Center for Advanced Microelectronic Manufacturing
CAMM
January 2010

Binghamton University
State University of New York

FlexTech Alliance
for Displays & Flexible, Printed Electronics

Endicott Interconnect Technologies, Inc.

Cornell University
What is CAMM?

- USDC / Flex Tech R2R toolset
  - Photolithography, vacuum deposition & inspection
  - CAMM created a facility for USDC / Flex Tech to:
    - install and test tools
    - generate company interest in tools and mission
    - fabricate prototypes
    - specify the next generation of tools and facilities
- Additional tools and infrastructure obtained with NY State support
  - NY State, BU and EI tripled (and more) the original USDC investment
- Member company projects using CAMM facilities
  - To leverage toolset for individual company needs
- CAMM Technical Advisory Board (TAB) selected and funded University based research projects
Why Roll-to-Roll Manufacturing?
R2R can lead to reductions in cost.

- Thin Film Deposition & Laser Processing
  - Supply Roll
  - Take-Up Roll
  - Cooling Drum

• Engineering Challenges
  – Need to develop R2R equipment to operate at IC-industry specifications
  ▪ Existing hurdles:
    – Damage due to handling
    – Particle generation
    – Impurity due to contact
    – Yield management
    – Linear processing

• Financial Opportunities
  – A fully integrated facility
  – Lower capital & labor cost
Facilities at Huron

Panel Microfabrication Laboratory
- Large area photolithography and sputtering
- Suitable for prototyping and early development

CAMM R2R Laboratory
- Clean Room Project
- Azores Photolithography
- ECD Defect Inspection
- Bobst/GV High Vacuum Deposition
- CHA High Vacuum Deposition

CAMM
CAMM Facilities at Endicott Interconnect

Lab -- 53,000 sq ft lab & Service Core -- 6500 sq ft
Growing list of Partners

CAMM
The Center for Advanced Microelectronics Manufacturing

Applications

Binghamton University
State University of New York

Sensors & Reliability

Process Equipment

Endicott Interconnect Technologies, Inc.

Fundamentals

FlexTech Alliance
for Displays & Flexible, Printed Electronics

Novel Packaging

Novel Packaging

Cornell University

Devices

Electronic Materials

Electronics

Electronic Materials

General
Center Objectives

- R2R vacuum deposition, photolithography, wet and dry processing of flexible, unsupported, thin film based active, passive electronic devices and advanced interconnect technology.
- Evaluate flexible R2R substrate materials and process capability.
- Fabrication of specialty prototype electronic substrates for members and sponsors.
- Design, develop and build future tool and processing equipment.
- Development of materials and processes for inkjet printed electronics.
Recent accomplishments

• Continuous development of process tools and facilities.
• Resolution of 2-5 micron lines/spaces on unsupported flexible plastic substrates with 1-2 micron overlay and registration.
• Design of artwork.
• R2R photolithography and wet processing of 2-5 micron sized features on unsupported flexible plastic.
• R2R and panel sputter and reactive sputter of Al, Cu, Cr, Ti, Si and Al oxides.
• Fabrication of top-side: flexible sensors, medical electronics, capacitors, optical waveguides and other devices of interest to members and sponsors.
• Fabrication of top-side multi-layer semiconductor coatings on unsupported flexible plastic films.
Tools & Facilities
<table>
<thead>
<tr>
<th>Major Equipment</th>
<th>Supplier</th>
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<tr>
<td>Cleaning/Wet Process</td>
<td>Kraemer Koating</td>
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<tr>
<td>Precision Wet Coat &amp; Bake</td>
<td>at Frontier Industrial</td>
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<tr>
<td>Wet Developer</td>
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<tr>
<td>Precision Web Handling</td>
<td>Northfield Automation</td>
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<tr>
<td>Precision Lithography Stepper*</td>
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<tr>
<td>In-line Defect Inspection*</td>
<td>ECD-IV</td>
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<tr>
<td>In Line Sputter Down Deposition</td>
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<td>Scanning Projection Lithography</td>
<td>Tamarack</td>
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<tr>
<td>R2R High Vacuum Coater (GVE)</td>
<td>General Vacuum/Bobst</td>
</tr>
<tr>
<td>DES Wet Line (w/ R2R handler)</td>
<td>ME Baker (El R&amp;D tool)</td>
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<tr>
<td>Precision Laser Drill &amp; R2R handler</td>
<td>ESI (El R&amp;D tool)</td>
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<tr>
<td>R2R High Vacuum Coater* (CHA)</td>
<td>CHA</td>
</tr>
<tr>
<td>Linear plasma reactive ion etch source* (for GVE)</td>
<td>EITI</td>
</tr>
<tr>
<td>XenJet 5000 inkjet printer* (multi-head)</td>
<td>Xennia</td>
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<tr>
<td>Aerosol inkjet printer* (multi-head)</td>
<td>Optomec</td>
</tr>
<tr>
<td>R2R Plater</td>
<td>M E Baker</td>
</tr>
<tr>
<td>OLED Evaporation Source* (available)</td>
<td>KJL</td>
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* supported tool
Azores Corporation Model 6600 FlexPrinter™

The Model 6600 FlexPrinter provides advanced photolithography imaging for flexible electronics by incorporating Preeco Industries roll-to-roll handlers with a stepper system.

Funding for the $4M project was shared by Azores and the United States Display Consortium (USDC), and included Army Research Laboratory appropriated funding to advance the capability of U.S. industry in the flexible microelectronics market.

System Attributes:

- Advanced photolithography for applications that require resolution down to 4 μm
- G-Line (436 nm) and I-Line (365 nm)
- Accurate alignment compensation
- Accommodation for substrate distortions characteristic of flexible substrates
- 8” to 24” wide substrates
- Thicknesses of 100-200 μm
Energy Conversion Devices Defect Inspection

ECD and Integral Vision’s Defect Inspection System provides digital-optical inspection of web material during all stages of processing.

The $1.3M project was funded by ECD, Integral Vision and the United States Display Consortium (USDC) using Army Research Laboratory appropriated funding to advance the capability of U.S. industry in the flexible microelectronics market.

System Attributes:

- 6” width inspection
- Bidirectional unwind/rewind interleave capability
- Target defect size: ≤1 to 5 μm
- Scratch detection: ≥1 x 10 μm
- Web location tracking
- Pass/fail sensitivity to 3 μm
- Web widths up to 24"
- Throughput speed from 24” to 120” per minute
General Vacuum/Bobst High-Vacuum Coater

The General Vacuum/Bobst High-Vacuum Coater deposits thin film metals or insulators on flexible substrates.

The $1.6M project was funded by a New York state grant given to Binghamton University to advance high-technology commercialization.

System Attributes:
- Four independently pumped zones
- Up to five sources for sequential processing
- Cooling drum for supporting plasma preprocessing
- Coating range thicknesses of 100-500 Å
- Separate cooling drum for sputtering
Northfield Automation R2R Web Handling Systems

The Northfield Automation R2R Web Handling Systems enable precision-controlled unwinding and rewinding of flexible electronics materials.

These systems were funded by a New York state grant given to Binghamton University, and were built to CAMM specifications.

System Attributes:
- Interleave capability
- HEPA mini cleanroom enclosed cabinet
- Precision web splicing
- Active static control
- Horizontal dancer allowing for continuous or intermittent movement of web
- Touchscreen interface
- Closed loop tension control
Hollmuller Siegmund Photoresist Processing

Hollmuller Siegmund Systems are used to clean, develop and strip the photoresists used in lithography.

System Attributes:
- Stainless steel and polypropylene tools
- Northfield Automation web handling system
- Up to 15" widths
- Multiple tanks for process and rinse
- Used for cleaning, develop etch and strip processing
- Aqueous-based chemistries (TMAH, NaOH)
CHA Industries High-Vacuum Deposition System

The High-Vacuum R2R coater sputters thin films of metals onto flexible substrates.

Funding for the $6M project was shared by CHA and the United States Display Consortium (USDC), and included Army Research Laboratory appropriated funding to advance the capability of U.S. industry in the flexible microelectronics market.

System Attributes:
- Provides for plasma cleaning prior to sputtering
- Can handle up to five sources
- Interleave capability
- Vacuum 10^-7 torr
- Capable of handling thin films down to 12 μm
- Large bay allows for custom source R&D such as metal or OLED evaporation
- Designed to minimize defects, particle generation, and contamination
Tamarack System 303 Scanning Projection Lithography System

The Tamarack Scanning Projection Lithography System provides photolithography for single substrates in batch mode.

The $1.2M system was funded by a New York state grant given to Binghamton University to advance high technology commercialization.

System Attributes:

- 400 x 500 mm expose area
- 2 kW mercury short arc lamp
- >3000 mW/cm² BB UV (300-450 nm)
- Filter selectable I, I+H, H+G, G line
- 4 μm resolution (NA = 0.14)
- Positive and negative resists, 2 to 100 μm
KDF In-Line Sputter Down Batch Deposition System

The KDF System deposits metals on substrates in flat panels.

The $931,000 system was funded by a New York state grant given to Binghamton University to promote high technology commercialization.

System Attributes:
- Pallet size 20” x 20”
- Single-ended loading
- Dual-level vacuum load lock
- Stainless steel (304) chambers
- Shielded sputter targets (4), CD/RF
  - Initially Cu(2), Cr, Ti
- Ultimate pressure ≤ 10⁻⁷ torr
- Substrate pre-heat
- Plasma clean capability
EITI LPS 2500 DF
Plasma Pre-clean Prior to Sputtering
Reactive Ion Etcher
Plasma Etch of Oxides/Nitrides
LPS 2500 DF Exhaust side Mounting Plate
Xennia Xenjet 5000

- Range of travel: 600 mm x 600 mm
- Maximum print area: 300 mm x 300 mm
- Substrate size - initial tests: 200 mm x 200 mm
- CCD camera for alignment
- Measuring System Accuracy: ±3 µm
- Repetition Accuracy: <1 µm
- Three printhead system using Xaar 760 GS8 print heads
  - 764 active nozzles (360 dpi)
  - Print swathe width is 53.8 mm
  - Drop size: 7 pL (ink dependent)
  - Nozzle pitch is 70 µm
  - Viscosity range printhead is 5-15 cP
  - Compatible with solvent, UV and water-based inks
- Bulk ink assembly for large volume & syringe feed for small volume
- Smallest features: 50 µm for normal process
  - UniPixel process: < 10 µm line width
- Nordson DropCure UV lamp
  - Tack cure printed inks to minimize the ink spread.
Applications
**Intravascular Ultrasound (IVUS)** is a catheter-based system that allows physicians to acquire images of diseased vessels from inside the artery. IVUS provides detailed and accurate measurements of lumen and vessel size, plaque area and volume, and the location of key anatomical landmarks.

**Part Description**
- **Description:** Flexible polyimide substrate with transducer (receiver/transmitter)
- **Dielectric:** Polyimide, 12.5 µm
- **LW/LS:** 14µm / 14µm
- **Flip Chip:** 22µm bumps, 70µm pitch

*CAMM*
Circuit Traces on Flexible Substrate

Prior to Device Placement

After Device Placement

Transducer

ASIC Die

200 µm
EI Optical Interconnect Technologies
Polymer optical waveguides for 10+ Gpbs data rate applications

**Technology Highlights**

- Low Loss Multi-mode @ 850 nm wavelength (<5dBm per meter)
- Flexible
- Can be connectorized
- Can be used for board to board and within board optical communications
- Compatible with PCB manufacturing*

**Reliability (Passed Tests)**

- Damp Heat: 85°C/85%rH for 2000 hours (GR-1221)
- Thermal shock: 100 cycles from -40°C to +70°C
- HAST (Highly Accelerated Stress Test): 96 hours @ 130°C / 85% rH / 33psi
- Solder Reflow: 6 cycles at standard SAC solder reflow profile

Optical polymer waveguide on Frame Mounted Flexible substrate

Closed Up Top View

Flexible Polymer Optical Waveguide

Clad 250μm

Substrate

Core

Endicott Interconnect Technologies, Inc.
Optical Polymer Waveguide on Flexible substrate

Test Mask

Polymer Waveguide with in-plane Crossing on Flexible Substrate

35μm @ 62.6μm spacing

35μm @ 250μm spacing

35μm @ 125μm spacing

35μm @ variable μm spacing

Endicott Interconnect Technologies, Inc.
Design
Transistors with lengths of 20, 75 and 200 microns, widths of 1, 2, 3, 5, 10 and 20 microns

Kelvin probes for measuring throughvia effectiveness

Hall effect or 4-point probes

Conductivity Probes

Schottky diodes for measuring metal work function

Alignment marks for different level combinations

Gate capacitors for measuring the dielectric quality
Benchmarking Photolithography & Printing

• As printing techniques continue to advance, standardized test patterns are needed to compare printing with photolithography.
• CAMM current activities include:
  – Photolithography process development using unsupported flexible substrates,
  – Inkjet printing, substrate surface modification, ink and process development.
• The CAMM will create artwork and test patterns:
  – based on industry standards,
  – based on Flex Tech members standard test patterns,
  – and with input from CAMM TAB members.
  – When feasible, both photomask and printer design files will be created.
  – The design will include: graphic test patterns, sensors, TFT and conductivity elements.
• Substrates (w/ or w/o metal coatings), photoresists and inks will be defined.
• The Azores and Tamarack will be used for photolithography.
• Inkjet printing will be primary printing technique.
  – the CAMM has: Dimatix, Uni-Jet, Optomec and Xennia printers.
  – other printing techniques will be included as available.
• The CAMM will lead and sponsor the initial phases of this benchmarking study and will seek funds to continue the project into the future.
Roadmap
Flexible Electronics: material, tool and application space

- Line width / space
- Process
- Device
- Tooling
- Layer
- Integrated
- Multilayer
- Lithography
- Passive
- Sequential
- Single / top
- Web
- Printing
- 2 - 5 µm
- 10 - 20 µm
- Piece
- Complexity
- Time
- CAMM
Substrates
- Glass panel (as a standard)
- PET film
- PI film
- PEN film
- Flexible glass
- Metals (Cu, SS, etc…)
- Others

Design & Fabrication

Processing
- Vacuum deposition
- Photolithography
- Wet/dry processing
- Slot-die coating
- Ink-jet printing
- Aerosol ink-jet printing

Technology
- Fine circuitry
  - single & double sided
  - single & multilayer
  - registration & overlay
- Sensors
  - environmental
  - biometric
- Medical
  - catheter technology
  - implantable
  - diagnostic
- Passive displays
- Lighting
- Optical waveguides
- Solar energy conversion
- Active devices
- Active backplanes
### Baseline Equipment/Process
- Conventional Wet Cleaning
- Azores Lithography Tool
- Tamarack Projection Litho
- Wet Spray Chemical Process
- Precision Coat (Vendor)
- GV & CHA UHV Coaters
  - Sputter Metals & ITO
  - Dielectrics (Si & SiO2)
  - PE-CVD (a-Si)
  - Evaporate Metals
- KDF UHV Coater (Cr/Cu, ITO,...)
- Particle Inspection
- Precision Cleaning
- Feature Inspection
- Dry Etch (Si / dielectrics)
- Precision Wet Coat / Bake
- Web Storage & Handling

### Novel Equipment / Process
- Inkjet printing
- Azores w/ NAS handlers
- High throughput Lithography
- OLED Evaporation

### Applications
- 10 - 20 µm features
- 5 -10 µm features
- Stacking / overlay & multilayer
- Specialty substrates (e.g. barriers)
- Precision flex circuitry
- Passive display backplane
- Large area lighting
- Integrated passive devices
- Photovoltaic devices
- Active circuitry (low speed)
- Active backplane
Applications of Flexible Electronics at CAMM
Education
MSE 583  
Tuesday and Thursday  
11:40 am to 1:05 pm  

Special Topics in Materials  
Flexible Electronics  

Imagine displays that roll up and fit in your pocket. Imagine your clothes as a source of solar power. If microelectronics could be made flexible enough and low cost enough, then everything we use could be electronic.

Course Overview: Flexible electronics holds the promise of transformative developments in: (1) flat panel lighting (low cost, low energy), (2) energy production systems (solar) and (3) infrastructure control and monitoring (sensing, energy control, hazard monitoring). Practical realization of flexible circuits will require dramatic progress in new materials that are compatible with flexible media and amenable to facile and low temperature processing as well as major advances in manufacturing technologies such as roll-to-roll processing. This course will discuss these and other developments.


Offered: Fall 2008 & 2009
Sept 1   Organizational meeting, what is flexible electronics? (Poliks)  
Sept 3   Rigid versus flexible, traditional Si electronics fabrication (Silicon Run Lite video, Poliks)  
Sept 8   Basic solid-state physics (White)  
Sept 10  Thin film electronics and vacuum deposition (Wickboldt)  
Sept 15  Basic electronic devices (White)  
Sept 17  Metal deposition (Magnuson)  
Sept 22  Materials: substrates for flexible electronics (Poliks)  
Sept 24  Biomedical applications of flexible electronics (Turner)  
Sept 29  Materials and processing: patterning (Poliks)  
Oct 1    Special Seminar: a-Si devices on flex Prof. Mike Thompson, Cornell  
Oct 6    Special Seminar: FlexICs story of a startup Prof. Mike Thompson, Cornell  
Oct 8    MSE Seminar: Organic light emitters and flexible lighting (Martin Yan, GE)  
Oct 13   Basic microfabrication techniques (Switzer)  
Oct 15   Nanomaterial inks for flexible electronics (Wang)  
Oct 20   Conducting polymers and energy conversion (Jones)  
Oct 22   MSE Seminar: Laser annealing of a-Si Prof. Mike Thompson, Cornell  
Oct 27   CAMM TAB meeting (all day) ITC 2221  
Oct 29   Course project pre-proposals (in class discussion)  
Nov 3    Towards flexible super capacitors for energy storage (Rastogi)  
Nov 5    MSE Seminar: "Crumpling Polymer Films" Al Crosby, Univ of Mass  
Nov 10   Energy conversion: flexible solar cells (Rastogi)  
Nov 12   Printed electronics (Wang)  
Nov 17   Flexible sensors (Zhong)  
Nov 19   Towards flexible battery technology (Whittingham)  
Nov 24   Roll-to-roll processing of electronics (Poliks)  
Nov 26   No class (Thanksgiving)  
Dec 1    Class project presentations 1  
Dec 3    Class project presentations 2  
Dec 8    Final class held in Binghamton, course survey  
Dec 12-13 Reading period  
Dec 14   Final exam period begins  
Dec 18   Final exam period ends – last day to submit all assignments, exams and term papers  

Optional lecture topic: Flexible polymer optical waveguides (Lin, EI)