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Advances in Flexible Hybrid Electronics Reliability

LOPEC
Smart & Hybrid Systems
Munich 3/29/17

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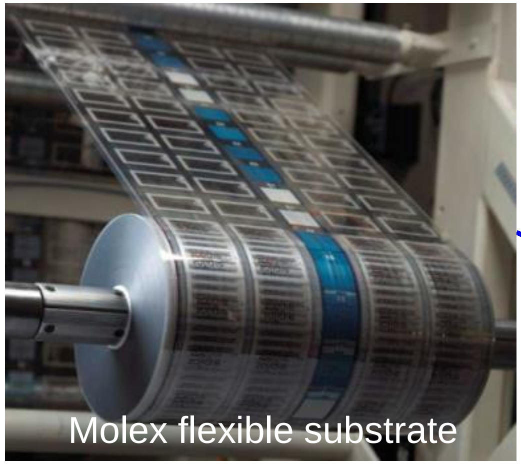
What are Flexible Hybrid Electronics?

Printed Electronics

Low Cost, R2R, Large Format



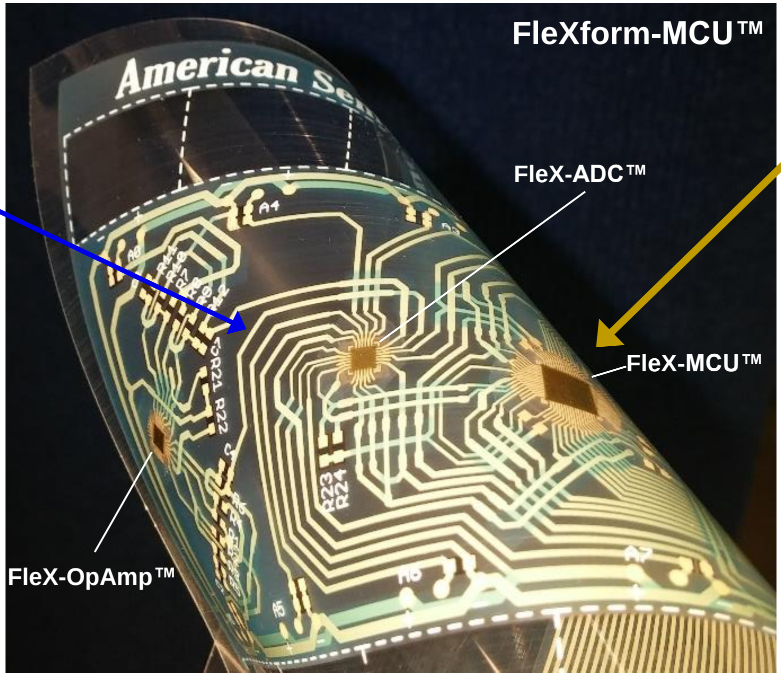
Printed Electronics

- Sensors
- Interconnects
- Substrates
- Displays

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

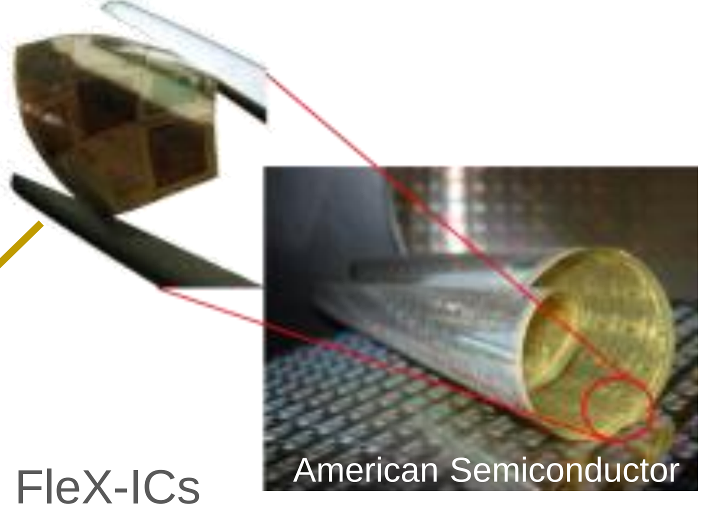
Flexible Hybrid System

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



Flexible *FleX*-ICs

High Performance, High Density



FleX-ICs

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

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

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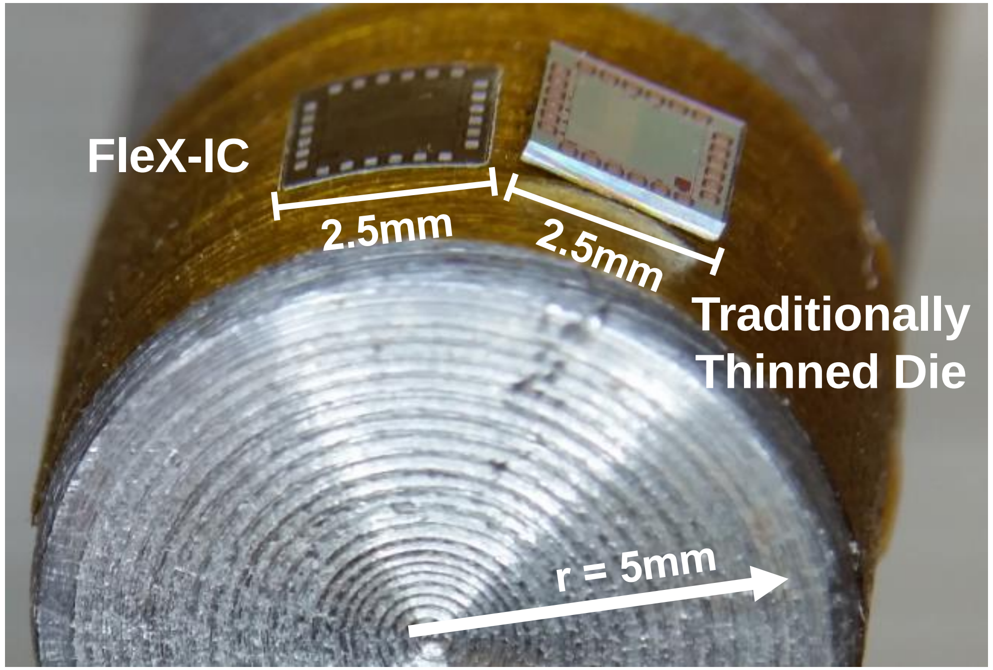
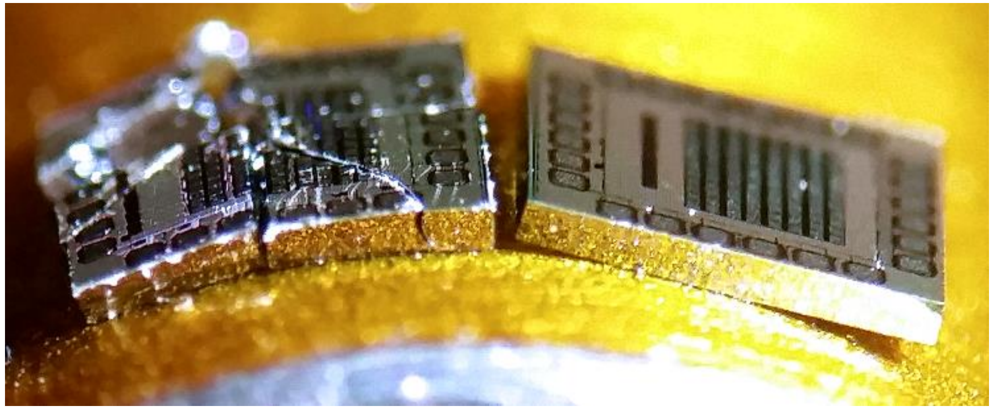
Why Flexible Hybrid Electronics?

- New Applications
  - Internet of Things (IoT)
  - Wearables
  - Structural

- New Requirements
  - Conformal
  - Dynamically Flexible
  - Ultra thin
  - Ultra light weight

- Improved Reliability
  - No Die Cracking
  - Reduced Breakage of Interconnects

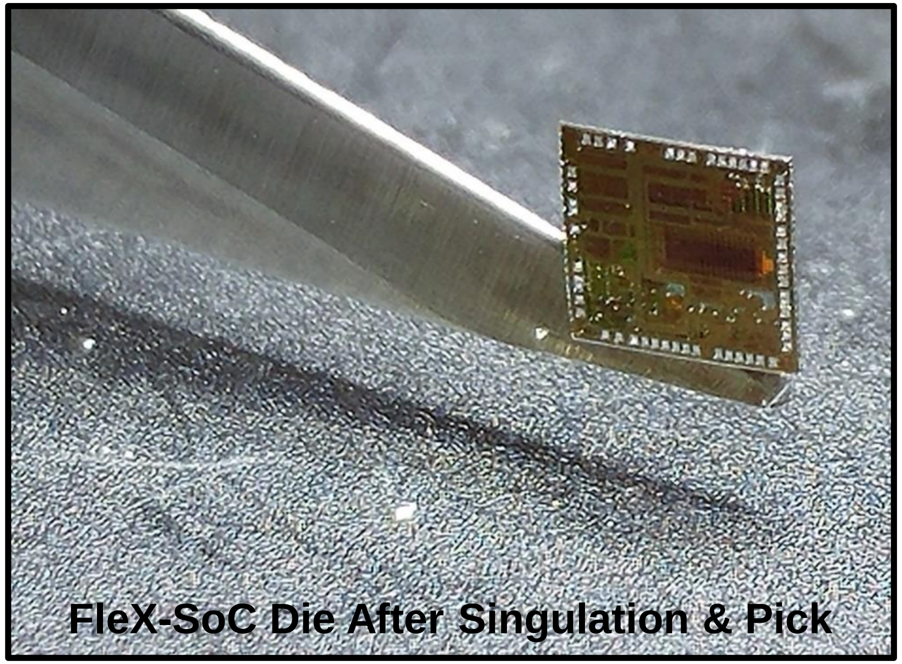




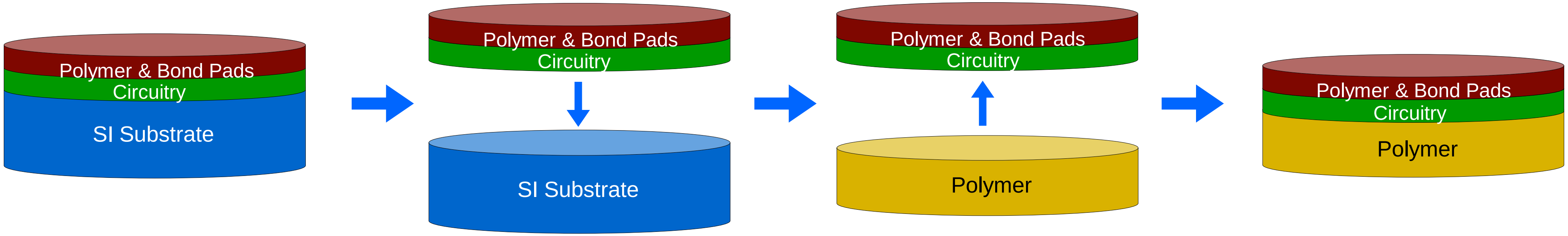
Traditionally Thinned Die at 5mm Radius

FleX™ Silicon-on-Polymer™ Wafer Conversion

- First high-volume major semiconductor IC available as a FleX SoP thin device
- 200mm (8”) wafers converted to ultra-thin form factor
- 130nm CMOS
- 4 metal layers
- 2.2 mm X 2.3 mm, 2.5mm^2, 5mm^2 die



FleX-SoC Die After Singulation & Pick



Standard CMOS Wafer from any IDM or Foundry

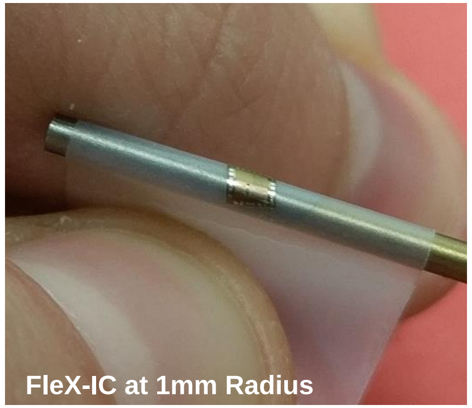
Handle Silicon Removed

Polymer Substrate Applied

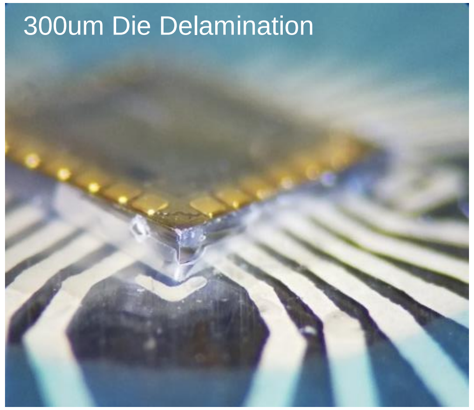
SoP Wafer

Radius of Curvature (RoC) Testing

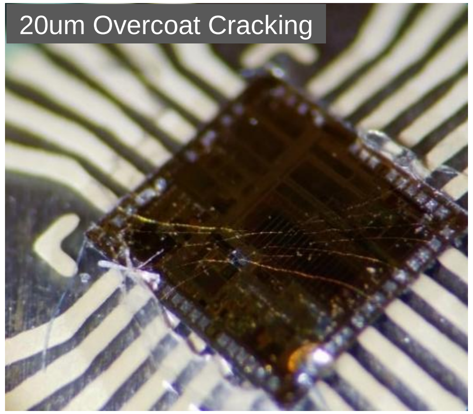
Per ASI Procedure TEST003



FleX-IC at 1mm Radius



300um Die Delamination



20um Overcoat Cracking

- FHE systems are bent around precision mandrels until mechanical and/or electrical failure
- Progressively smaller radii of 40, 30, 25, 20, 15, 12, 10, 8, 7, 6 and 5 mm

Mechanical Test Results

- Mechanical failure observed by microscopic visual inspection
- Failure methods: die delamination from the substrate and die cracking
- Conventional 300um die: RoC is die area dependent
  - Small die may achieve 12mm
  - Large die fail at 30mm
- Conventional 40um die: RoC fails at 12mm for small die
- Conventional 20um die: RoC fails at 12mm for small die
- FleX-IC die: RoC down to 5mm for small die

FleX-IC Radius of Curvature Testing

Orientation	Radius (mm)	LTOL	Heat Neutral	HTOL
Convex (Die Out)	5	PASS	PASS	PASS
	2.5	PASS	PASS	PASS
	1	PASS	PASS	PASS
Concave (Die In)	5	PASS	PASS	PASS
	2.5	PASS	PASS	PASS
	1	PASS	PASS	PASS

	Die Thickness (um)	Die Size (mm)	Sample	RoC Failure (mm)	Failure Mode
No Thinning	725	2.5 x 2.5	1	7	Delamination
			2	8	Delamination
			3	12	Delamination
		5 x 5	1	20	Delamination
			2	20	Delamination
			3	20	Delamination
Traditionally Thinned Die	300	2.5 x 2.5	1	12	Delamination
			2	12	Delamination
			3	12	Delamination
		5 x 5	1	30	Delamination
			2	30	Delamination
			3	30	Delamination
	40	2.2 x 2.2	1	10	Materials Crack
			2	7	Delamination
			3	8	Materials Crack
			1*	8	Delamination
			2*	8	Delamination
			3*	12	Materials Crack
	20	2.2 x 2.2	1	5	Materials Crack
			2	12	Materials Crack
			3	10	Materials Crack
			1*	8	Materials Crack
			2*	7	Materials Crack
			3*	10	Materials Crack
FleX ICs	FleX	2.5 x 2.5	1	5	PASS
			2	5	PASS
			3	5	PASS

FHE Dynamic Reliability Testing

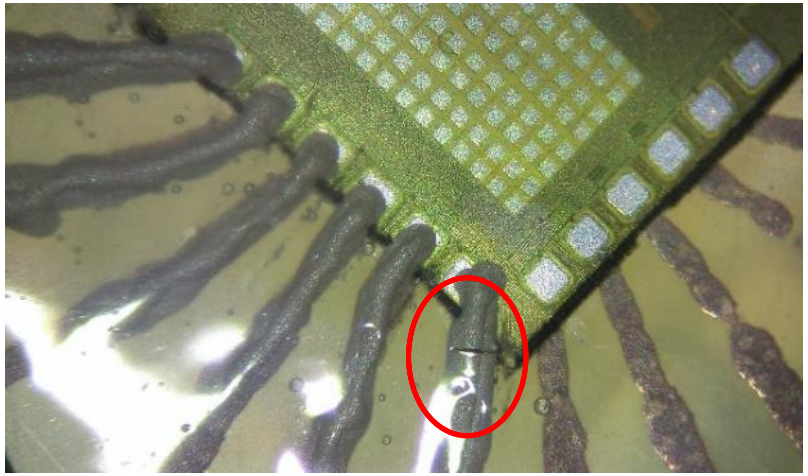
Per ASI Procedure TEST003

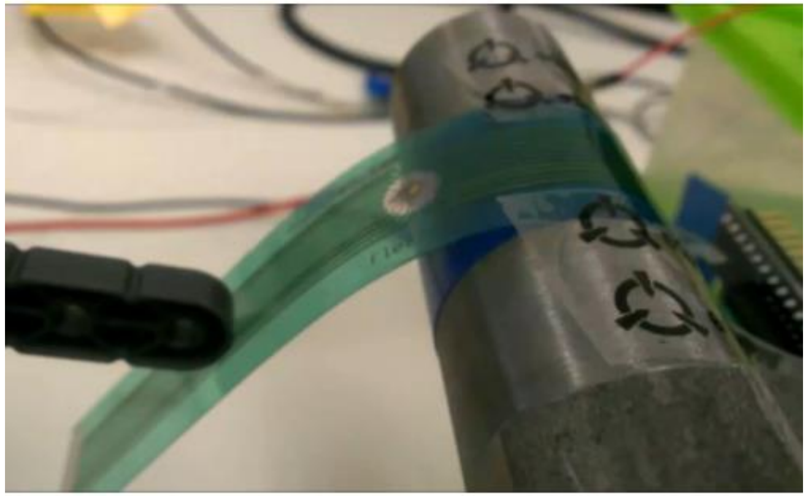
Dynamic Radius of Curvature Testing

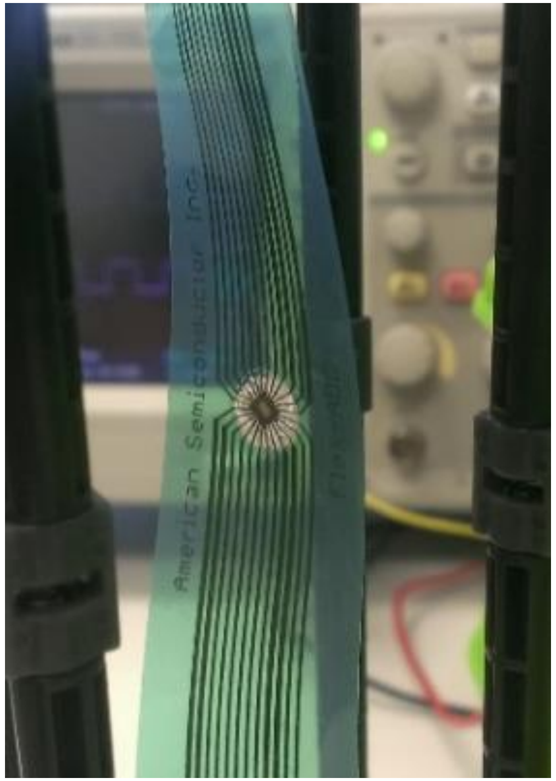
- Robotics system used to dynamically flex the FHE system around a 15mm radius mandrel
- Continuous electrical testing
- Sample 1 – 10K cycles convex followed by 13.6K cycles concave without failure
- Sample 2 – 11K cycles concave followed by 15.8K cycles convex before first failure
  - Failure due to crack in the silver flake conductive adhesive used for interconnect on the VDD line
  - Sample would still function if stress applied to bridge the crack

Dynamic Torsion Testing

- Robotics used to rotate the sample ±60 or ±90 degrees
- Continuous electrical testing
- Sample 3 – 10K cycles of ±60 degrees followed by 92K cycles of ±90 degrees before failure
  - Failure mode indicates a crack in the silver flake conductive adhesive







ESD Testing

Per ASI Procedure TEST010

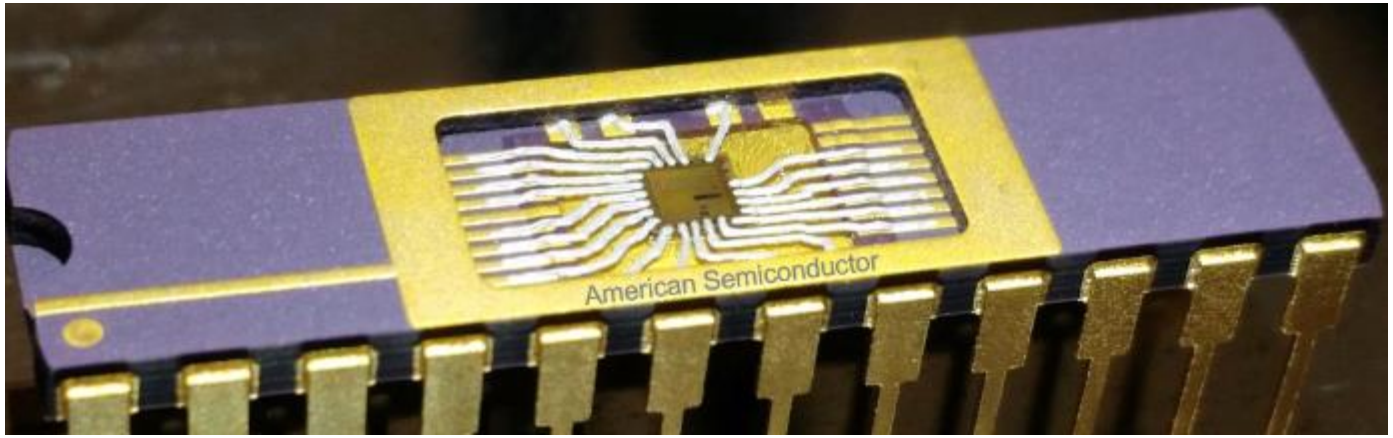
FHE test procedure adapted from ANSI-ESDA-JEDEC_JS-001 and JS-002

TEST 1 – Rigid, Full Thickness Die

- Six AS_ADC1004.pkg packaged ADCs using full thickness die wire bonded to the lead frame
- Pre- and post-stress functional testing
- Pin leakage testing
- RESULT: Passed both 2kV and 4KV human body model (HBM) testing

TEST 2 – Thinned, Flexible Silicon-on-Polymer Die

- Three AS_ADC1004.fxd FleX-ADC die mounted to PET substrates, inserted into packages and connected to the lead frame using conductive epoxy
- FHE system mount designed to accommodate industry standard ESD test equipment and methodologies
- Pre- and post-stress functional testing
- Pin leakage testing
- **RESULT: Passed 4KV HBM testing**



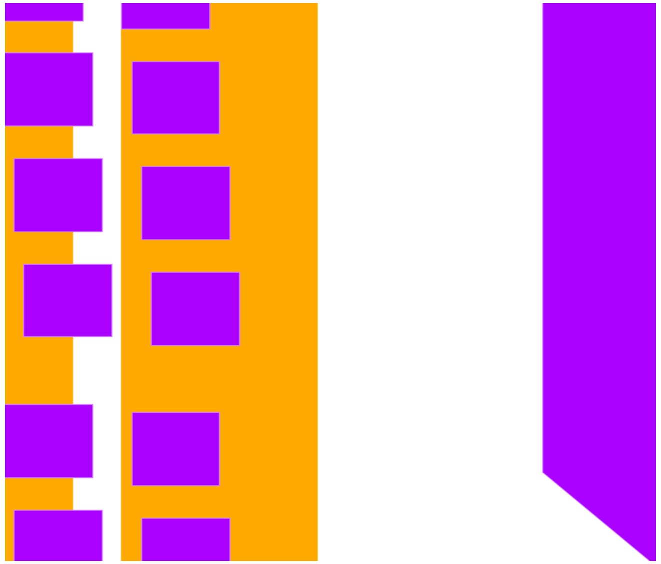
Industry first: FHE ESD reliability testing

IC Materials Delayering Analysis

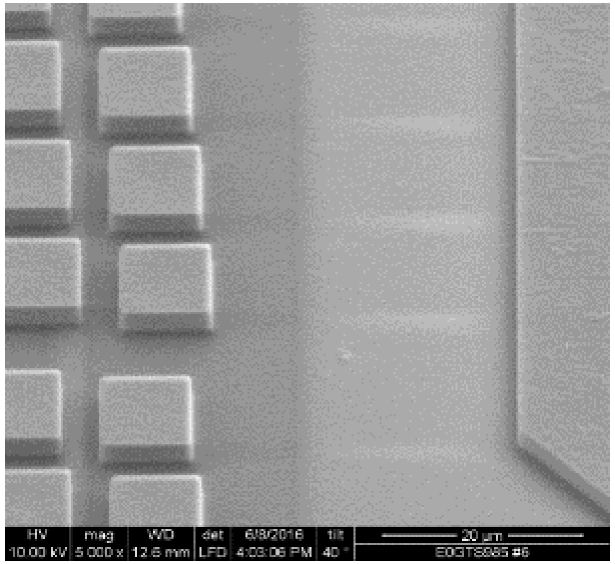
Per ASI Procedure TEST007

- Scanning Electron Microscope (SEM) inspection based upon MIL-STD-883K, Method 2018.16
- Layer by layer deconstruction analysis of all passivation and all 4 metal layers
- The purpose of this analysis is to look for cracking, delamination, or other visual defects
- Six thin, flexible FleX-ADC die, AS_ADC1003.fxd, used for analysis
- RESULT: **PASS. No defects attributed to the FleX SoP process.**
    - Expected result, consistent with functional testing of FleX-ICs before and after FleX conversion

Industry first: FleX-IC SEM reliability testing



Layout View



SEM Image

Layout View – M3 & M4

- Metal 4 (purple) is deposited on planar interlayer dielectric over Metal 3 (orange)

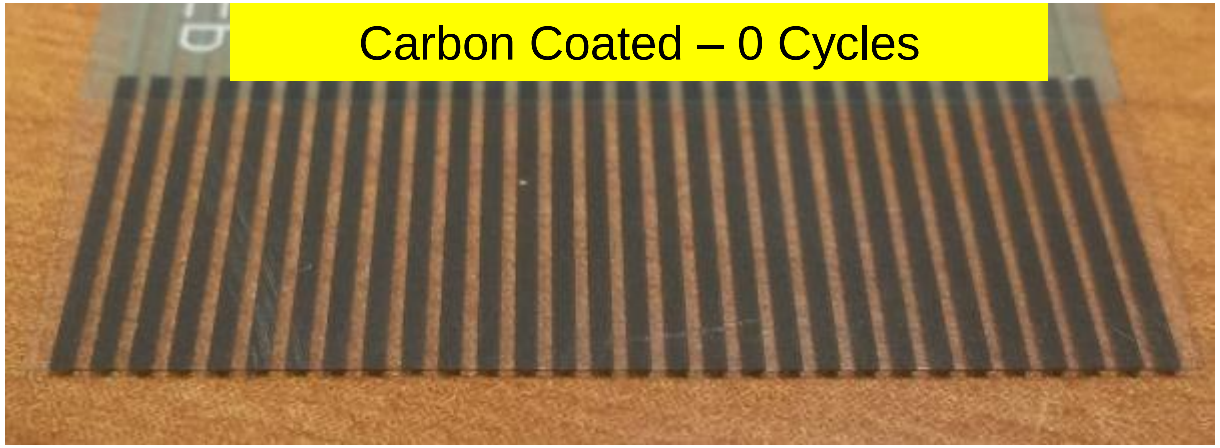
SEM Image – Metal 4 (Top Metal – 2.8um thick)

- No delamination, cracking, or visible defects
- Metal 3 is faintly visible through the interlayer dielectric

ZIF Reliability Improvements
Silver Ink vs Carbon Coated

- Repeated insertions of the printed ZIF tail into the Amphenol FCI SFW30S-2STE1LF connector
- 3 pin groups (left, center, right) shorted together for electrical testing during each cycle
- Silver ink only sample exhibited significant wear after only 200 cycles, failure at 882 cycles
- Carbon coated sample had no failures and very little wear after 1000 cycles

Silver Ink Only – 0 Cycles



Carbon Coated – 0 Cycles

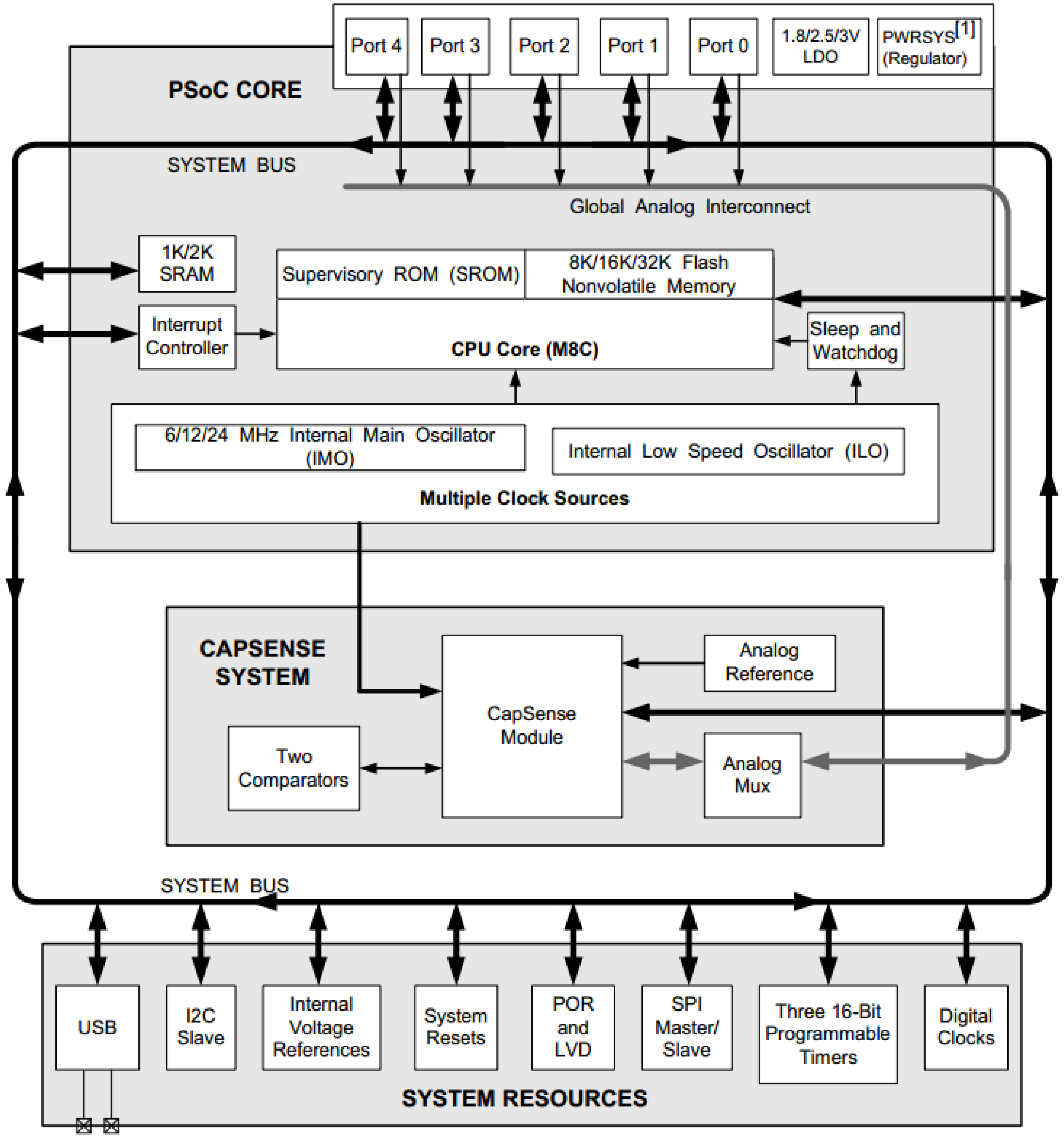
Silver Ink Only – 882 Cycles

Electrical Failure

Carbon Coated – 1000 Cycles

No Failures; Very Little Wear

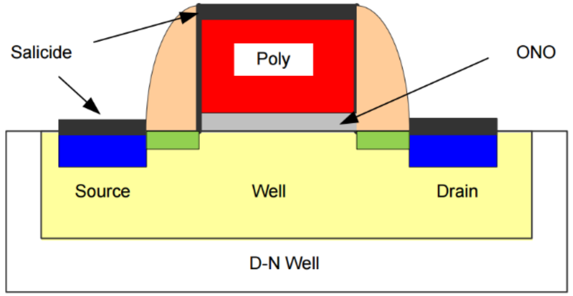
FleX-SoC™
Programmable System on a Chip



Features:

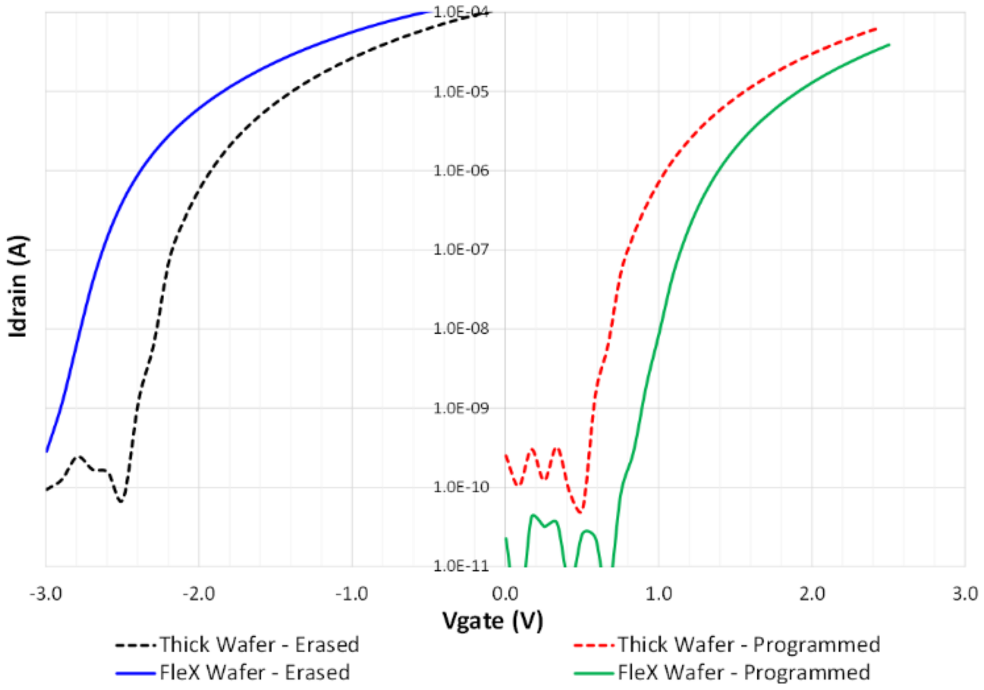
- 8-bit Microcontroller Core
- 1.7 – 5.5V Operating Range
- Low Power, Including 0.1uA Deep Sleep
- **32KB (256Kb) Flash NVM with 50K program/erase cycles**
- 2KB SRAM
- USB 2.0 – 12Mbs Full-Speed Compliant
- 10-bit Analog-to-Digital Converter
- 2 Analog Comparators
- Low Power Sense Module
- 36 Programmable Input / Output Pins
- 6/12/24MHz Internal Oscillator

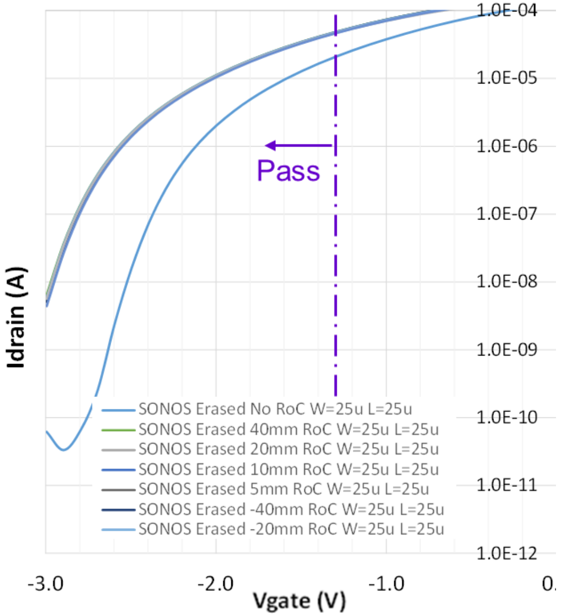
Flash Non-Volatile Memory Transistor Testing



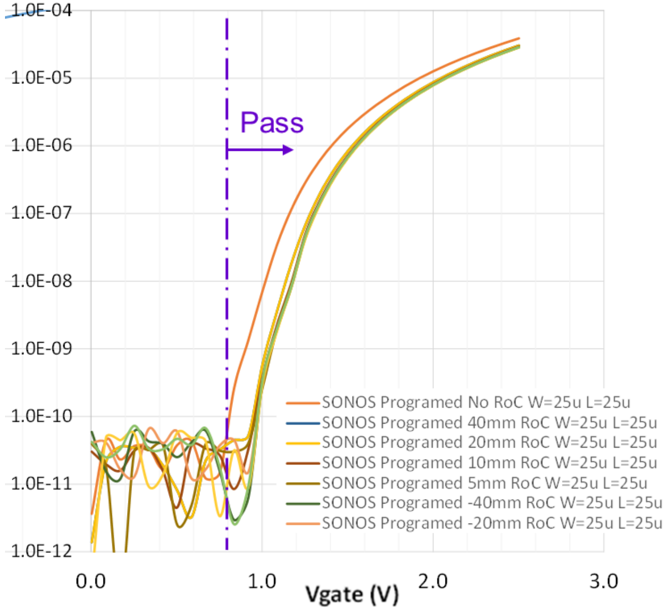
- Flash memory using SONOS technology
- Program / erase operations shift transistor operating point
- Known good devices from thick control wafers used as reference

- Devices tested for before and after bending around radius of curvature test mandrels
- Program, erase and read operations all tested
- NVM transistors passed to 5mm RoC in both concave and convex directions





FleX-SoC NVM Erase RoC Results



FleX-SoC NVM Program RoC Results

Thank You

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