Flexible Hybrid Electronics Fabricated with High-Performance COTS ICs using RTI CircuitFilm™ Technology

Scott Goodwin¹, Erik Vick² and Dorota Temple²

¹Micross Advanced Interconnect Technology
Micross Components, Research Triangle Park, NC

²Engineered Materials, Devices and Systems
RTI International, Research Triangle Park, NC

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Technologies
- Developmental foundry for microfabrication and 3D microsystem Integration
- Thermal management solutions for integrated microsystems
- Novel microfabricated sensors

Core strengths
- Advanced semiconductor processing equipment and analytical instrumentation
- 25 years+ track record in microelectronics and optoelectronics technology development
- Diverse client base: government, commercial and academic—translational research
- Collaborative research with RTI International
Micross Wafer-Level Microsystem Integration

Extensive toolbox of wafer-level microsystem integration techniques to reduce size, weight and power and enhance performance of electronic components and systems.
Emergence of Flexible Hybrid Electronics

Flexible Hybrid Microsystem

- Ultrathin battery
- Microcontroller
- Communicators (comm)
- Sensors
- Antenna

Printed transistors and passives

Flexible Electronics

- Roll-to-roll processes

Electronic Packaging

- Sheet-to-sheet or wafer-to-wafer processes

Si CMOS ICs

Wafer Chip Package Printed Circuit Board (PCB)
Commercial and Defense Applications of FHE Microsystems

- Flexible electronic systems for use in limited space applications where there is not enough physical space for rigid boards
  - Small missile systems, UAVs
- Conformal surface applications for antennas and associated electronics
  - Airframe surfaces
  - Infantry uniforms and flexible armor
- Support electronics for small form factor displays
- Wearable sensors
  - Fully flexible, thin and light while incorporating advanced data processors and RF transmitters and transceivers for wireless communications

- Calls for **high-performance** integrated circuits (ICs)
- Ease of system design requires ICs to be COTS
Process Technology Dilemma and Potential Solution

- Progress in development of bottom up process technology for fabrication of thin-film transistors on flexible substrates
  - Compatibility with wide range of flexible substrates
  - Uses low temperature processing techniques, such as printing or physical vapor deposition
- Performance of thin-film transistors has been limited to cutoff frequencies in MHz range for a long time
- State-of-the-art ICs built in monocrystalline materials have cutoff frequencies in GHz to THz range.
- Paradigm shift in properties of traditional monocrystalline ICs was introduced by development of 3D IC integration technology—ICs can be thin, light, bendable without impact on performance.
- Opens doors to embedding of ultra-thin monocrystalline ICs in flexible substrates.
Key process modules include wafer thinning, bonding and bump and direct interconnects.
RTI CircuitFilm™

**CircuitFilm™**

- ultrathin battery
- microcontroller
- sensors
- antenna

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**COTS devices are thinned and embedded in a polymer**

**Benefits:**
- Use of best-in-class COTS components
- Integration of mixed semiconductor technologies (e.g., Si, GaAs, HgCdTe, etc.)
- Rapid design-to-delivery cycle time
- Includes integration of passives
- Direct interconnects
- Potential for full integration including power

**Applications:**
- Defense and security
- Implantable medical devices
- Wearable physiological sensors
- Fabricated using conventional wafer processing
- Can use known good COTS die
- Release from handle wafer at conclusion of processing
- COTS die passivated by flexible substrate and MLM dielectrics
Design Considerations

- Path needed from PCB-based design to FHE-based design
- While there are broad similarities between PC Board design and thin flexible systems design, there are important differences that need to be addressed
  - Different design tools in PC Board design and IC design
    - Thin flexible systems will exist in both design spaces
    - Most tools can adapt to FHE systems with relatively small changes
    - Need better layout to GDS file conversions
  - Different scale and dimensions in the physical traces between PC Boards and thin flexible systems
    - Generally small dimensions and fewer layers in thin flexible systems than in PC Boards
    - Different RF performance, ground and power plane resistances, different parasitics
  - Concepts of power, testing, and connectors are different
Passives

- Passives are key to being able to integrate COTS parts into a complete system on a flexible substrate
- Some passives are commercially available that are thin enough to be incorporated into CircuitFilm™ substrates
  - Too thick and air bubbles can form around edges
  - IPDIA has 100µm thick capacitors available
- Small capacitors and resistors can be fabricated from MLM levels
- We fabricated inductors on 100µm thick quartz substrates 1.4nH to 61nH on 2mm die
- Resistors could be fabricated with appropriate choice of metals on wafers that are thinned

Additional commercial suppliers needed
Other Issues

- Availability of ICs of different materials and device types in thinned formats or that can be thinned

- Connectors to thin flexible films
  - Need new designs with either mechanical or metallurgical interfaces that are compatible with thin flexible films
    - Some designs may be wirelessly interfaced
  - Testing of thin flexible film systems
    - Use of temporary connectors or probes
    - Testing only possible of completed systems

- Power sources
  - Require thin and flexible, capable of process integration

- Reduced substrate thickness may place antenna elements near ground planes
  - Reduces antenna operating bandwidth, reduces data rates
- PLL RF Transmitter based on Atmel T5750
  - Uses bare die Atmel T5750, MEMS oscillator, passive inductor and capacitor, additional resistor and capacitors fabricated in wiring levels
  - Two wiring levels
  - 21.1 x 13.4 mm
Fabricated Demonstration Circuit

- Based on Atmel RF Transmitter bare die
- Air bubbles formed around unthinned MEMS oscillator die
  - Tears in overlying thin polymer layers
  - Repaired with silver colloidal paste
Operation of Completed CircuitFilm™ Demonstration

- Atmel RF transmitter generates ASK signal from input signal (1kHz) and oscillator output
  - Increases oscillator frequency 64X
    - $64 \times 14.318\text{MHz} = 916.4\text{MHz}$
- Probed while still on carrier wafer
- Measured using spectrum analyzer

Frequency sweep of output showing peak at 916.4MHz

Transformed output generated by spectrum analyzer showing 1kHz signal 45µW output signal
Operation of Completed CircuitFilm™ Demonstration

- Circuit released from handle wafer
- Probed flat
- Probed on curved surface
  - Radius = 44 mm

Released CircuitFilm™ probed on flat surface

Released CircuitFilm™ Probed on curved surface
RF transmission test using two random length long wire antennas (42 inches) connected to output of circuit. Measure expected power decrease of 6dBm with doubled distance.

~ -80dBm at ~260ft
Mechanical Flexing Testing

- Mechanical testing of parametric test circuits has been done
- Circuits investigate different aspects of CircuitFilm™ technology
  - Integrity of CircuitFilm™ metal lines
  - Integrity of CircuitFilm™ vias
  - Integrity of metal lines routed up over embedded passives
  - Integrity of direct interconnects to contact chain passive
- Flexed multiple cycles with different radii and directions of curvature
  - Radii of 11mm and 22mm
  - Cumulative flexed cycles up to 11,000
  - No formation of open circuits in any of the test sites
- Testing continuing
Conclusions

- New, emerging opportunities in thin flexible hybrid microsystems
  - Defense and security applications, implantable medical devices, wearable physiological sensors
  - Paradigm shift from traditional printed circuit board systems

- Development of 3D IC integration technology opens pathway for fabrication of ultra-thin monocrystalline ICs with excellent performance

- RTI CircuitFilm™ technology incorporates thinned COTS devices in flexible polymer film
  - Best-in-class COTS devices and performance

- Design tools and design methodology need to be adjusted for flexible hybrid microsystems
  - Thinner and finer pitch metal lines available on IC processing tools

- First demonstration circuit fabricated using CircuitFilm™ technology
  - Demonstrates incorporation of thinned COTS die, direct interconnect, and passive components
  - Fully functional circuit on handle wafer and released flexible film
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