage

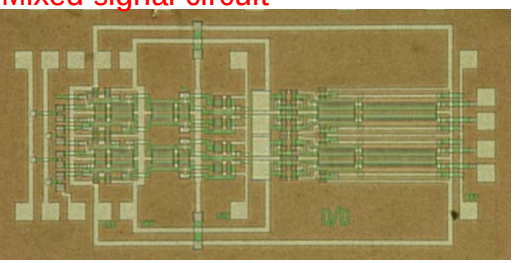
TFT channel length: L = 1 microns

Vdd = 15V $\tau_{stage} = 0.88ns$

Vdd = 11V $\tau_{stage} = 0.92ns$

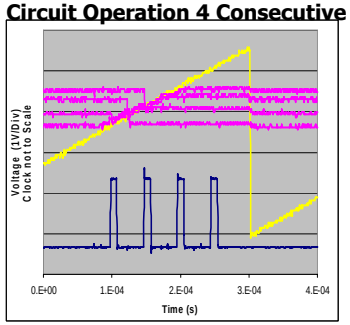
Vdd = 9V $\tau_{stage} = 1.03ns$

Mixed signal circuit



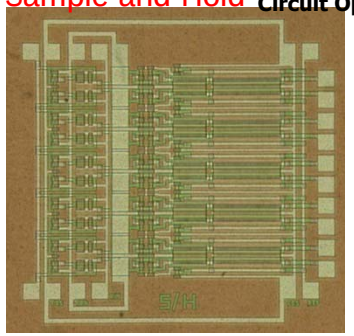
Sample and hold clocked by
integrated half bit shift registers

Circuit Operation 4 Consecutive Stages

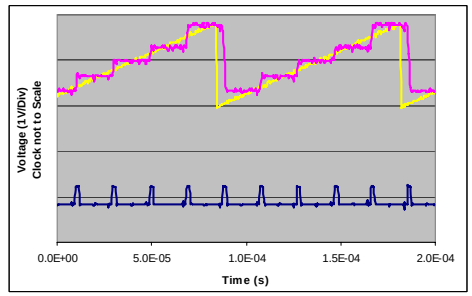


Stage 4
Stage 3
Stage 2
Stage 1

Sample and Hold



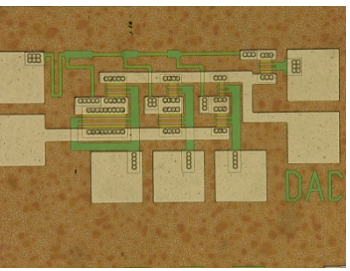
Circuit Operation at 50KHz Sampling Rate (Digital Clocks

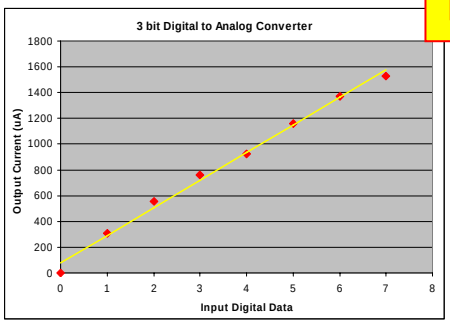


Analog voltage sampling circuit for
sensor circuit building blocks
All 10 stages functional (110 TFTs)

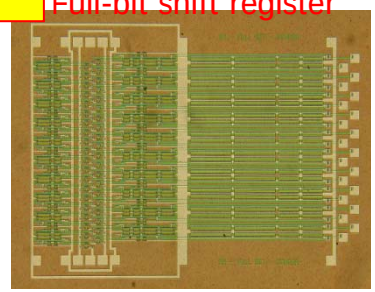
M. Hatalis
Lehigh U.

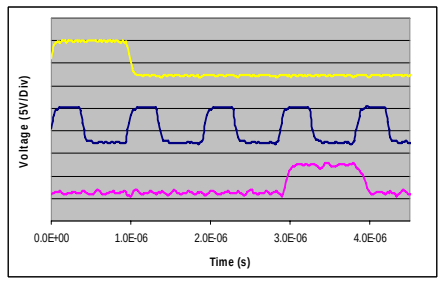
3-bit DAC





Full-bit shift register

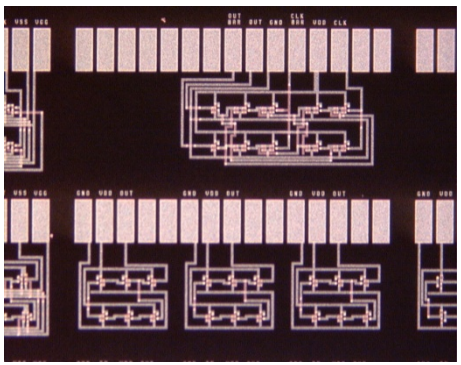




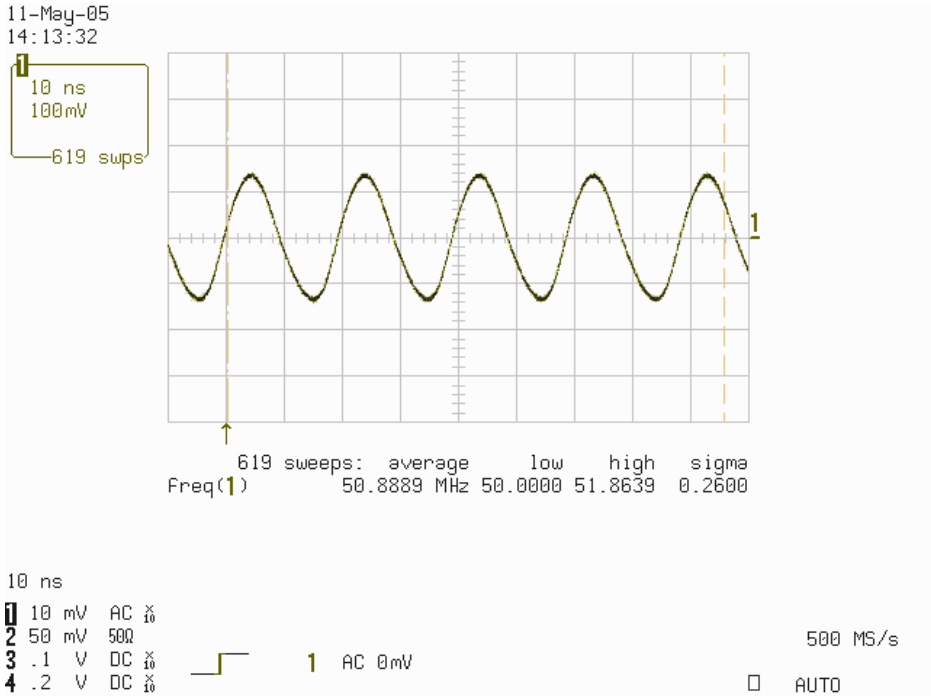
Digital clocking circuit, 240 transistors
Testing limited by clock distribution
10 MHz operation demonstrated

LTPS TFT-on-Polyimide Results

- **NMOS and CMOS circuits functional with high yield**
- **Ring oscillators operate up to 60 MHz**



SLS-on-polyimide circuits

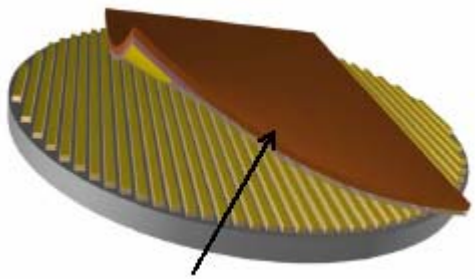


SLS-on-polyimide L = 5 µm NMOS ring oscillator running at 51 MHz (V_{DD} = 15V)

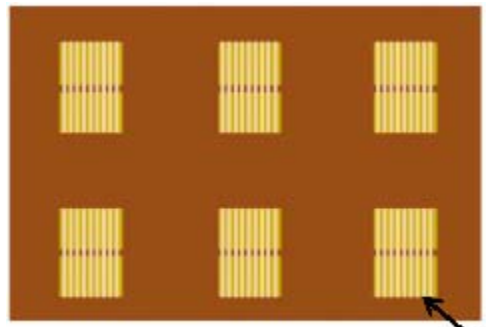
M. Kane, IEDM, 37.8.1, p 1087 (2005)

Single Crystal Si TFT on Plastic

A printable form of silicon for high performance TFTs on plastic substrates, John Rogers & co-workers App. Phys. Lett., 88, 213101 (2006)

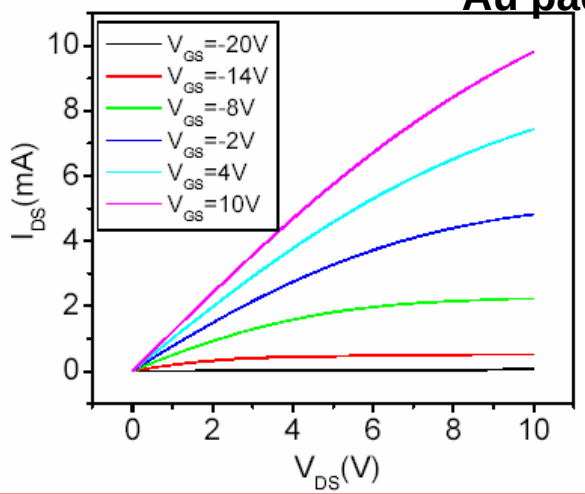


Plastic Substrate

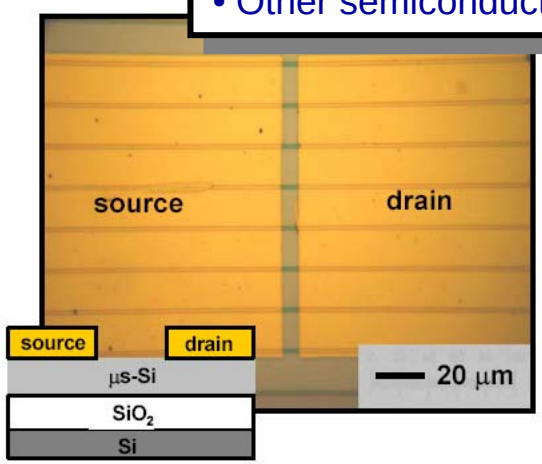


Au pads

Issues being addressed:
- Si thickness
- Contact materials
- Transfer method onto substrate
- Other semiconductor materials



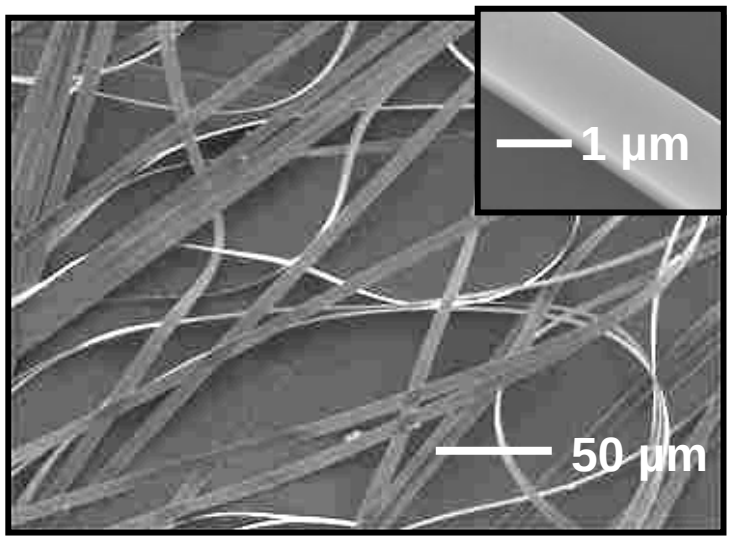
Microstructure Si TFT fabricated with mobility of 180 cm²/Vsec



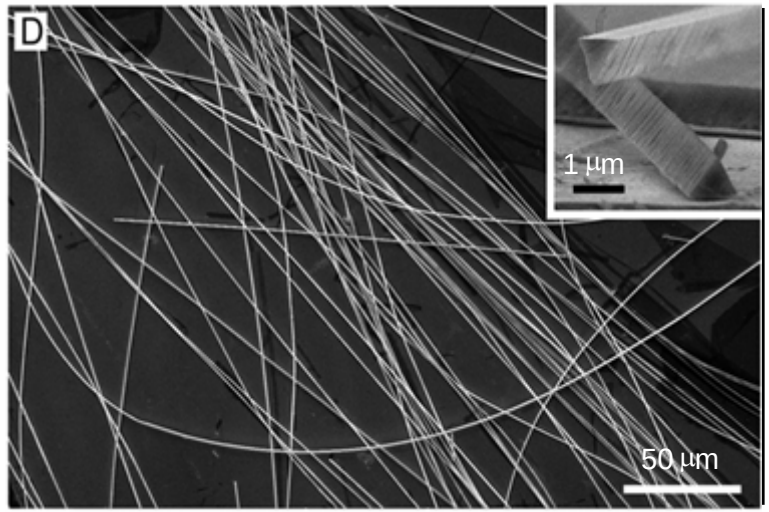
Nanowires can also be coated uniformly across a substrate to provide high performance TFTs. (X. Duan, MRS Bulletin, 32, 134, Feb 2007)

Printable Semiconductor Micro/Nanostructures from Wafers

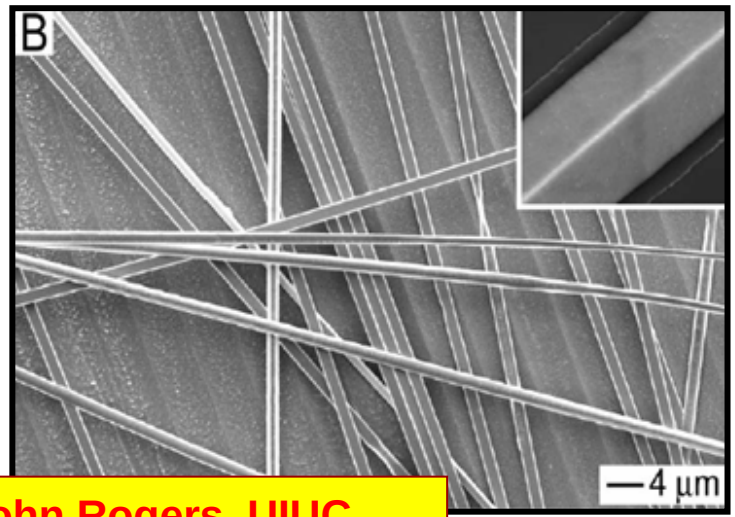
Si



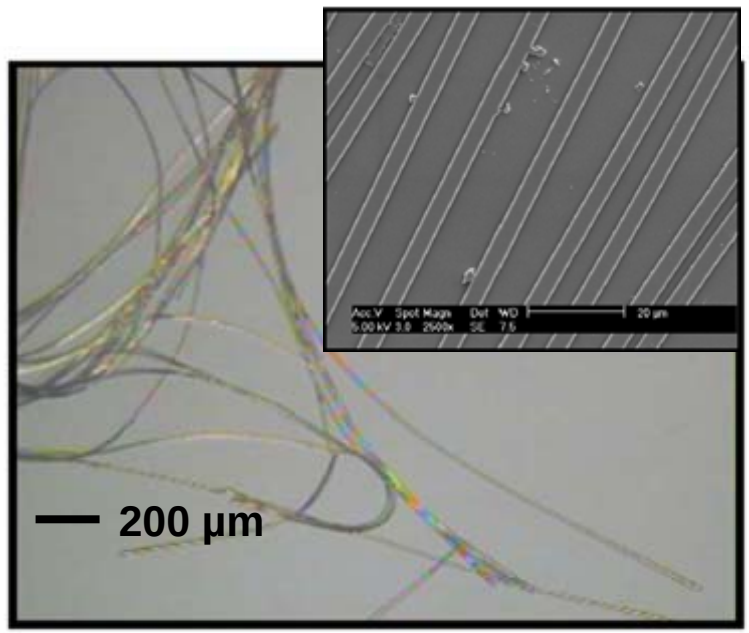
GaAs



InP



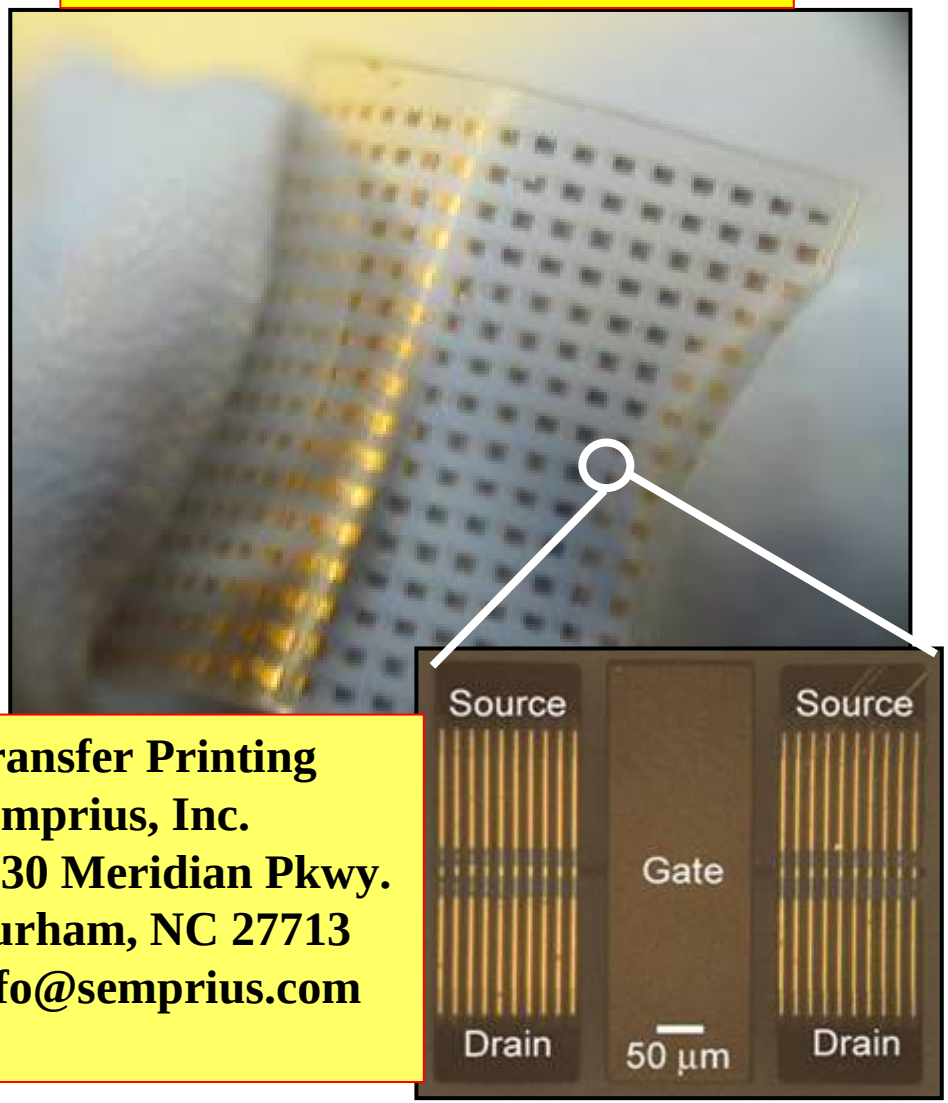
GaN

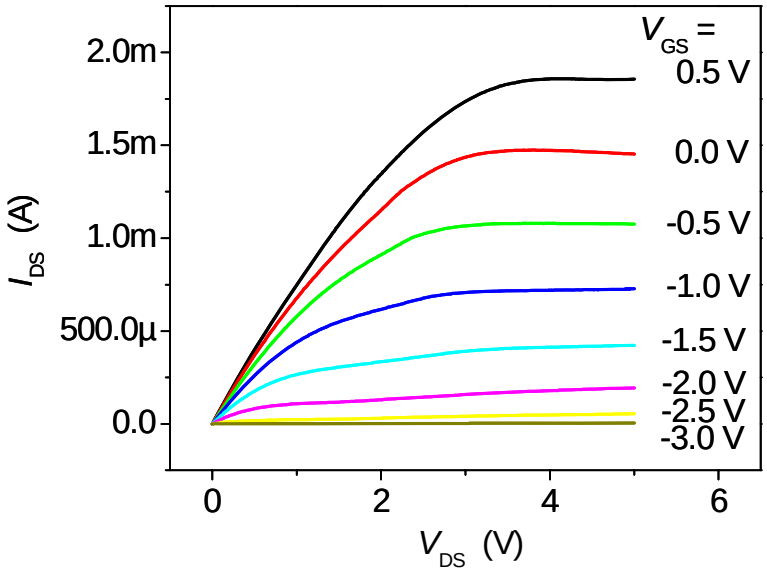


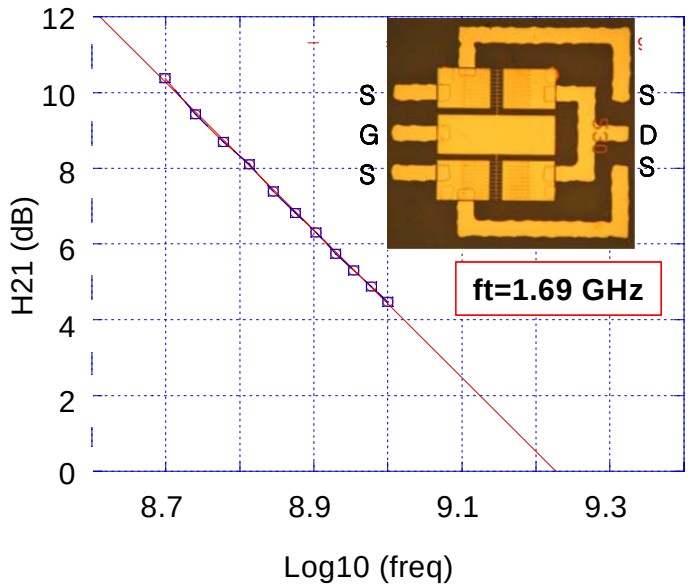
John Rogers, UIUC
Nano Letter, 4, 1953 (2004)

GHz Devices on Plastic : GaAs MESFETs

App Phys. Lett. 88, 183509 (2006)







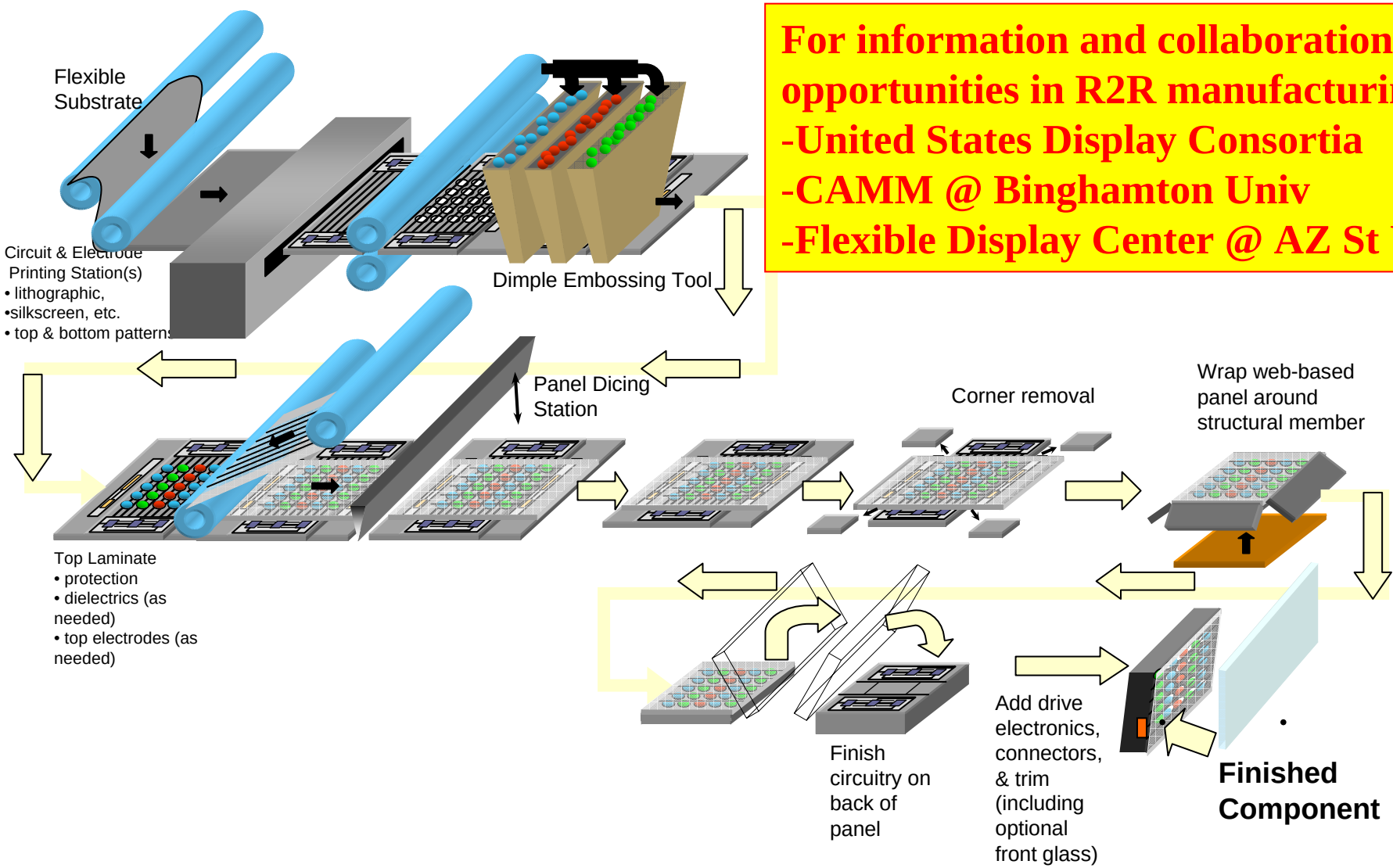
Transfer Printing
Semprius, Inc.
2530 Meridian Pkwy.
Durham, NC 27713
info@semprius.com

Some Additional Challenges

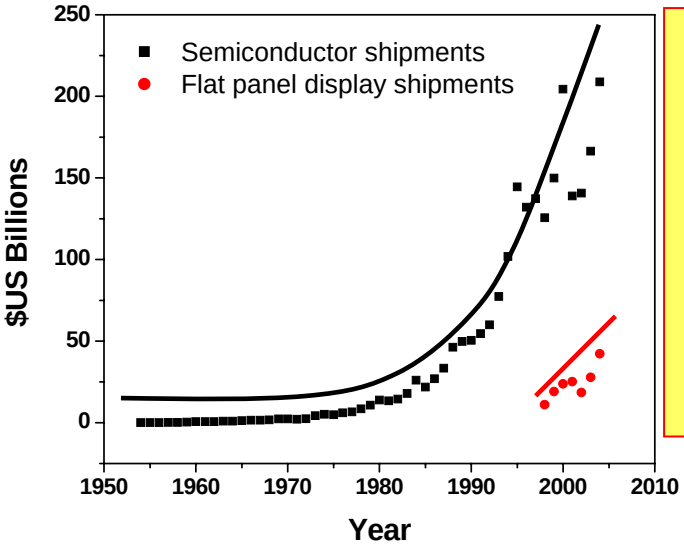
- Solution depositing ‘high quality’ nanomaterials
- Aligning, patterning the nanomaterials
- Providing high quality gate dielectric
- Establishing low resistance, ohmic contacts
- Provide for variation in doping as required
- Develop TCAD & circuit design tools
  - Digital (perhaps based on async logic?)
  - RF (to include gain, NF, linearity)
  - thermal effects
- Develop tools and process for multi-component integration of MEMS etc.

Roll-to-Roll Manufacturing Needed for Economic Success?

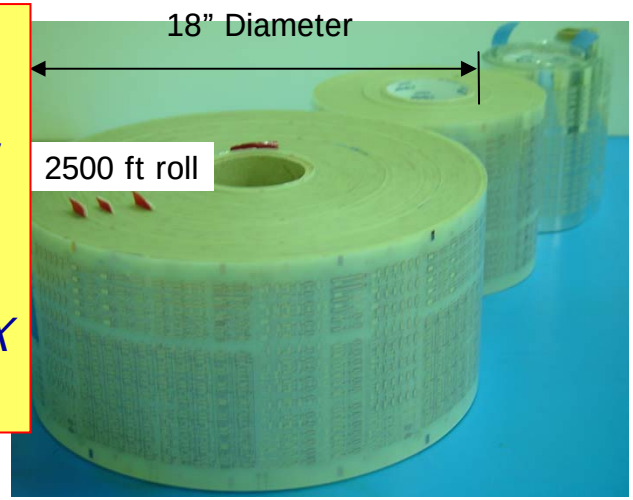
For information and collaboration opportunities in R2R manufacturing
-United States Display Consortia
-CAMM @ Binghamton Univ
-Flexible Display Center @ AZ St U

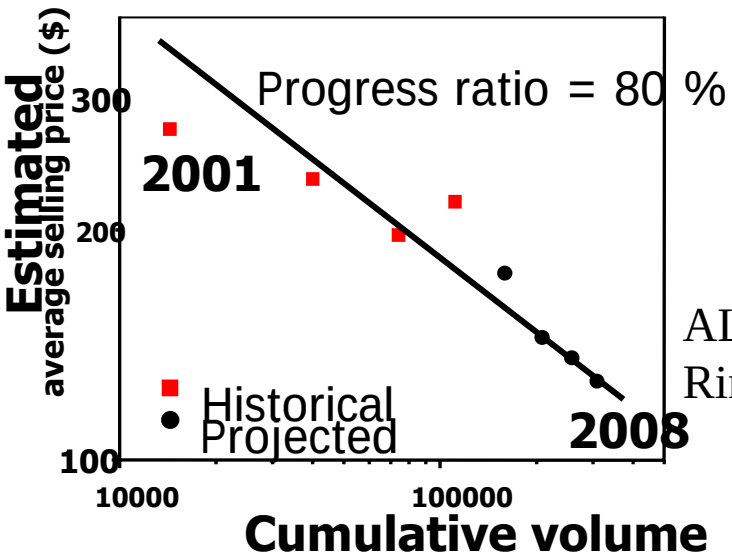


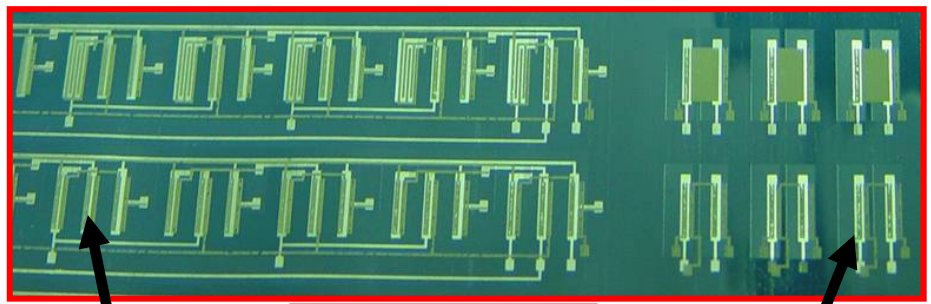
Display and Printing Manufacturing as a Cost Driver



Functional circuitry demonstrated at manufacturing speeds of 300ft/sec on a 6in web platform and 7000sheets/hr on a 24in X 36in sheet-fed platform.







ALL Printed Ring Oscillator

Courtesy Dan Gamota Motorola

ALL Printed ChemFETs

Process Tool Attributes for Large Area Electronics

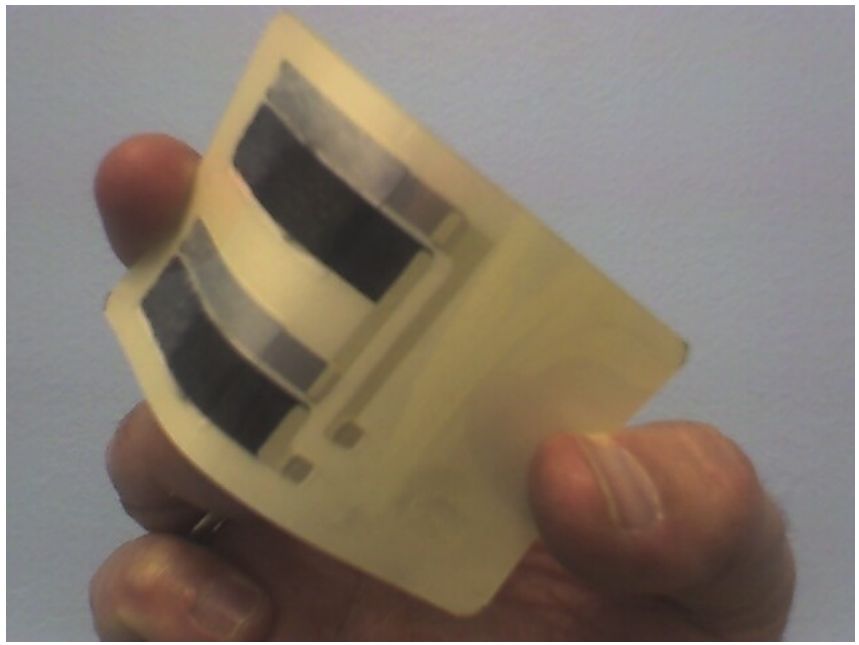
- **High process rates compatible with wide range of materials**
- **Easily integrated with other fab tools**
- **Additive vs. subtractive imaging**
- **≤ 1 micron resolution with alignment consistent with micron design rules**
- **Large-Area lithography, photoablation, and recrystallization/anneal solutions**

Courtesy of Anvik corporation K. Jain Proceedings IEEE 93(8), 1500 (2005)

Goal: Printable, High performance Electronics on Arbitrary Surfaces and Shapes

Integration of Battery & Electronics

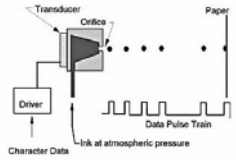
- Full integration
  - Battery
  - Circuit
  - Package



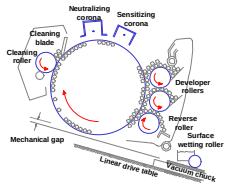
Thin film Li and MnO2/Zn battery technology available

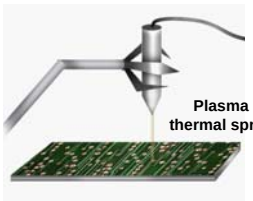
Powering Innovation™ by Thin Battery Technology Inc. Parma, OH 44130

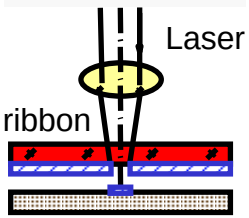
The Goal: Sensor Strip on Tape

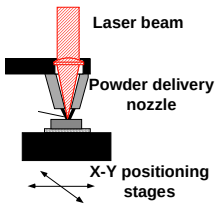


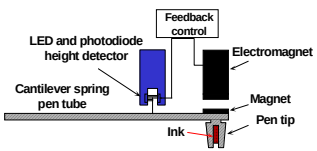
Tools

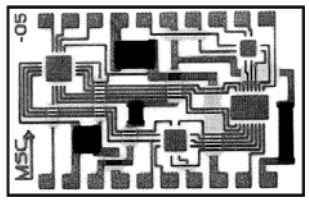




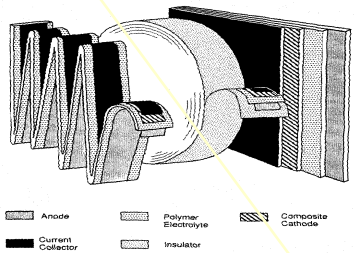




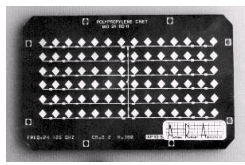




Direct-write passive components & interconnects



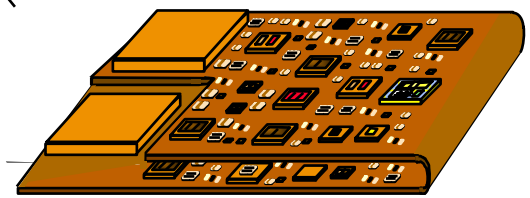
Direct-write batteries



Direct-write high gain antenna

ICs*

Components



Sensor Strip or Tape

Printed OFET TFTs

Miles of printed MHz Tags

- **Prototype 13,56 MHz RF Tags**
  - **fully flexible and thin**
  - **roll-to-roll manufactured with printing processes**
- **High Speed (up to 20m/min)**
- **Roll-to-Roll printed logic circuits (ring oscillators)**
- **First demonstration at OEC06 Sep 25-27, 2006 Frankfurt**

PolyIC 2005 25/X
Tel: +49 911 20249-0
email: info@polyic.com
Web: www.polyic.com
FürthGermany

Add Vision Military Wearable Displays

- **Flexible, wearable low cost "consumable" OLED "patch" as key component for IFF system**

- **Modulated IR Laser scans potential target**

- **"Smart" OLED patch detects encoded IR Laser and "flashs" response in IR to avoid RF detection**

- **Solider wearing Night Vision Goggles Identifies "friendly"**

AVI Military Wearable Displays
Scotts Valley, CA

Smart Textiles

Sensatex holds the worldwide license from the Georgia Institute of Technology Research Corporation to a series of patents related to Smart Textiles. The Patented technology was first developed with funding from DARPA for Advanced Military Combat Care Applications.

What is a SmartShirt?

- **Moves Data From Multiple Sensors to Common Collection Point**
- **Allows Flexible Sensor Placement Through Data Bus Structure**
- **Provides Comfort and Functionality of Garment While Eliminating Wires**

The SmartShirt Is A Convergence of Advanced Textiles, Sensors and *Wireless Technology Designed to Collect Vital* Information from the Human Body Sensory.

Sensatex, Inc. (www.sensatex.com, info@sensatex.com)

Smart Skin Patches

What is a smart skin patch?

Adhesive patch that interacts with the skin

Impregnated patch that sends substance through the skin

Sensor patch that detects, displays, records vital signs

Four generations of skin patches

1st Generation: Transdermal patches, available > 15 years, sold in volume

Skin patches deliver drugs and ointment. Works only for certain chemicals, absorption is slow and varies with other factors e.g. temperature

2nd Generation: Electrical patches, available for over 5 years

Skin patches employ iontophoresis: penetration increased by 10-16 times. Big boxes of electronics becoming thin throw away skin patches

3rd Generation: Electronic patches

Skin patches employ circuits to improve drug delivery, e.g. reversing bias causes 36 times faster penetration than 1st Generation.

4th Generation: Closed loop control of medication

Feedback systems which can control the release of drugs based on real time diagnosis or constant monitoring. Human intervention (the error) progressively eliminated

Dr Peter Harrop (p.harrop@idtechex.com

IDTechEx Phone +44 1223 813703

Printed Antennas

Parmod® Printed, low cost , Ag ink antennas

- **UHF Performance(800 – 1000 MHz)**
- **At 2.5 – 3.5 micron thick comparable UHF performance to etched metal**
- **Developing prototypes with 4 UHF IC Suppliers**
- **Area of common UHF antenna 320 mm2 / 0.5 sq.in.**
- **PET thickness normally 2 mil for tensioned web or paper**
- **Printed antenna materials cost < $0.0035**
- **Price target <$0.008**

Richard Morris +1 (630) 715-2369
rmorris@parelec.com
Parelec +1 (609) 279-0072
www.parelec.com

Novel Components

What is Thinking Ink? Ink that replaces/facilitates:

- **Switches & Buttons**
- **Wires**
- **Sensors**
- **Temperature Control** (heat & cool)
- **Antennae**
- **Speakers & Microphones**
- **Batteries**
- **Biostatistics Msmts** (temp., heart rate, hydration , pulse, O2)

Andrew Ferber, T-INK, Inc.
244 West 54th St., NY, NY 10019
212.757.0700 info@t-ink.com

Speakers and Microphones (?)

- **Until recently sound overlooked in the Printed Electronics industry**
- **A thin-form factor low cost high quality audio solution could deliver**
- **that promise of interactive high information content now**
- **NXT is working closely with appropriate partners to deliver Invisible Sound for Printed Electronics**
- **The applications: *smart packaging; smart labels; selfauthentication;***
- ***ID cards; greetings cards and novelties; magazine, newspaper, book inserts;***
- **Distributed Mode Actuator (DMA) is a recent NXT invention**
- **DMA is the "engine" that drives NXT panels to produce sound**
- **Using smart materials a new class of audio driver has been produced**

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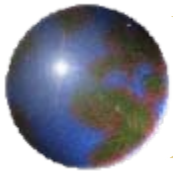
5210 Terner Way, #307
San Jose, CA 95136-4160
1 408 269 4498
e: g.boyd@nxtsound.com



Micron Sized Resolution Printing

Printable Electronics: Materials and Processes

Graciela B. Blanchet
DuPont Central Research

Flexible Display and Microelectronics
Phoenix, AZ
February 6-8, 2007

Microcontact Printing

Semprius, Inc.
2530 Meridian Pkwy.
Durham, NC 27713
info@semprius.com

Roll-to-Roll Manufacturing

Towards Roll-to-Roll Manufacturing of Electronics on Flexible Substrate

- **Performance of a-Si TFTs**
  - **on-off ratio > 107**
  - **100µA on-current**
  - **mobility as high as 0.8 cm2/V/S**
  - **near linear scaling of Ion vs1/L to L~2µm**
- **Extending to ZXO semiconductors for mobility & transparency**

Carl Taussig
Hewlett-Packard Company
Palo Alto, CA