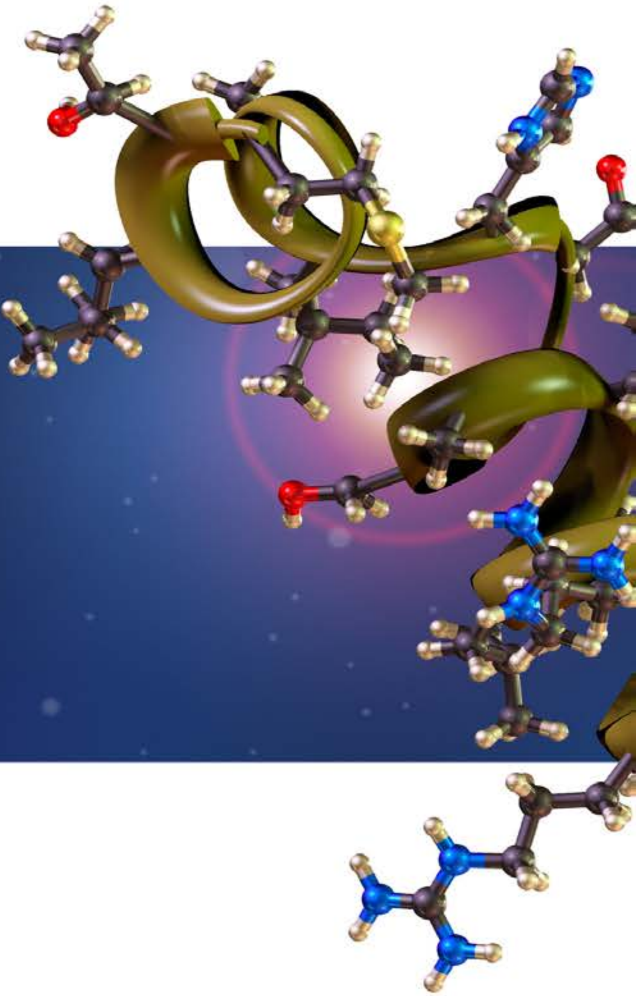
Nano-Bio Manufacturing Consortium

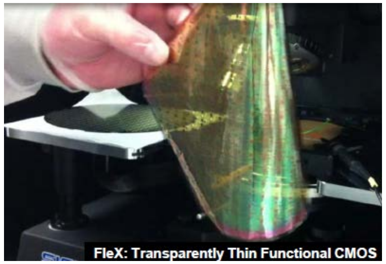


Flexible Electronics Integration and Supply Chain Challenges

Malcolm J Thompson PhD

CEO

Nano Bio Manufacturing Consortium

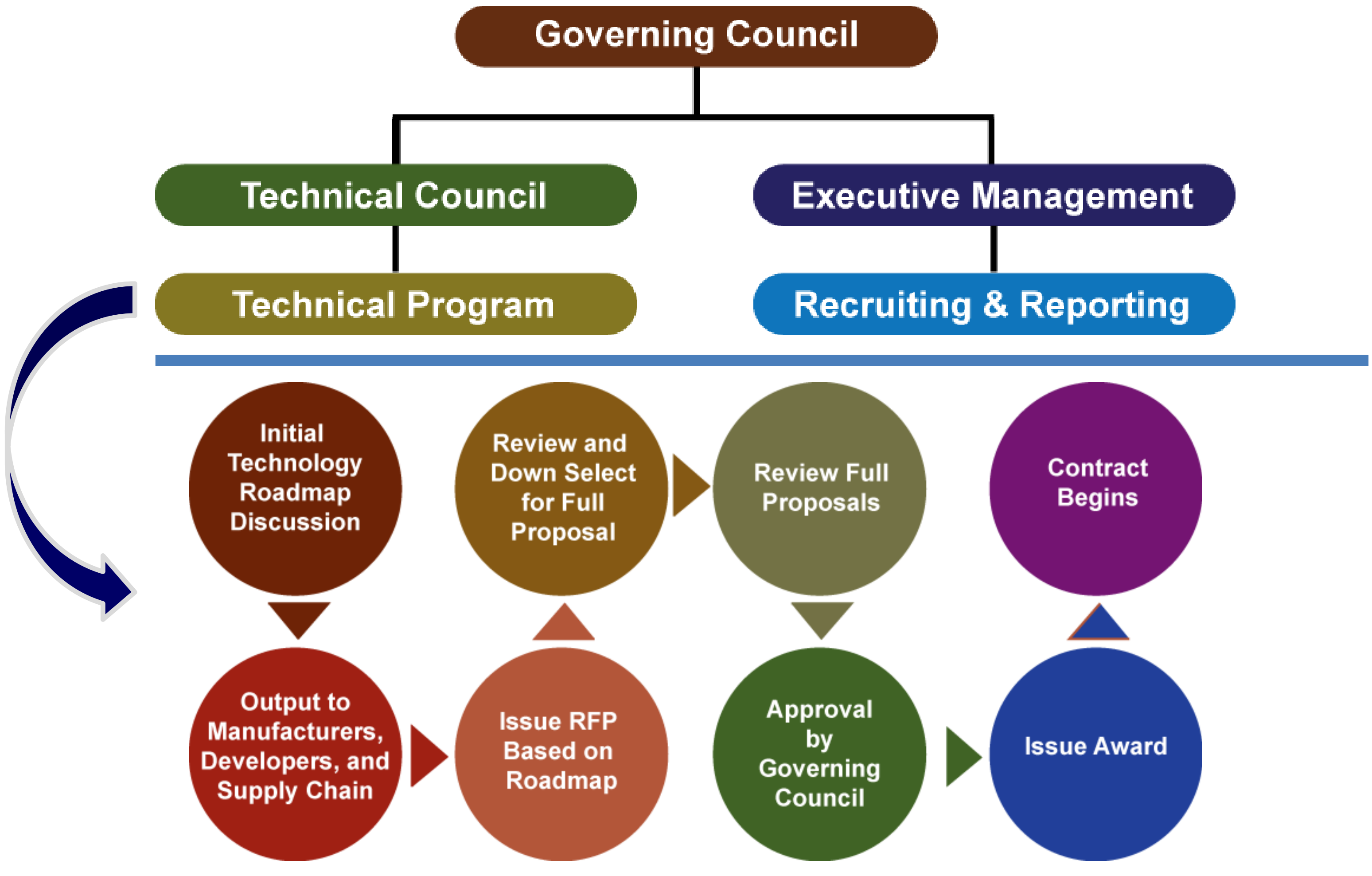


Program Supported By:

FlexTech & NBMC Business Model

- 20+ years as industry-led manufacturing consortium w/ government participation
  - Supported DARPA, AF, **ARL, AFRL, SOCOM**
  - Access to leading companies and PhD level SMEs
- Industry cost-shared manufacturing development program –> 60%+ industry funding
  - 165 projects since 1994
  - Demonstrated results in tools, materials, processes and demonstrators
- Creative, Collaborative, Cost Effective

How FlexTech Works

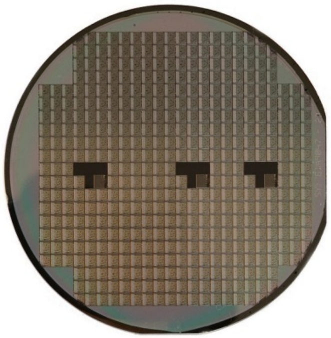


1. Define objectives 2. Set cost share floor 3. If equal technical merit, the higher the cost share the higher the score

Why Flex Electronics?
Change the Way Electronics Are Built

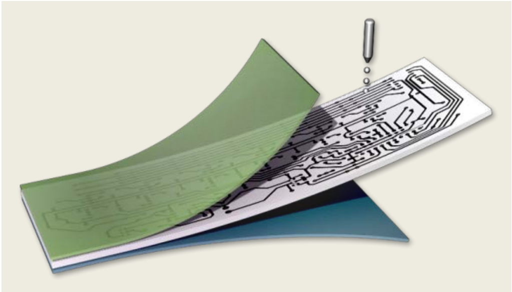
Printable electronics combines graphic arts printing and microelectronics technologies

- Requires <u>new devices</u> AND <u>new manufacturing paradigms</u>
- Potential to <u>reduce cost</u> at a <u>greater rate</u> than traditional silicon integrated circuit manufacturing
- **Low Cost Distributed Manufacturing**
- **Rapid Fielding**



Source: Wiki Commons

Conventional Silicon Electronics



Printed Electronics

Source: LM Corp

PE Paradigm: More product flexibility, lower costs, shorter time to bring products to market, and overall innovation and new business opportunities.
Rapid Fielding and Distributed Manufacturing

NBMC Background

AFRL Flexible Hybrid Electronics in Aerospace

NBMC Goal
Integration of Materials and Manufacturing within a common platform to address various flexible device applications

Challenges and Opportunities

February 2013 AFRL awarded FlexTech with a contract to set up the Nano-Bio Manufacturing Consortium

A consortium of Government, Industry, and Academic Laboratories that provides **R&D funding** for **collaborative team projects, workshops and working groups** to accelerate the **maturation of platform capabilities** and the **creation of innovative product technologies** .

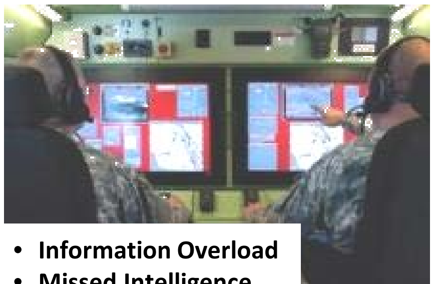
NBMC IS A CATALYST FOR CREATING A NEW INDUSTRY

Nano-Bio Manufacturing Consortium

Flexible Hybrid Electronics

Human System and Cognition

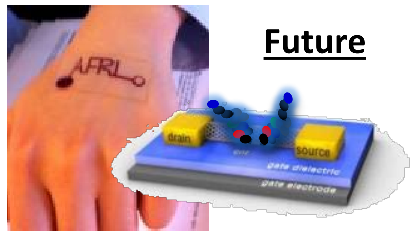
Human Performance limits capability in MANY Military Missions ….and New Technologies are Needed to Sense, Assess and Augment the "Man-in-the-Loop"



- **Information Overload**
- **Missed Intelligence**
- **Threat/Danger Missed**

Today

Future

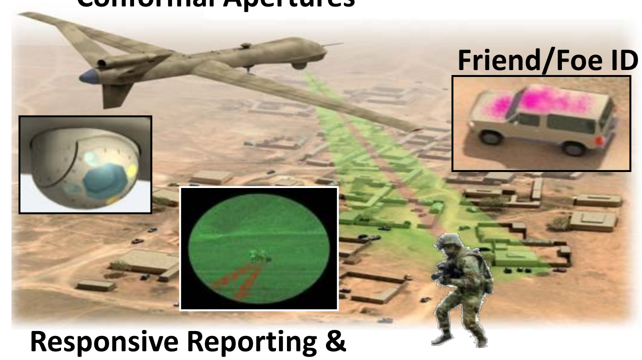


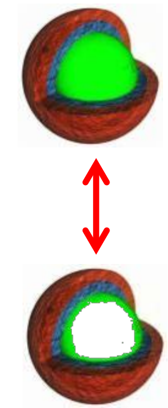
ISR and EW Integrated Capabilities

Information and tracking in contested environments (A2/AD) is foundational to decision making and force projection

Conformal Apertures

Friend/Foe ID





Responsive Reporting & Threat Detection

Energy Autonomous 24/7 Operations

Energy limit operational capabilities and mission impact for large time and distances scenarios

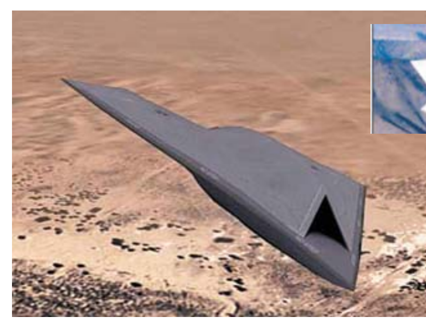
Issues:
- **Cost & Weight**
- **Scale-up**
- **Durability**

Integrated Power harvesting, storage, and management

Expected 1.5X – 3X increase in flight endurance.

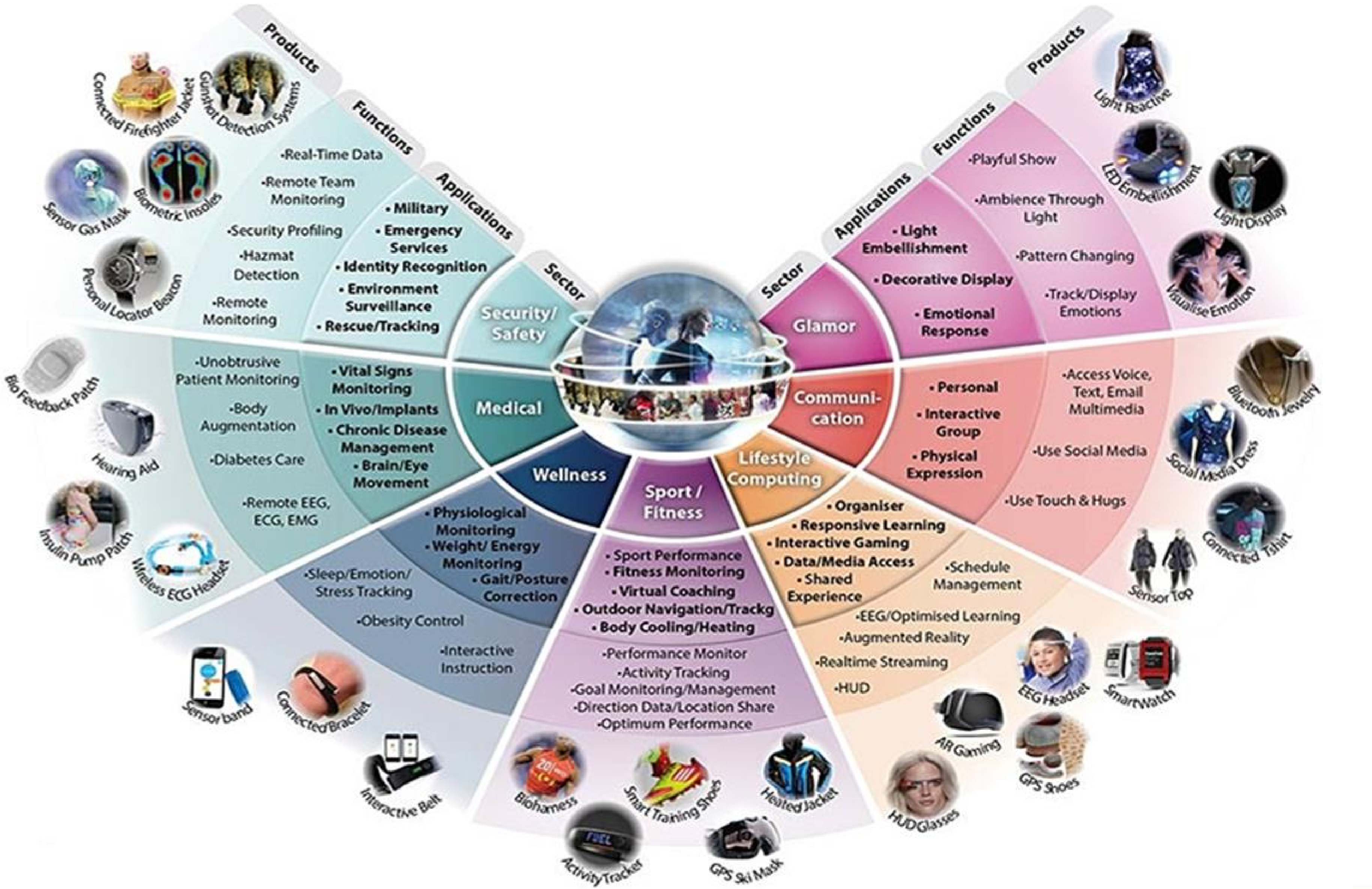
Low Profile, Robust Munitions

Precision effects with smaller, low profile munitions pressing requirement for current and future platform effectiveness



- **Structure integrated electronics**
- **Print energetic**
- **Conformal comm**
- **Shock resistant devices**

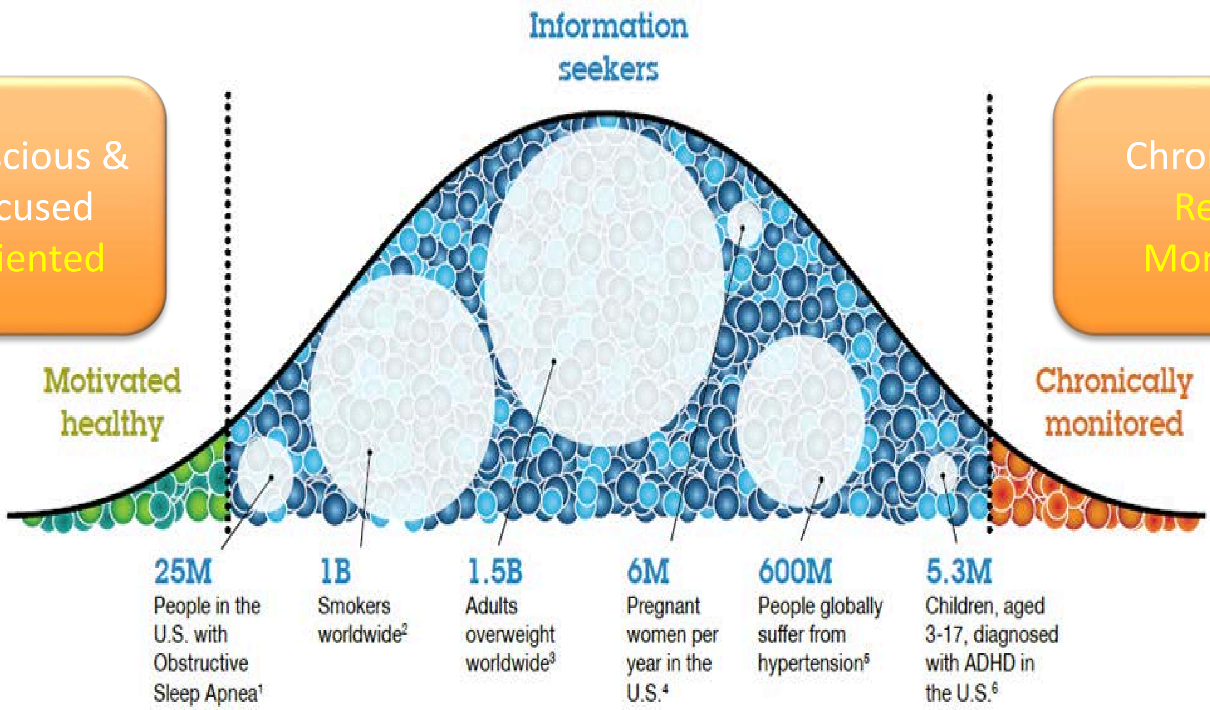
World of Wearables



Health Monitoring – Target Population ?

Health Conscious & Fitness focused
Gadget Oriented

Chronically ill
Require
Monitoring

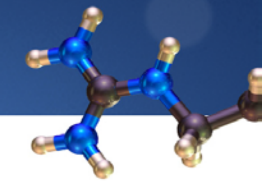


Seeking some measure of control over a potentially serious health risk or condition that is difficult to manage
Willing but underserved population

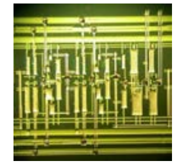
Huge emerging market for wearable electronics

Source: IBM Global

Flexible Hybrid Electronics

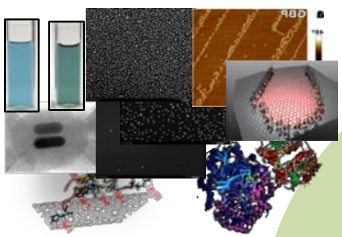


More product flexibility, lower costs, shorter time to bring products to market, and overall innovation and new business opportunities.



Rapid Fielding and Distributed Manufacturing

Flexible Hybrid Electronics



Flexible substrates

Nanomaterials

sensors, batteries interconnect etc

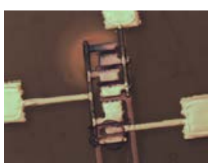
Low cost manufacturing

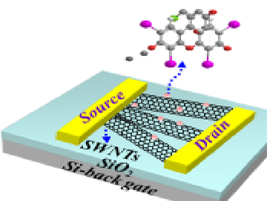
e.g., R2R, printing

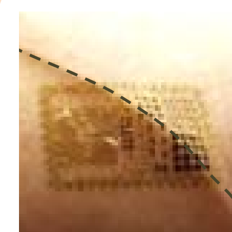
Low cost hybrid integration and assembly

Flexible thin high performance chips

Processors, wireless communication



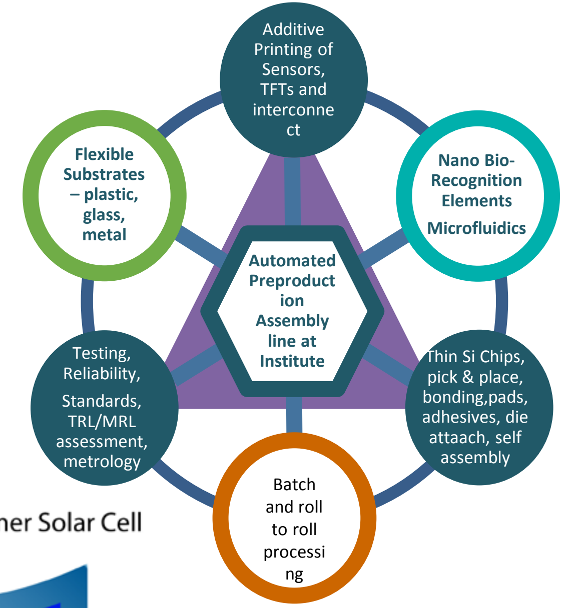




nbmc
Nano-Bio Manufacturing Consortium

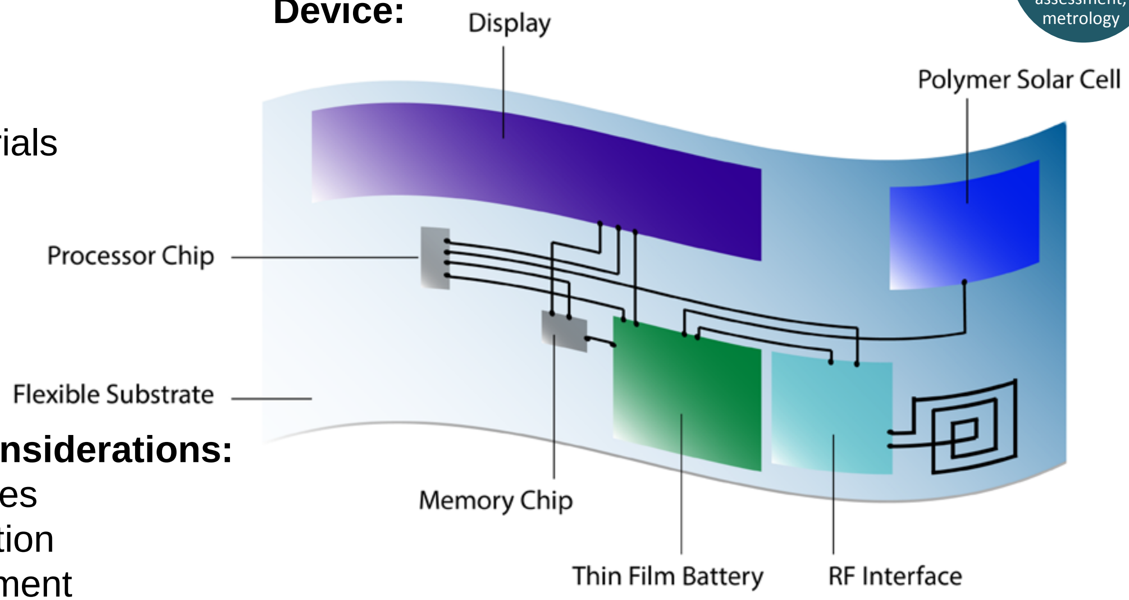
Program Supported By:

FHE Eco-System



Advanced Materials:
Functional Inks
Nanomaterials
Graphene
Adhesives
Encapsulants
Substrate Materials
Bio-recognition Elements

Possible Components of an FHE Device:



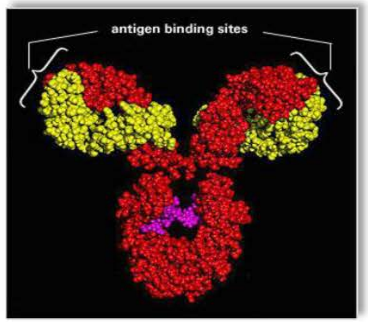
Manufacturing Considerations:
Integration Strategies
Modeling & Simulation
Prototype Development
Moving to Pilot line
Roll-to-Roll Web Processing
Packaging & Pick-Place
New Tools
Material Handling
Test & Reliability

Applications:
Human health Monitorings
Structural Health Monitoring
Wearables
Smart Packaging
Solar/PV
Solidstate Lighting
Smart Sensor Systems

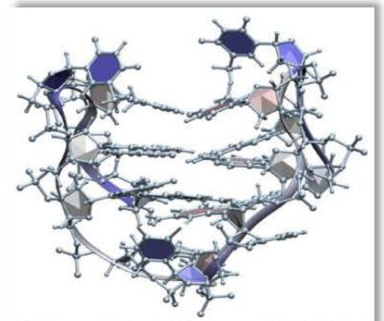
Biological Recognition Elements (BRE)

Needs:
- Sensitivity and selectivity
- Stability (shelf-life)
- Functionalization

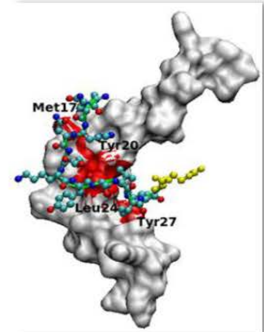
Antibodies

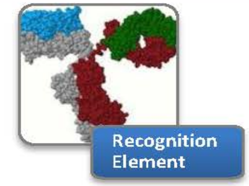


Aptamers

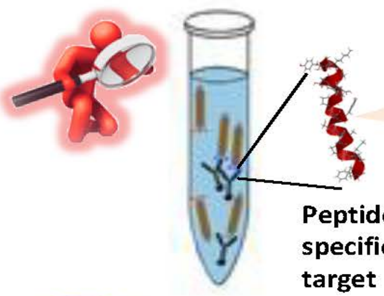

Solution Structure Of A Thrombin Binding Aptamer; J. Mol. Bio. Vol. 235 (1994)

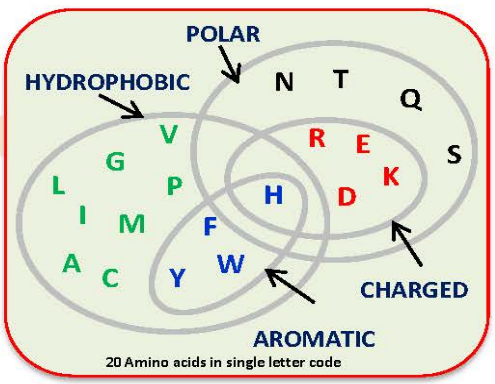
Peptides





Evolved Recognition Elements Using Combinatorial Libraries: Exploiting the chemical diversity of amino acids to identify selective binders!





Materials Specific BREs

SiO_2: MSPHPHPRHHHT
Graphene/CNT: HSSYWYAFNNKT
Au: AYSSGAPPMPPF

Kim *et al.* (2012). *JACS* 133, 14480; Slocik *et al.* (2008) *Small* 4, 548; Naik *et al.* (2002) *Nature Materials* 1, 169-172

Biomarker Specific BREs

NPY: YHPNGMNPYTK
TNFα: NNNKPNPHELHR
Orexin A: DQSNKIISLQRL

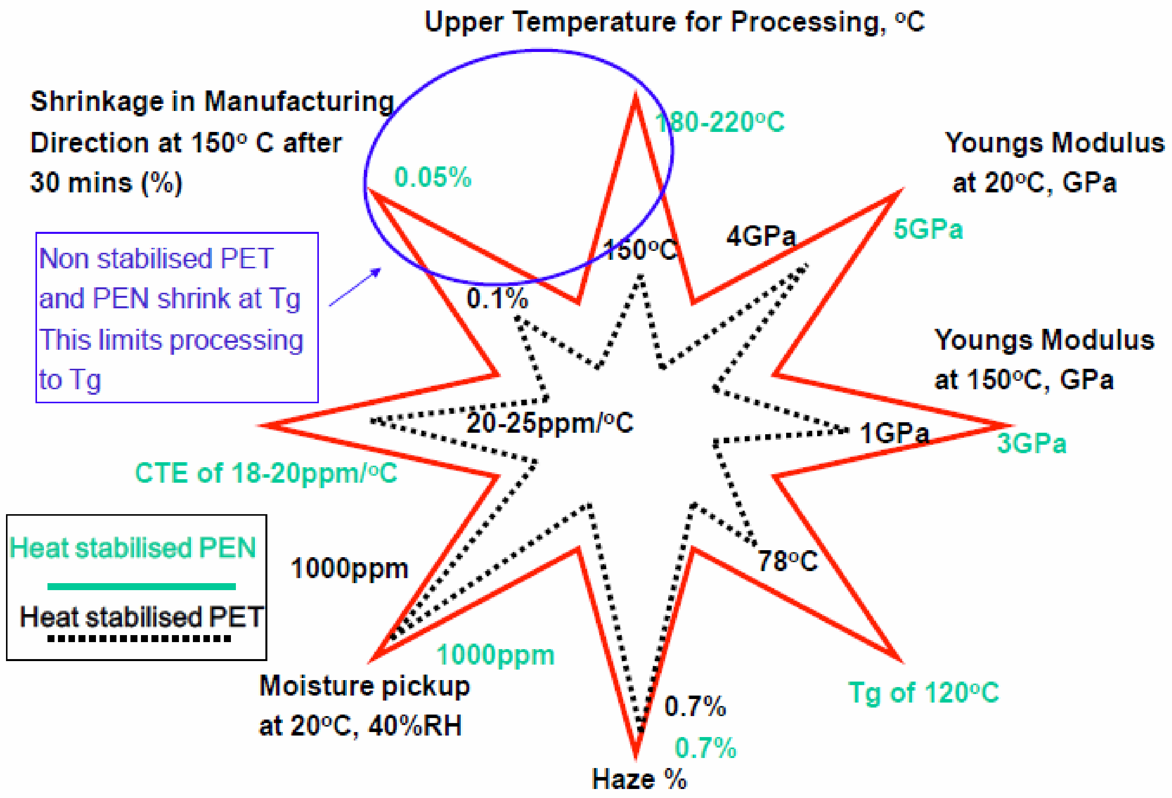
Hagen *et al.* (2012). *ACS Chem. Neurosci.* 4, 444; Naik *et al.* (2012) *Lab Chip*, 12, 562.

Flexible Substrates

- Polymer Substrates
- Glass
  - FlexTech Project with Corning
- Metal
- Ceramics
  - Flextech Project with ENrG
- Stretchable Substrates
- Fibers and Fabrics

- Excellent Clarity
- Low CTE
- Solvent Resistance
- Low moisture pick up
- Mechanical Strength

PET & PEN Properties



Substrates

Application/Substrate Properties			Smoothness	Barrier Properties	Optical Transparency	Dimensional Stability	Thermal Stability	Mechanical Strength/ Flexibility
RFID tag	Antenna		2	3	3	2	2	2
	Circuitry		1	2	3	1	2	2
OLEDs			1	1	DS	1	1	APS
Display Backplanes	Inorganic	Passive	2	3	DS	2	2	APS
		Active	1	2	DS	1	1	APS
	Organic	Active	1	1	DS	1	2	APS
Organic Photovoltaics			2	1	DS	2	1	2
Batteries			3	2	3	2	2	2

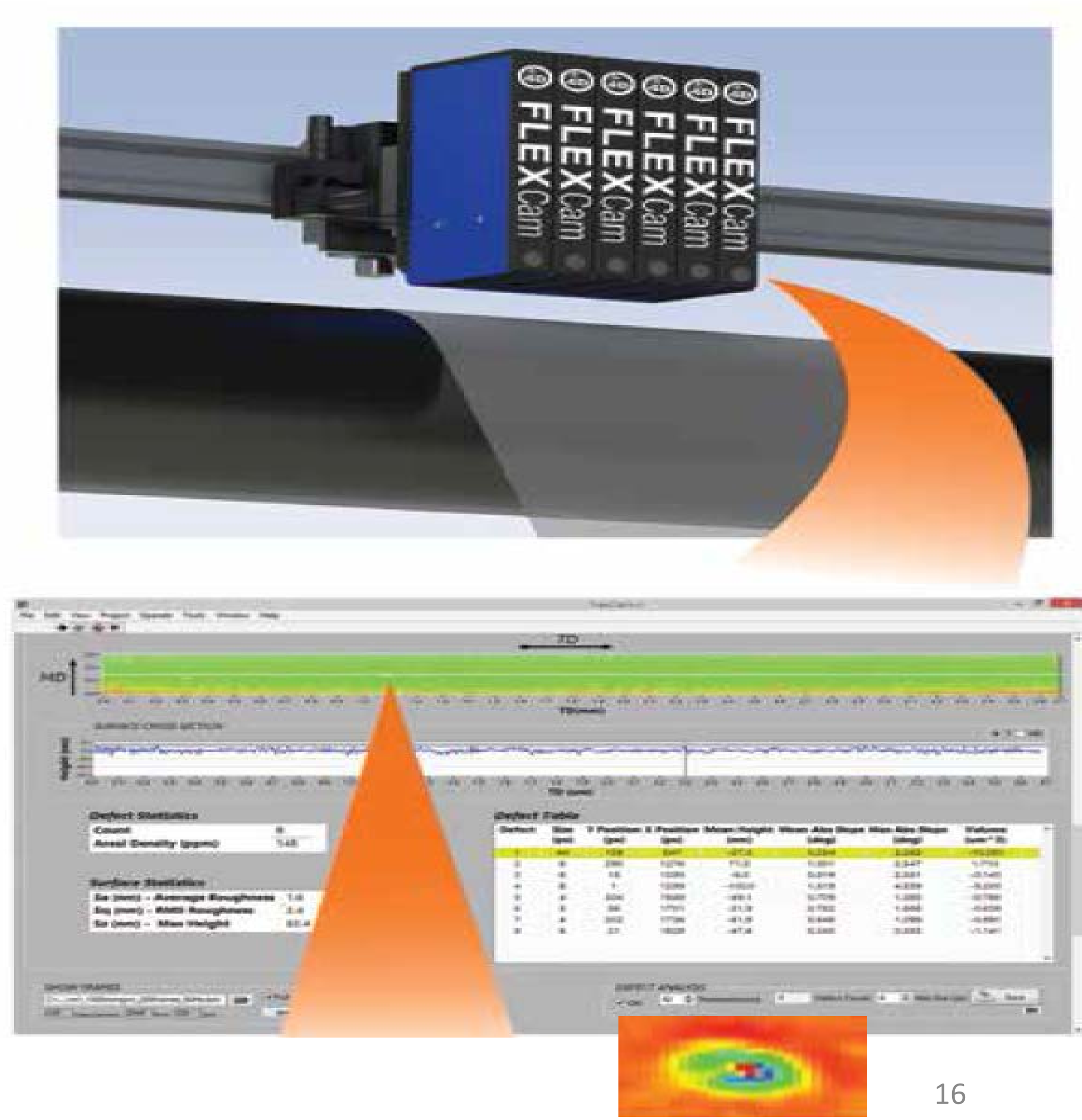
(1 – very important, 2 – medium and 3 – less important, APS – application and product specific and DS – design specific)

Metrology – Substrate roughness and defect measurement

- 4D is a leading developer of vibration-immune 3D metrology solutions
- Vitriflex is a leading developer of high-performance transparent ultrabarrier films for displays & flexible electronics using an R2R process
- In 2012 Vitriflex and 4D Technology partnered to receive a FlexTech Alliance grant to design a 3D metrology module that:
  - Deploys in-line on R2R systems
  - Scales from single sensor to an array for full areal coverage
  - Continually monitors roughness at the nm-level
  - Quantifies heights, slopes, volumes and areas of micron-level defects
  - Handles back-side reflection effects from transparent substrates

4D Technology Project Final Results

- FlexCam enables **real-time monitoring and control of roughness** to less than 0.5nm rms
- FlexCam metrology module released Feb 2015
- Met or exceeded all technical goals



4D's FlexCam Commercial Opportunity

- Strong reception at launch at FLEX 2015
- More than 9 quotations outstanding, including to large OEM customers
- Estimate FlexCam will have sales > 100 units in in 2016, growing rapidly
- Have ID'd follow on product to serve even larger flexible electronics market

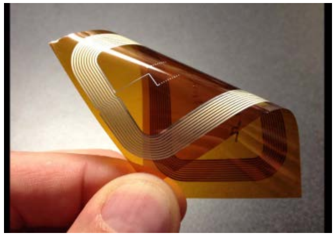
Additive Processes

Plotting
Siimple

- **Graphtec FC2250 Plotter**
- Easy to use & inexpensive
- Vector graphics
- Plots, cuts, creases
- Up to 1000 g force
- 5 µm mechanical resolution
- 25 µm programmable resolution
- 140 µm minimum line width (so far)
- Path planning

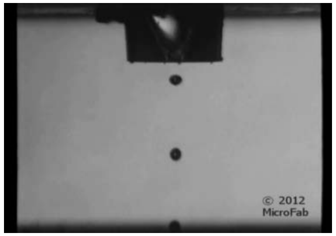
Aerosol Jet Printing
High Resolution

- **Optomec M³D Aerosol Jet Deposition System**
- Expensive
- Great repeatability
- 10 µm to 5 cm line widths
- 0.7 – 5000 cP ink viscosity
- High material loading (vs. Inkjet)
- Inherently clog resistant
- Substrate Heating
- Standoff / working distance of 1 – 5 mm



Inkjet Printing
Rapid

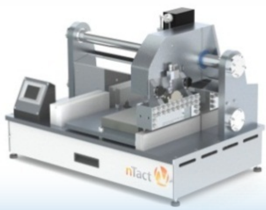
- **Microfab JetLab 4-xlA**
- Piezo based
- Drop-on-Demand
- Single nozzle, 4-head
- Vector graphics
- Low waste
- ~10 µm minimum line width
- < 40 cP ink viscosity
- Ink pH range of 2 – 11
- Heated platen, nozzles



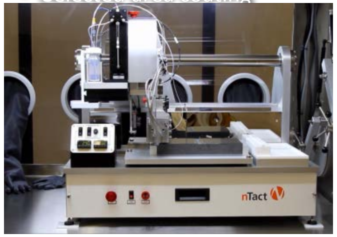
Micro Dispensing
High Viscosity

- **nScrypt 3Dn Series Micro Dispensing Tool**
- Servo-controlled pump
- Volumetric control to 20 pL
- 1 to 1,000,000 cP ink viscosity
- Dynamic flow control
- 3-part ink mixing
- Laser sensor for conformal mapping
- Vector graphics

Slot-Die Coating
Large Area



- **nTact nRad Extrusion Coating System**
- 20 nm to 100 µm Coating Thickness
- Coating uniformity of ± 3% for films over 150 nm, otherwise ± 5%
- 1 to 70 cP viscosity
- Minimum 10 mL of material
- Scalable
- Adjustable lip slot die
- Selected area coating



Properties of R2R Printing Platforms

Property	Screen	Gravure	Flexography	Lithography
Lateral Resolution [µm]	50	15	20	15
Average Dry Ink Film Thickness [µm]	3 – 60	0.8 - 8	0.8 – 2.5	0.5 - 2
Viscosity of Ink [Pa. s]	0.5 – 50	0.05 - 0.2	0.05 - 0.5	30 - 100
Functional Fraction* [wt %]	15 – 25	5 - 20	12 - 20	20
Pigment Particle Size [µm]	0.8 - 2.5	0.1 - 0.5	0.1 - 0.5	0.2 - 0.7
Amount of Material	Medium	High	High	High
Shear Rate	Low	High	Medium - High	Medium - High
Web Speed [ft/min]	300 - 500	1500 - 3000	300 - 1000	500-3000

Properties of R2R Printing Platforms

Property	Ink-jet	Microdispensing	Laser Assisted Forward Transfer	Electrostatic
Lateral Resolution [μm]	50-20	50-20	10	30
Average Layer Thickness [μm]	0.3 - 10	5-100	0.01-1	1-10
Viscosity of Ink [Pa. s]	0.001 - 0.04	0.02-10	N/A	N/A
Functional Fraction* [wt %]	3 - 10	10-60	100%	5-75
Pigment Particle Size [μm]	0.05 - 0.5	0.8 - 75	N/A	0.05-20
Amount of Material	Low	Low		Low
Shear Rate	N/A	N/A	N/A	N/A
Web Speed* [ft/min]	1400	100		50

*Web fed UV curable inkjet

Functional Inks

Conductor
- Metal, organic based
- Sub-micron particulates
- Transparency
- Bulk conductivity > 104 S/m
- Low processing temperature (< 200 °C)

Dielectric
- Polymeric or nano particulate based
- Electrical resistivity > 1014 Ω-cm
- Film thickness < 5 µm
- Permittivity (2-20), low loss
- Transparency
- Semiconductor compatible band gap
- Low processing temperature (< 200 °C)

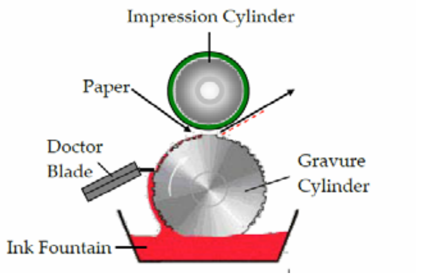
Semiconductor
- Organic, inorganic, organic/inorganic blends
- Electron mobility 100 - 102 cm2/V s
- Transparency
- Low processing temperature (< 200 °C)

Resistive
- Organic, metal, or inorganic
- Resistance (10 - 100K Ω/□)? ?
- ± 10 % Nominal resistance tolerance

Light emitting
- Luminous efficiency (cd/A)
- Radiant efficiency (W/A)
- External quantum efficiency (%)
- Lifetime(T_{50})

Photovoltaic
- Power conversion efficiency (%)
- Open circuit voltage (Voc)
  - Lifetime

Printing



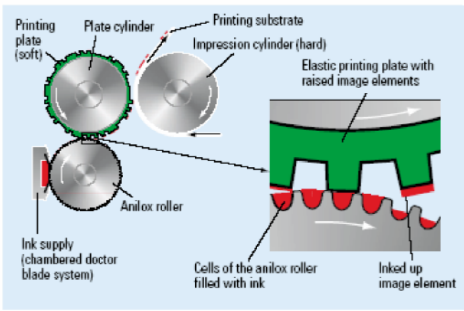
Gravure

• Low viscosity (0.02 - 0.2 Pa.s) for adequate flow in and out of engraved cells

• Short inking path and quick transfer – highly volatile solvents – rapid release of solvent

• Good lubricity, low abrasion and low corrosivity to enhance doctor blade and cylinder life

• Printed films dried mostly by evaporation, some absorption (substrate), UV curing for specialty applications



Flexography

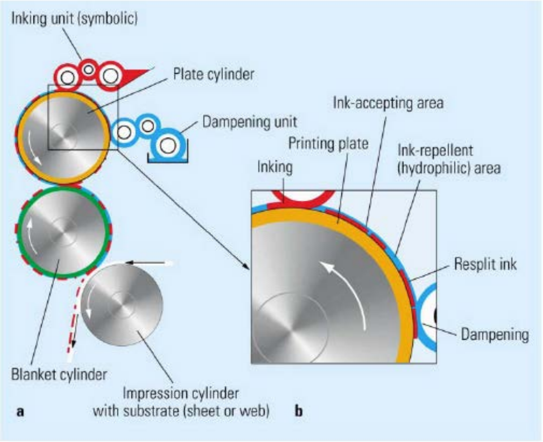
• Wider viscosity processing range than gravure (0.05 - 0.5 Pa.s)

• Solvent selection limited by flexo plate compatibility – photopolymer plates typically not compatible with aromatic and aliphatic hydrocarbons, ketones and some esters

• Good re-solubility and adequate evaporation rate of ink to avoid 'halo' effect (excessive ink build-up on the edges of raised image areas on plate) and thus lower printed feature definition

• Drying by evaporation, absorption or radiation curing (UV, EB) – water based and UV-curable inks are common for flexography

Printing



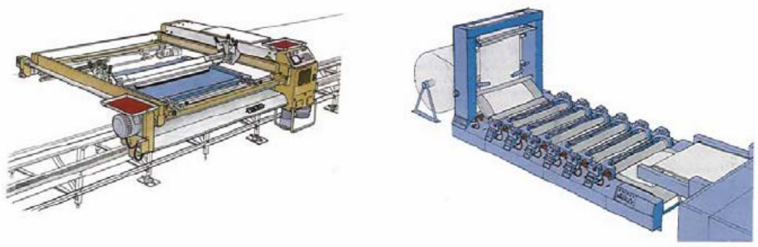
Offset (Lithography)

- Paste-like and tacky inks (viscosity 30 - 100 Pa.s)
- Long inking path – use of non-volatile solvents and oils
- Elastomers used for inking rollers and blankets prevent use of strong solvent that could soften and swell the elastomers
- Limited choice of binder chemistries (only soluble in weak solvents)
- Emulsification of fountain solution into the ink (not an issue with water-less offset)
- Drying by absorption, oxidation or chemical drying, some applications use UV-curable inks

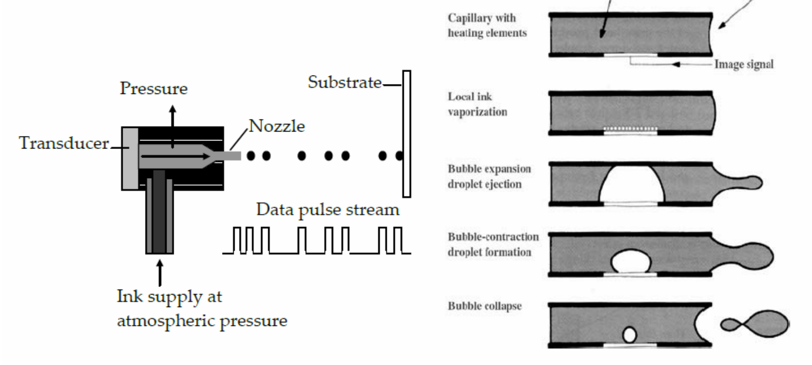
Screen

- Intermediate viscosity (0.5 - 50 Pa.s) - ink should flow easily through the mesh, then level fast to eliminate mesh markings and rapidly recover the structure to maintain definition and prevent slumping or a slurred print
- Ink solvents should not swell or crack free squeegee rubber or the stencil film
- Drying by evaporation, oxidation or UV curing

(Left) Flat bed screen printing, (Right) Rotary screen printing unit.



Printing



DOD Inkjet

• Very low viscosity inks, preferably Newtonian fluids, (viscosity = 0.001 - 0.04 Pa.s for thermal and piezo, higher viscosities possible for electrostatic inkjet) with surface tension optimally in the range 28 - 35 mN/cm for proper formation and maintenance of discrete droplets

• Dispersion stability and small size of functional particles or colloids required to avoid nozzle clogging

• Controlled drop formation by concentration and molecular weight of polymers

• Use of less volatile solvents and solvent mixtures to avoid drying at the nozzle ultimately leading to clogging

• Coffee-ring effect is often seen with inkjet - use the mixture of low and high boiling point solvents and controlling drying temperature

• Printed film is typically dried by absorption or evaporation - UV-curable inkjet inks are also very common

Aerosol Jet

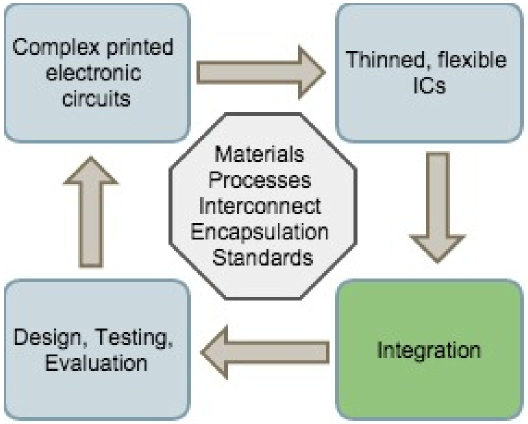
• Maskless, low temperature nanomaterial additive process

• The resulting electronics can have line widths and patterned features between 10 um and 100 um

• Capable of handling materials with a viscosity of 0.7 to 30 cp (ultrasonic atomizer) and materials with a viscosity of 1 to 2500 cp (pneumatic atomizer)

Integration

- Thin Si ICs
- Die attach
  - Pick and place
  - Laser-assisted
  - Self-assembly
  - Electrostatic printing
- Interconnect
- Testing



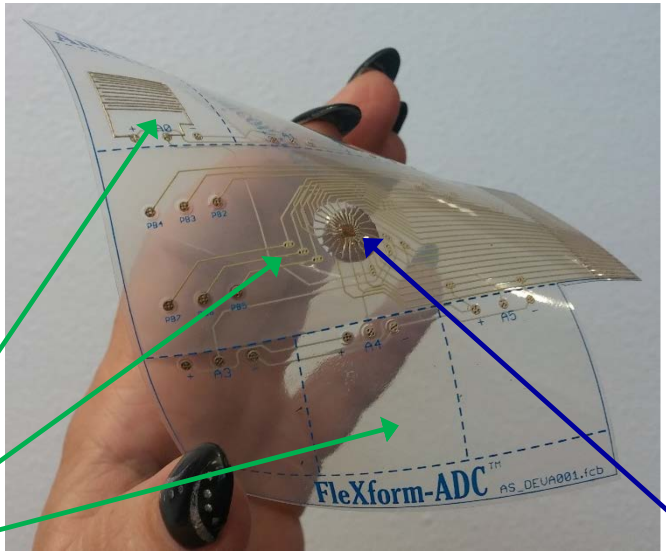
Integration of Thin Si Chips on Flexible Substrate

Flexible Hybrid System

"Combination of flexible printed materials and flexible silicon-based ICs to create a new class of flexible electronics."

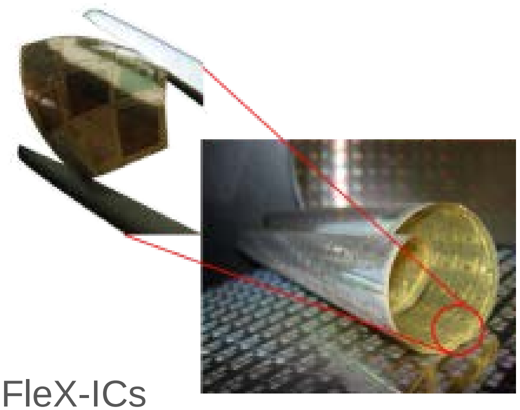
Printed Electronics

Low Cost, R2R, Large Format



Flexible ***FleX***-ICs

High Performance, High Density



Printed Electronics

- Sensors
- Interconnects
- Substrates
- Displays

- Low Cost, Large Format
- Roll-To-Roll, Screen, Inkjet Print, …

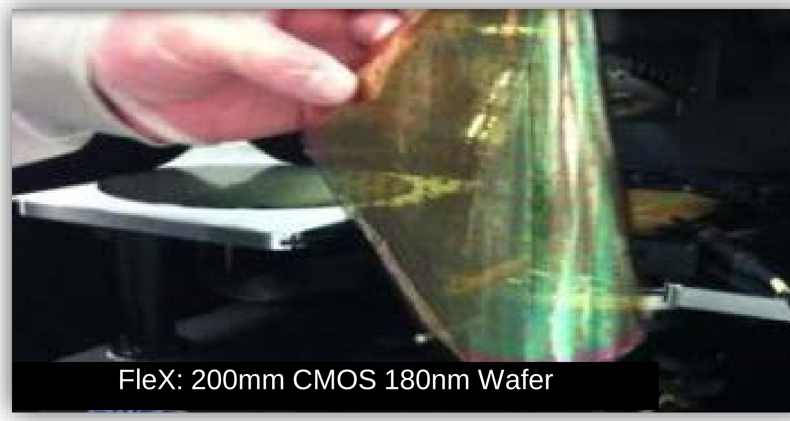
FleX-ICs

- Sensor Signal Processing
- Data Processing
- Data Storage
- Communications

- Low Cost, High Performance
- Compatible with Printed Electronics
- Foundry CMOS + FleX Processing

FleX™ Commercial Silicon-on-Polymer Process

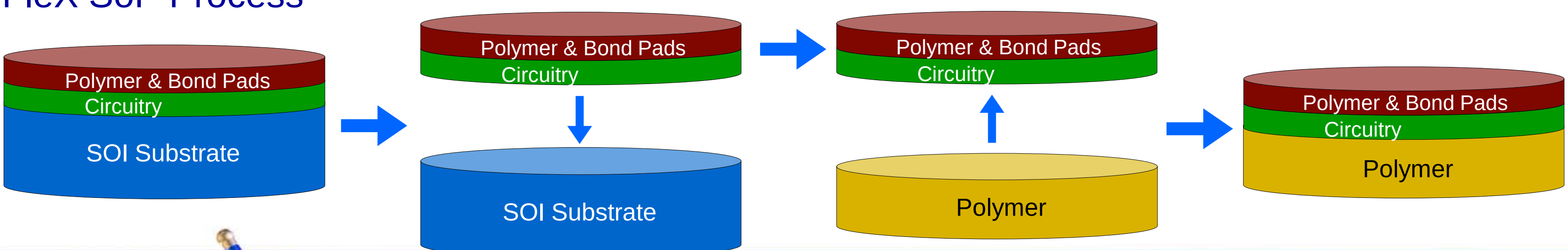
Silicon-on-Polymer (SoP) is a Thin Device technology developed by American Semiconductor to convert single crystalline foundry wafers into flexible thin devices.



FleX CMOS

- Technology TowerJazz CS18/13 PD-SOI CMOS
- Interconnect 4-level Aluminum
- Flexibility FleX Silicon-on-Polymer
- Devices ADC, MCU, RFIC, ASIC

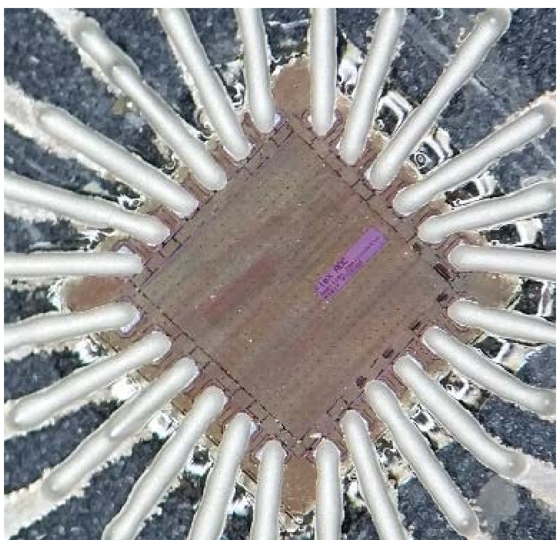
FleX SoP Process

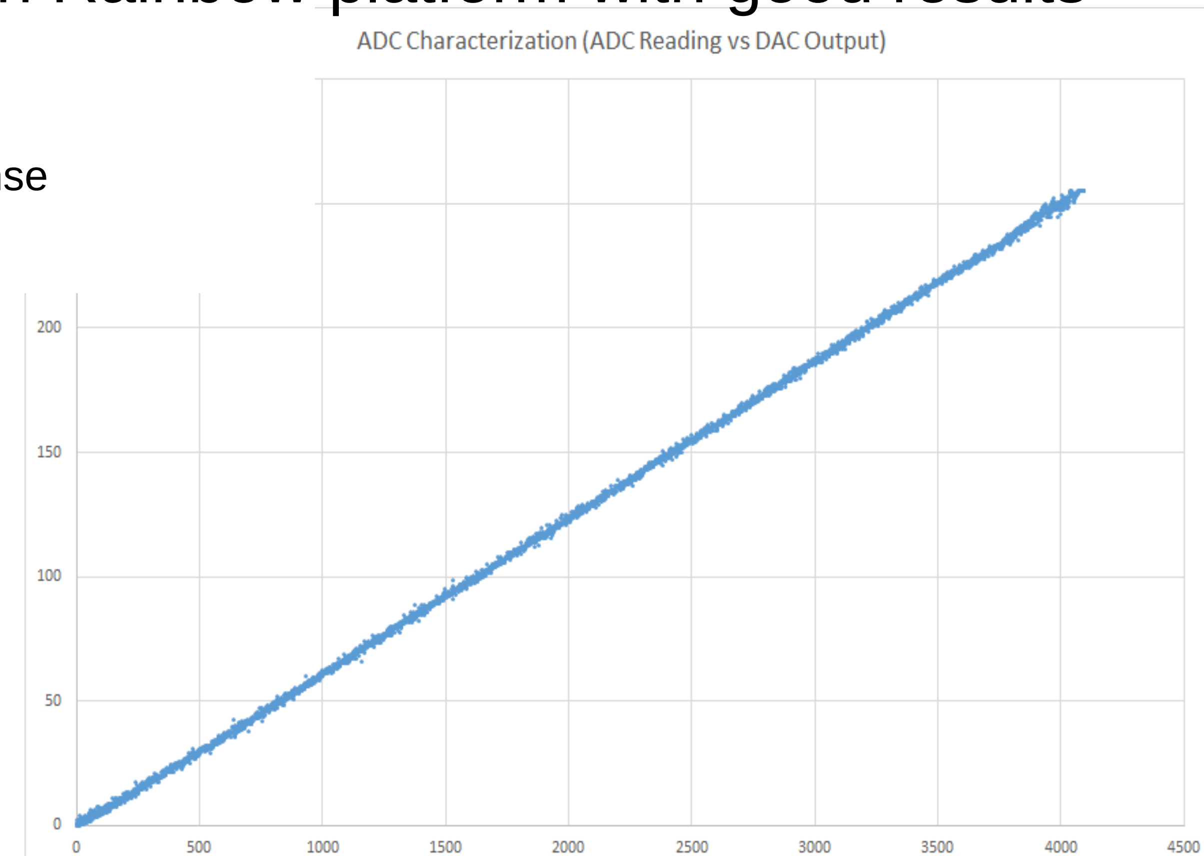


FleX-ADC Characterization

- FleX-ADC shows good characterization response with no change from traditionally packaged parts to FleX-IC format

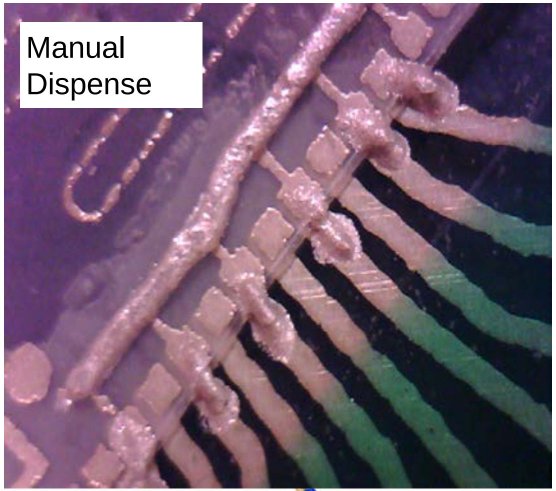
- FleX-ADC tested on Rainbow platform with good results
- Current revision
  - Improved bond pad ESD
  - Improved linearity response
  - Available Now

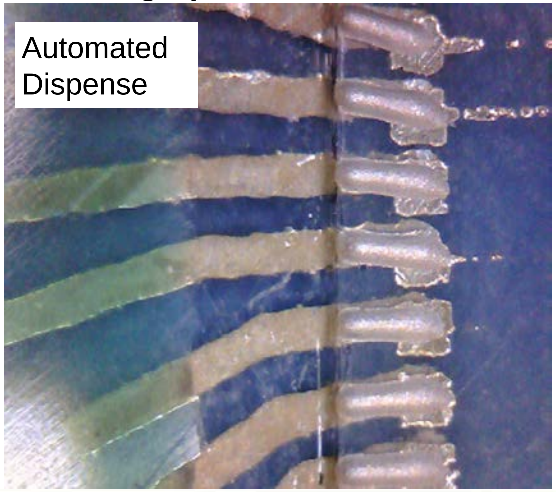




FleX-IC Integration: Attach & Interconnect

- Development of die singulation for volume manufacturing
  - Mechanical cutting
  - Standard die saw
  - Laser cutting
- Development of die interconnect for volume manufacturing
  - Physical flexibility after cure
  - Electrical conductivity versus bulk silver
  - Printability: pitch capability, z-height requirements, thermal budget
  - Manufacturability: throughput, total COO

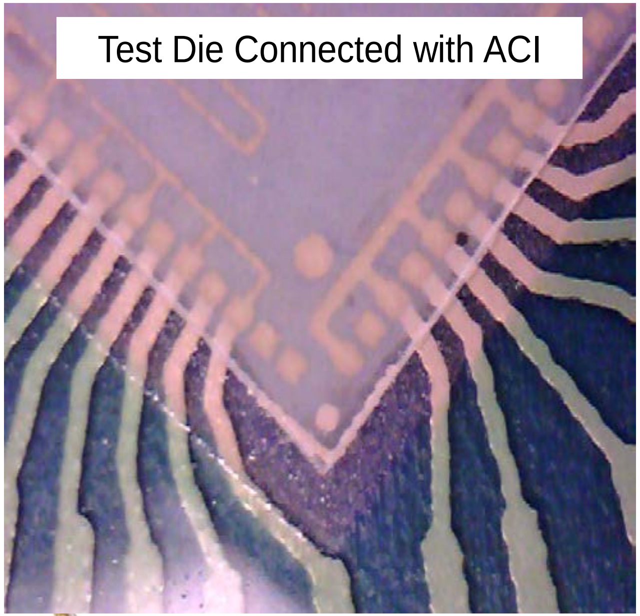


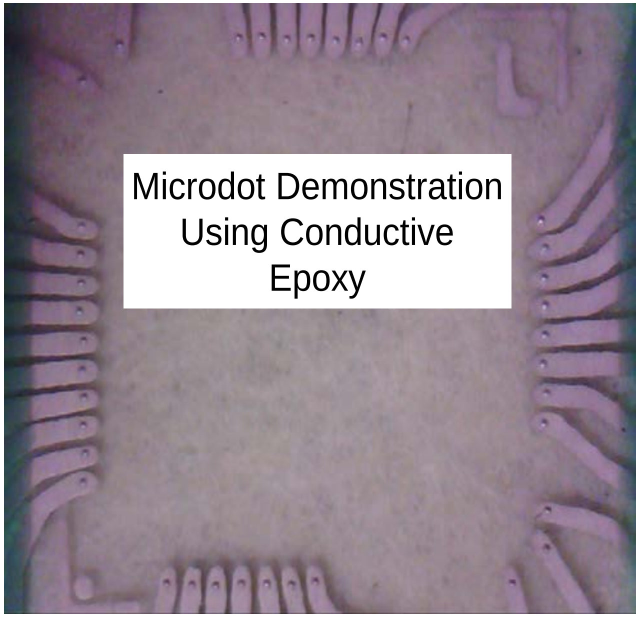


FleX-IC Integration: Attach & Interconnect

Development of Alternative Interconnect Materials and Methods

- Evaluation of anisotropic (z-axis) conductive adhesive materials
- Show good results using AS_MEC001 test die





Program Supported By:

FleX-IC Integration: Attach & Overcoat

FHS Die Attach and Physical Protection

- Evaluation ongoing for die attach materials.
  - Thin
  - Physically Flexible
  - PET compatible
- Evaluation ongoing for die overcoat materials.
  - PET compatible, UV cure, low water absorption, scratch protection
  - Flexibility characteristics after cure
  - Electrical isolation of interconnect traces
  - Mechanical robustness
- Existing overcoats meet most of the requirements. Materials evaluations continue for improved overcoat
- Evaluation ongoing for mechanical (ZIF) connectors
  - Printed metals lack robustness for repeated connections

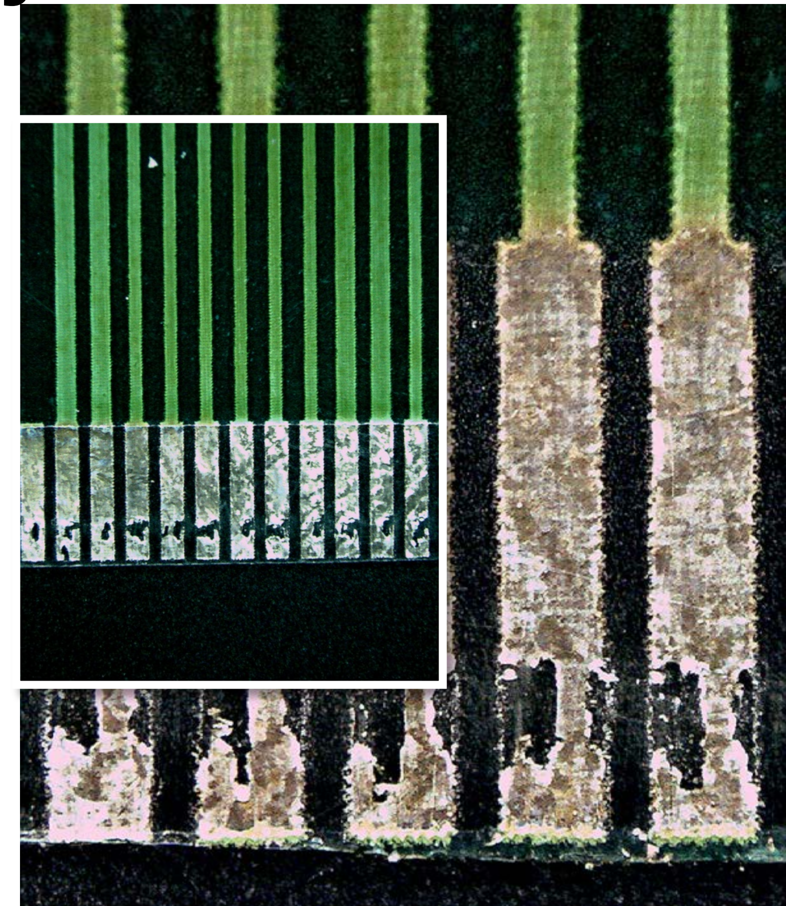
Flexible Hybrid System Reliability

Dev Kit FHS Qualification Test

- Sequence of 8 tests

Test #	Location	Test Description	Reps
1	ESD station	in/out of esd package	5
2	ESD station	mandrel 40mm bend both XY axis	5
3	ESD station	5" edge drop onto table	5
4	ESD station	shorting all zif pins together w/ conductor	2
5	no ESD	in/out of esd package	5
6	no ESD	mandrel 40mm bend both axis	5
7	no ESD	5" edge drop onto table	5
8	no ESD	shorting all zif pins together w/ conductor	2

- Initial Observations
  - ZIF connectors: Insert in/out failure at 30x
  - ZIF fcb, Nanoparticle flaking during use
  - ZIF pcb, Cracked housing
  - fcb can be trimmed to recover
- Edge drop
  - 5” drop to table, no failures
- ESD
  - Use at non-ESD station did not lead to failure of kit (Not recommended)

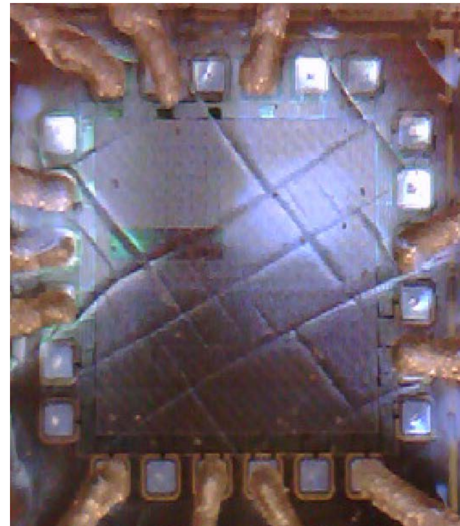


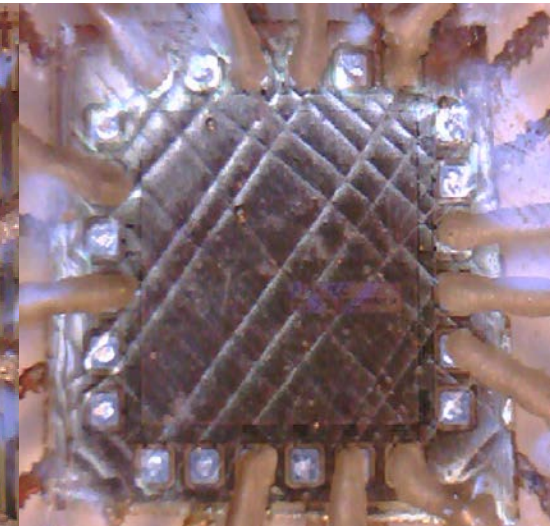
Printed fcb nanoparticle ZIF connector after testing

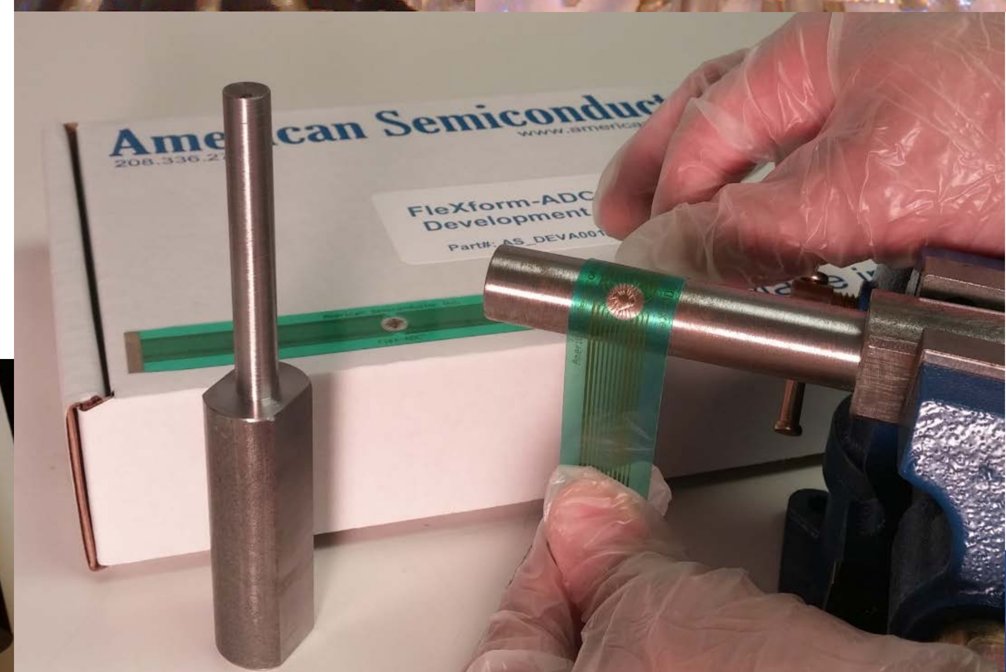
Flexible Hybrid System Reliability

Rcurve - radius of curvature test

- Static x/y orientation flexibility test
- Rainbow test coupon
- Mandrel radius sizes (mm): 5, 6, 7, 8, 10, 12, 15, 20, 25, 30, 40
- Test: bend rainbow strip sample around mandrel on two orthogonal axes, decrease radius until mechanical/electrical failure occurs
- Failure analysis – determine component or material(s) causing failure
- Update and execute new process matrix from mandrel results
- Rcurve testing part of all ASI FleX development







Rcurve Test Mandrels

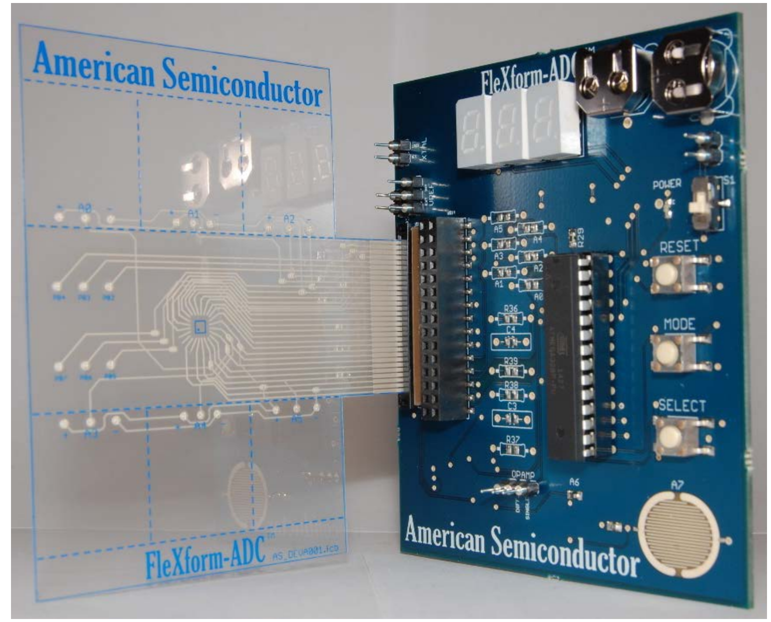
FleXform-ADC™ Development Kit

FleXform-ADC Kits provide:

- "Out-of-the-box" proof of FHE feasibility
- User printable FHE with on-board FleX-ADC™
- Integration Board and Software
- Enables printed device demonstrations
- Fully supported by ASI flexible technology integration team for design and manufacturing

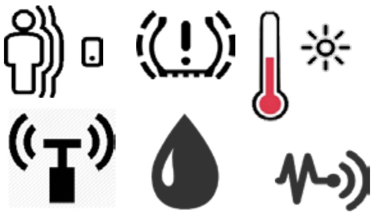
FleXform-ADC Kit contents:

- Quick Start Guide
- FleXform-ADC printed circuit board (PCB)
- Two button cell batteries
- One 8.5" X 5.5" flexible circuit board sheet with two instances of the FleXform-ADC flexible circuit board (FCB)
- Additional documentation, videos and software development tools are available for download



FHE Integration with FleX-IC Chipset

Sensors

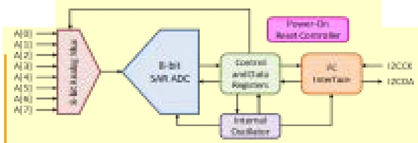


Sensors are Numerous

- Printed
- Flexible
- Physical
  - Temperature
  - Pressure
  - Humidity
- Physiological / Biological
- Electrical
  - Voltage
  - Current
  - Resistance

Signal Processing

FleX-ADC™



Product Overview

- 8-bit ADC
- 2.5V
- Flexible and conformal

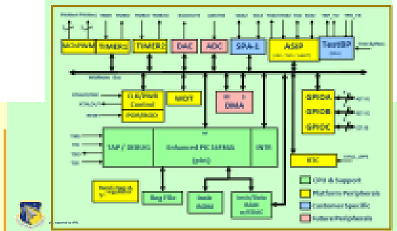
Product Features

- 8-bit Successive Approximation ADC
- 8 input, 100k s/s
- Single and continuous
- 2-wire I²C communication

Available Now

Data Processing

FleX-MCU™



Product Overview

- 8-bit Microcontroller
- Low Power

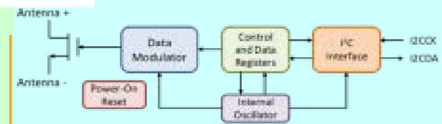
Product Features

- RISC microcontroller
- ROM and SRAM
- UART, I2C and SPI comm.
- Multiple programmable timers
- Multiple GPIO ports for sensor data collection

Available in 2015

Comm

FleX-RFIC™



Product Overview

- IP-X™ TTO protocol
- Programmable via 2-wire I²C interface
- 860-960MHz (UHF)
- 64-bit unique identification (UID) including 16-bit CRC
- 0.1m–10m read range
- 64kpbs or 256kpbs
- Anti-collision protocol

Available in 2015

Flexible Hybrid Electronics Status and Activity

Collaborators

Cooperative efforts are used to accelerate commercialization

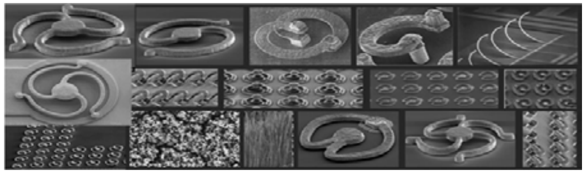
- FHE development
- nbmc Electronics platform
- sōligie Printed Electronics by molex — Scatterable media
- ASU FleXform evaluation
- BOEING FleX integration
- brewer science Sensor demo
- NORTHWEST NAZARENE UNIVERSITY RockSat (NASA)

Current Activities

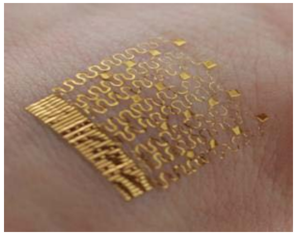
- **FleXform-ADC™** Dev Kit Product Launch
- FHE-MII Proposal Participation
- Customer product development
- New Boise FHE facility
- Internal R&D

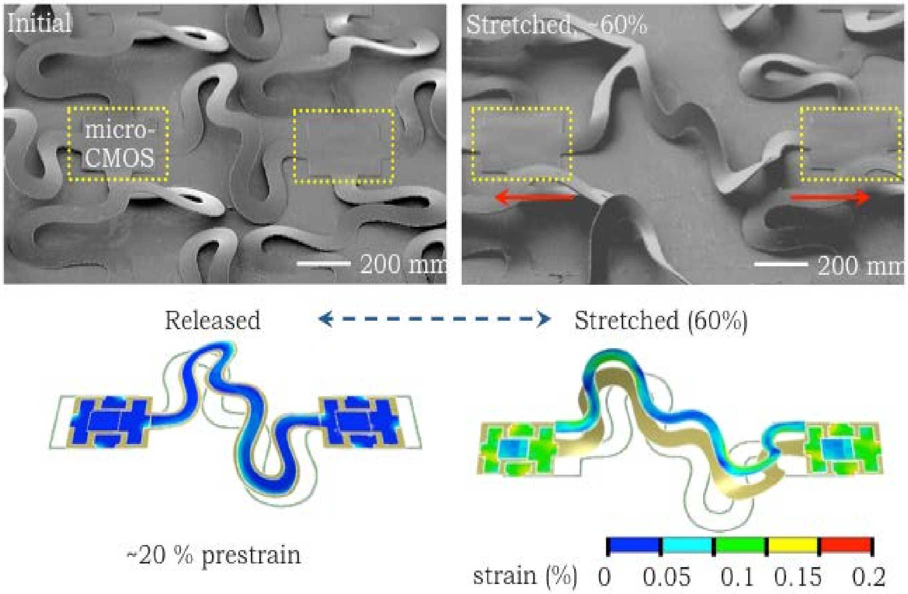
3M PAKSENSE FlexTech Alliance for Displays & Flexible, Printed Electronics GE Global Research U.S. DEPARTMENT OF ENERGY NASA University of Idaho Northeastern University

Advanced Novel Packaging

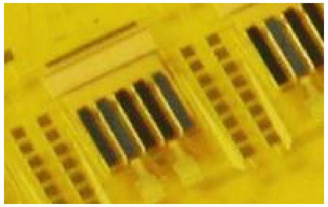


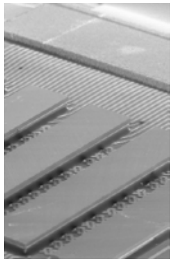
Compliant Interconnects



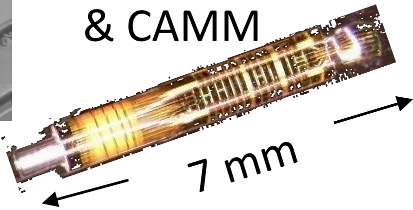


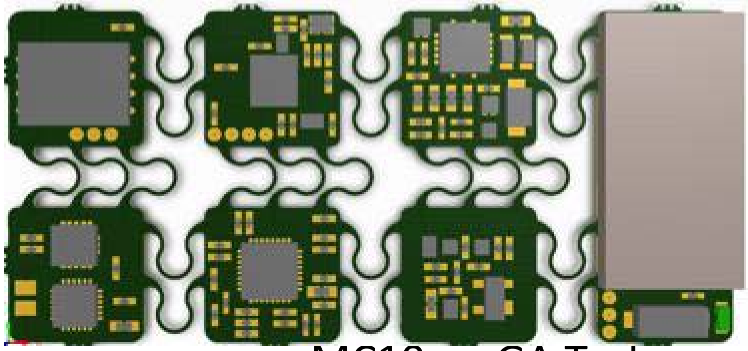
Intravascular Ultrasound (IVUS) is a catheter-based system that allows physicians to acquire images of diseased vessels from inside the artery.





Endicott Interconnect & CAMM

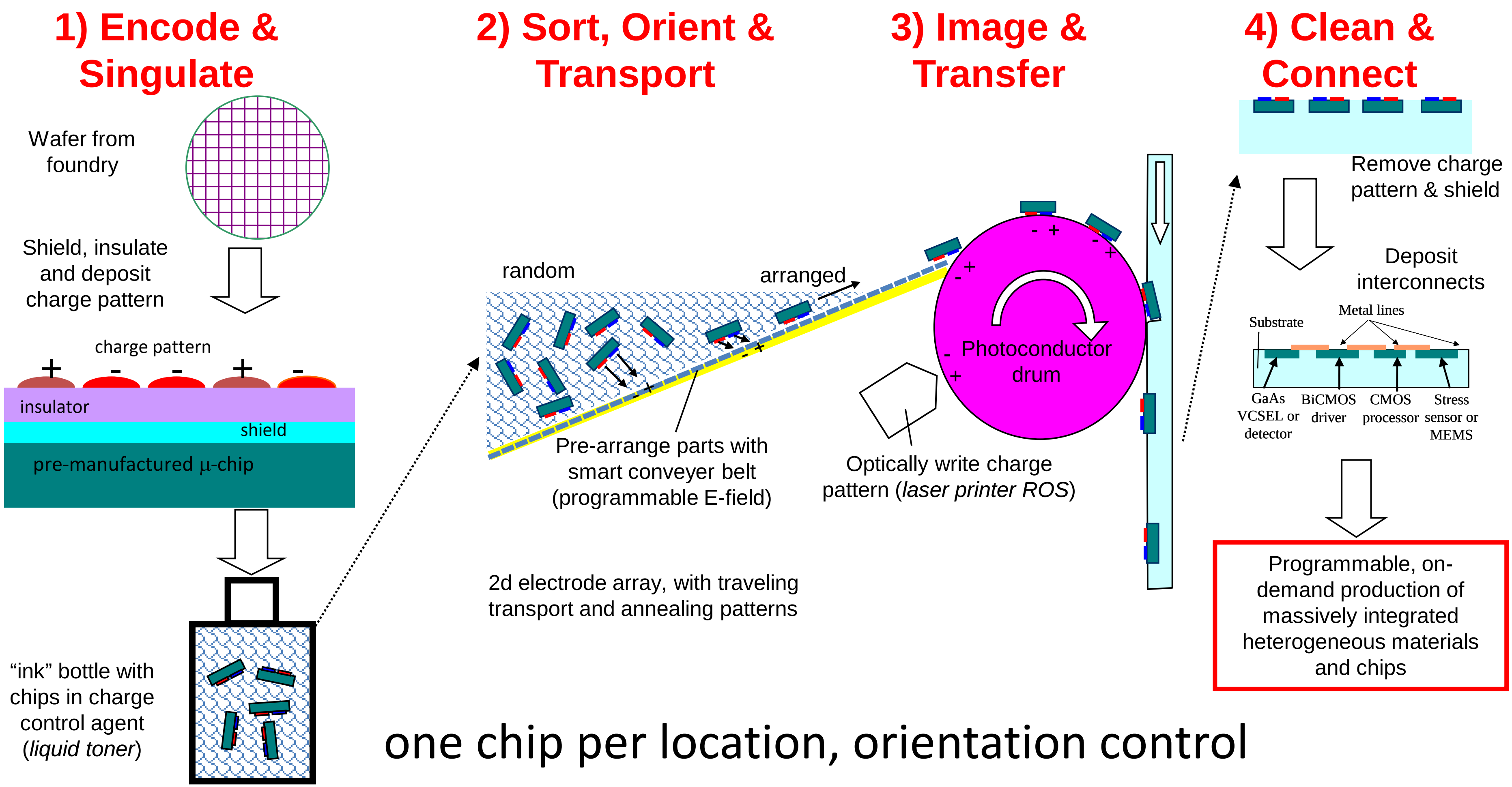




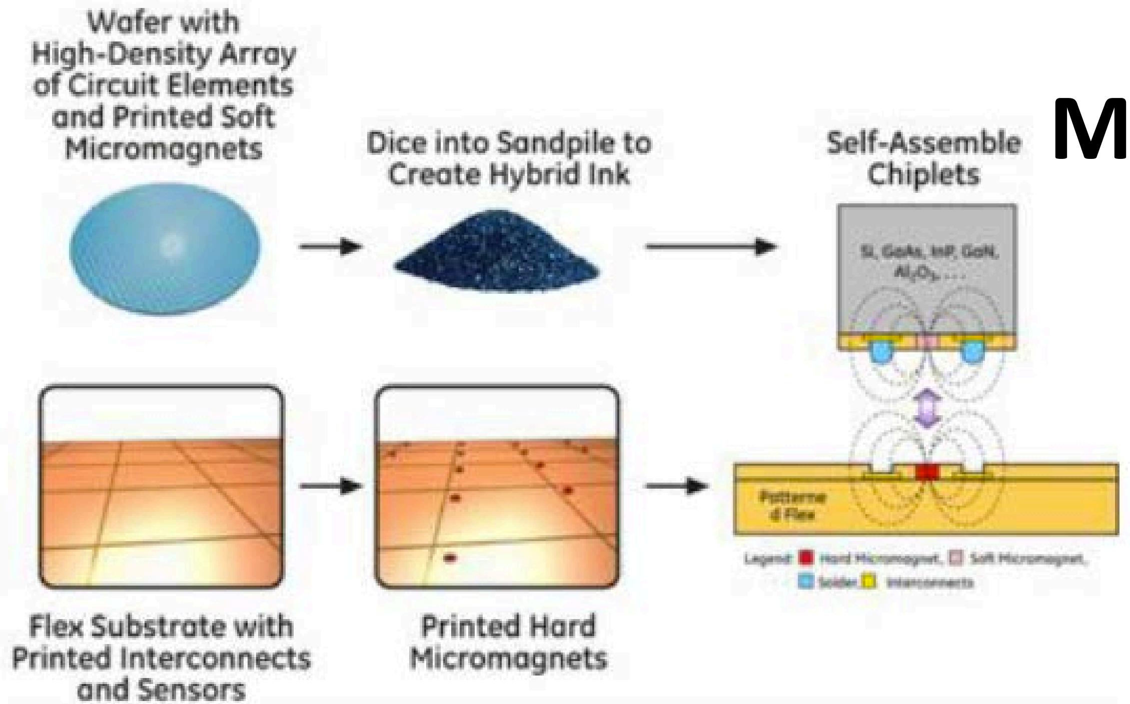
MC10 GA Tech

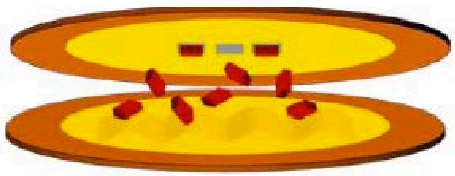
Digital Fluidic Microassembly

Use dynamic electric fields to transport, orient, and fix chips

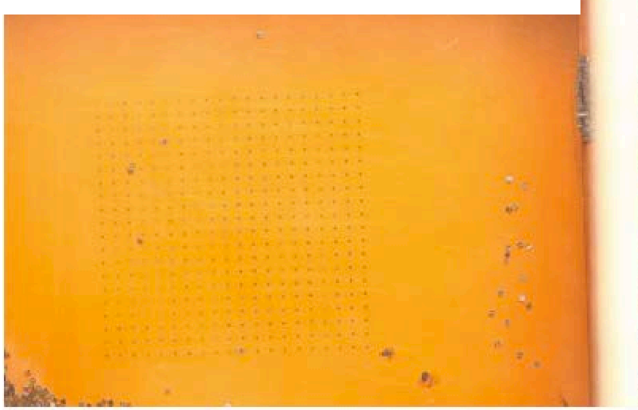


Magnetically Directed Assembly

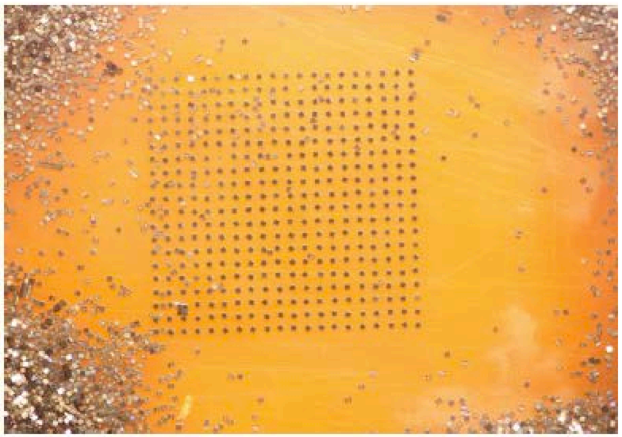




GE

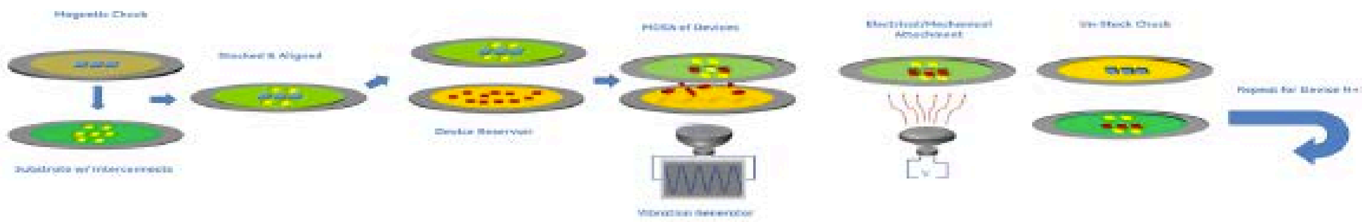


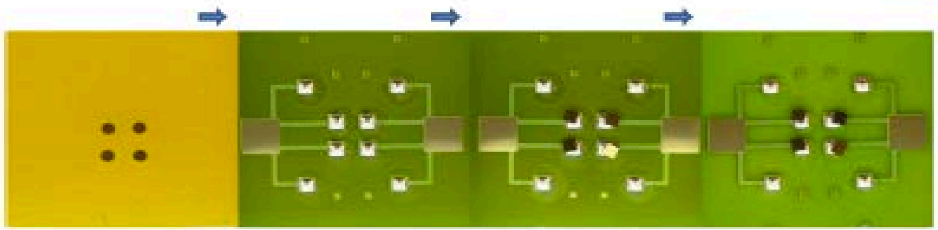
Unpopulated Substrate



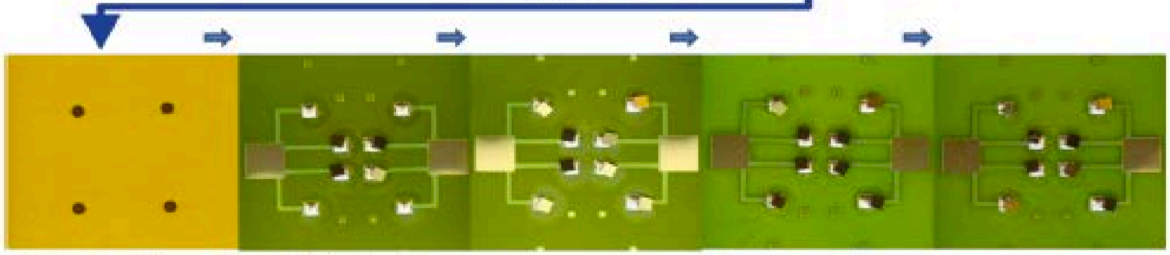
After Attraction

Magnetically Directed Self-Assembly: Process Flow

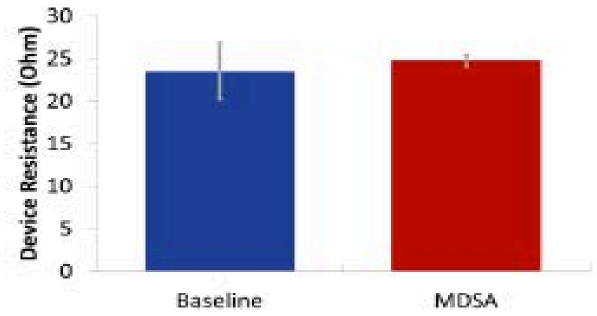




Chuck #1 | Add Substrate | MDSA #1 & Reflow | Remove Chuck

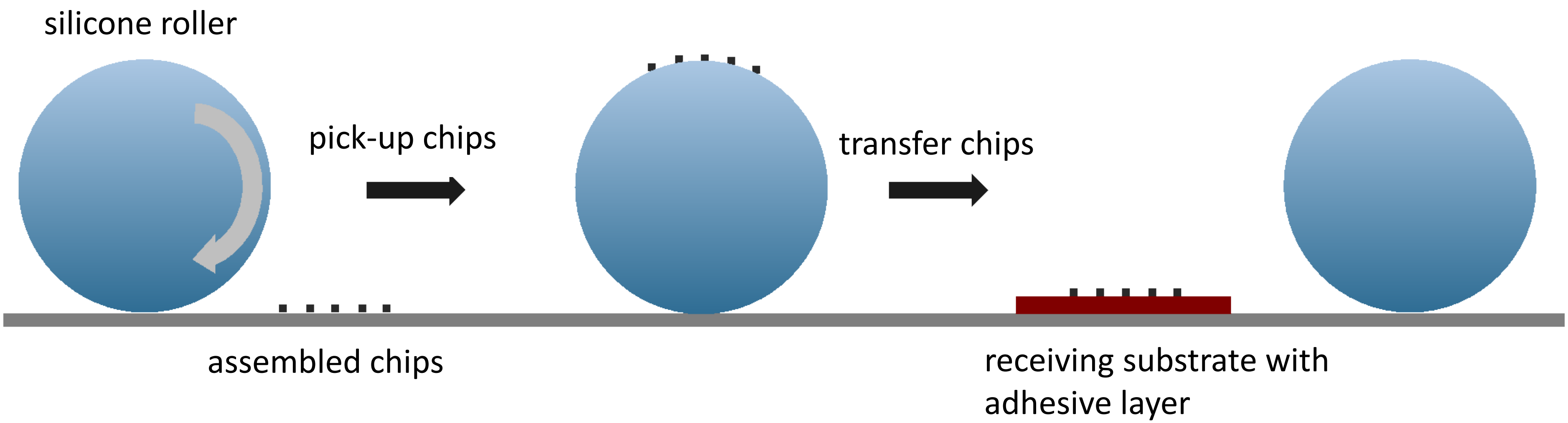


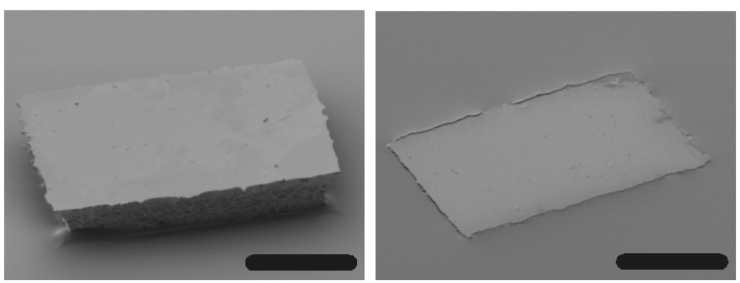
Chuck #2 | Add Substrate | Remove Chuck



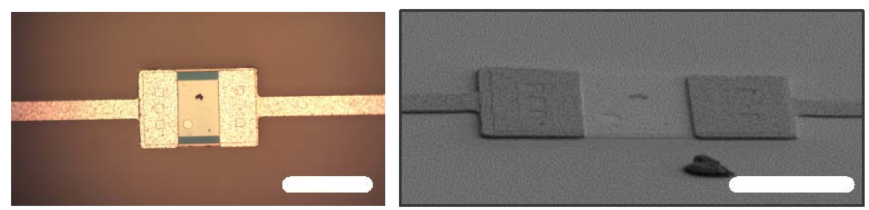
Hybrid integration and full electrical connection of semiconductor devices on flexible substrate using magnetically directed assembly is shown.

Transfer & Wiring

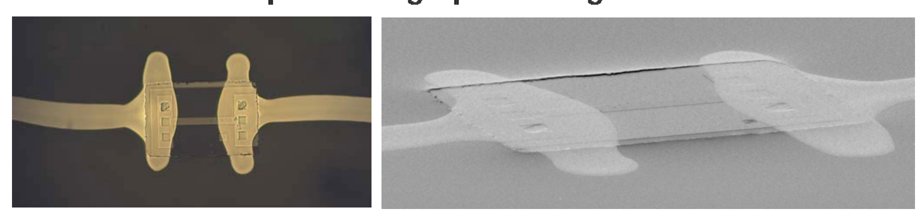




chip on surface embedded



photolithography



ink-jet printing

Conclusions

- An extensive Flexible Electronics Eco-system exists
- Eco-system will continue to grow rapidly with the explotion of applications
- The most significant technical challenges are the interfaces and integration of the technologies