Toolset for Confronting the Challenges of Roll-to-Roll Production of Advanced Microelectronics

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Introduction

The Center for Advanced Microelectronics Manufacturing (1) (CAMM) is an academic-industry-government research and development center established by an award from the FlexTech Alliance for Displays and Flexible Printed Electronics (formerly United States Display Consortium) (2) to Binghamton University, Endicott Interconnect Technologies and Cornell University. The CAMM will demonstrate the feasibility of roll-to-roll (R2R) electronics manufacturing by acquiring first generation tools and establishing processes capable of producing low volume prototypes. The CAMM will address R2R fundamental enabling science, technologies, and system design (integration, performance, yield and manufacturing feasibility) issues. This revolutionary approach will enable both ubiquitous and disposable electronic devices.

Roll-to-roll electronics manufacturing techniques may eventually lead to continuous production of high quality, flexible, thin film devices at significant cost reduction (3,4). Vacuum web coating (5) and photolithography (3) are the established means to fabricate micron sized features on flexible plastic substrates. Work continues in several US based academic laboratories to understand the electromechanical properties of flexible (6) and stretchable (7) electronics. Individual flexible display backplane prototypes are fabricated while supported on glass substrates at the "Flexible Display Center" at Arizona State University (8). The goal of the Center of Advanced Microelectronic Manufacturing (CAMM) is to develop electronic fabrication tooling and processes that use unsupported flexible polymeric substrates in individual pieces or in a roll-to-roll format. Processes and tooling under development include vacuum deposition, wet (slot-die) coating, photolithography, and wet processing.

Rather than trying to invent new technology from the outset, the intent in assembling these tools is to provide a laboratory to explore the challenges of this new field of flexible microelectronics fabrication. In choosing the tools, the following criteria where applied whenever possible:

- Flexibility: to allow different processes, types of webs, tool configurations for unsupported flexible substrates.
- High range of web speeds, widths (up to 24") and tensions.
- Minimal to no front surface contact.
- Large bend radius: most rollers and cores are 6" in diameter. Given the possible use of thicker, less well developed coatings, we need to avoid cracking / delamination of films when bent.
- Low particle or chemical contamination. (e.g. very low base vacuums, separation of "dirty" components from clean-room accessible areas.)
- Ability to program ranges of experiments along length of web.

Most often these criteria are a trade-off with the compactness and reliability of the tools, making them much larger and awkward compared to production systems. However, they also provide use to a larger range of users. Typical applications include: advanced electronics packaging and flexible electronics, display backplanes, photovoltaic and PE-CVD (plasma enhanced chemical vapor deposition) of amorphous silicon on flexible (plastic) substrates.

The CAMM facility will include two roll-to-roll enabled high vacuum deposition systems, one from CHA Industries in Fremont, CA and the other from Bobst/General Vacuum Equipment in Heywood, UK. The technical attributes of these unique systems will be described in this paper.

Bobst Group -- General Vacuum Equipment (GVE) multi-purpose OptiLab coater

The General Vacuum Equipment OptiLab roll-to-roll vacuum coater was selected by CAMM for its versatility, ability to operate in a clean room environment, function in both contact and non-contact mode with bi-directional interleaf wind and unwind and its ability to provide for a variety of sources, including PE-CVD. Elsewhere, this latest version of General Vacuum Equipment's OptiLab vacuum coater is being used to develop and manufacture the latest optical, OLED (organic light emitting diode) displays, photovoltaic and flexible micro-electronic devices. The system can process web widths up to 500 mm, with a maximum roll diameter of 400 mm, running at speeds from 0.01 m to 20 m/min. The coater is able to run a range of coating technologies and has the capability to include a range of different web treatment techniques, including medium frequency AC plasma pre-treatment on films ranging from 12 – 188 microns. The system can also monitor coatings 'on-line' via a tri-range resistance monitor that covers 0.02 to 0.8, 0.5 to 20 and 5 to 200 ohms/sq. The system is also configured for the addition of an optical density sensor at a future date.

General Specifications

Tool Model	OptiLab 520 mm sputter coater
Architecture	Roll-to-roll with cooling/heating drum
Tool Footprint	16' by 14' and larger
Throughput	0.01 to 20 m/min (0.03 to 66 ft/min)
Web Width	Up to 20 inches
Uniformity	Typically +/- 2%
Thickness Range	Angstroms to Microns depending on material
Film Thickness	12 to 200 microns

This system has three larger sputter zones (see Figure 1, bottom) for more flexible experimentation, in combinations of single and dual cathodes, planar and rotatable magnetron sputtering, in reactive and non-reactive configurations. The bi-directional winding system, with or without interleaf, in contact or non-contact mode enables multi-layer coatings to be deposited simultaneously, without breaking the vacuum. The machine is designed as a multipurpose laboratory roll coater for sputtering and PE-CVD development work as well as small scale pilot production.

A high accuracy servo drive system provides advanced web handling (seen from the service core side in Figure 1, top), precise process monitoring and control for superior uniformity and product quality for metallic or oxide coatings. Its bi-directional winding system enables multi-layer coatings to be deposited simultaneously, without breaking the vacuum. The machines compact design reduces the floor space needed. An intuitive software interface enables easy interaction with the control system for rapid process configuration, data input, retrieval and process monitoring.

The roll to roll vacuum coater is located in the primary CAMM clean room environment. The system has been prepared for PE-CVD operation and also includes the following accessories: high temperature range operation with a heater/chiller having expanded the range of -15 to +200 C; high temperature bearings and rotary union, pipe work complete with insulation, a floated drum and flange plate on the bottom of zone #2. See Figure 2 for a view of the tool from the service core side.

CHA Industries Mark 80 Web Roll Coater

The CHA Industries high vacuum multi-process station web/roll coating system was designed for a 24 inch wide web. The main process chamber is 78 inch inside diameter by 52 inch long, water cooled, with four 16 inch diameter high vacuum pumping ports, a left side source well, four high conductance roughing ports and various feed through ports. The main 78 inch diameter chamber is divided into five secondary chambers by conductance limiting shields: a) primary unwind chamber, b) secondary pumping/process chamber, c) main process chamber, d) secondary pumping chamber, and e) primary winder chamber. The non-process chamber door is trolley mounted and has twelve 4 inch diameter viewports and twelve 2 ¾ inch flange instrument feed through ports. The process chamber door is trolley mounted and motorized. The door configuration allows for mounting of all roll components (see Figure 3) and five process station ports for sputter cathodes. The four pumping stacks (all CHA designed components) consist of high vacuum valves, liquid nitrogen traps, combination micrometer adjustable variable orifice throttle valves, water cooled optically dense chevron baffles, high conductance water cooled fore-line traps, and Varian HS-16 10,000 liters per second diffusion pumps. There are four each Edwards E2M275 two stage 206 CFM direct drive mechanical pumps with high conductance mechanical pump sieve traps.

General Specifications

Line Speed	0.2 to 40 FPM
Speed Accuracy	+/- 0.1% of set point
Acceleration	20 seconds to max machine speed
Tension Range	-3.5 to 70 pounds total web tension (across the web)
Core Diameter	6 in. I.D.
Full Roll Diameter	12 in. Max O.D.
Material Thickness	2 to 7 mil plastic
Web Width	24 in

The web transport system is microprocessor controlled. It provides the ability to process a continuous strip of flexible materials from one roll to another. The operator interface occurs via a touch screen terminal and push buttons. The touch screen is mounted in the system control cabinet front of the system. The web roll system includes wind/unwind mandrels with manually activated 6 inch diameter core chucks to allow for accurate web placement in relation to the coating zone. The minimum roll diameters are 6 inches. There are two load cell systems, one at each winder/unwinder, to control the web tension. The web tension is measured with vacuum rated tension roll transducers using an extended range amplifier. Stepper motor drives balance the tension load across the tension rolls. A dual edge nip roll system with tendency drive prevents slipping of the web on the main cooling drum. None of the rollers are allowed to contact the process side/face of the web/substrate, except the edge nips that contact only the outer edges of the process side/face of the web material. A photoelectric sensed electric powered edge guide system centers the web as it runs through the roll system. A set of bowed rollers address wrinkle removal in thin substrate materials. Two interleaf rolls are present at the wind and unwind zones. The main processing drum is a water cooled/heated 36 inch diameter x 30 inch long drum which will support, cool/heat the web, and provide primary speed control for the process. The drum is cantilevered from the rear door of the chamber, so the front main support plate may be removed for service without supporting the drum. Drum speed is controlled by fully regenerative PWM (pulse width modulated) servo control and brushless gear motor. The drum speed is adjustable, with programmable acceleration and deceleration ramps. Speed set point is entered at the operator's terminal. The digital drive controller keeps a running total of material footage. Both line speed and material footage are displayed on the terminal.

The system utilizes four (each) serpentine cryo-coil assemblies and Polycold compressors for water vapor pumping. There are three magnetron sputter cathodes with internal gas manifolds for 5 inch wide by 36 inch long targets. The cathodes will be mounted on the back door and located radially from the process drum center line with sputter target facing the process drum. Water cooled plasma pressure zone shields for sputter cathodes allow the cathode to operate at a set pressure. Sputtering pressure is measured and controlled at each cathode. There are six Advanced Energy Pinnacle Plus 10kW pulsed DC sputter power supplies, two per cathode stacked to make 20 kW. The Pinnacle power supply delivers flexible process power for reactive DC sputtering. These enhanced features meet the needs for advanced processes. Upstream pressure gas control for DC sputter cathodes controls and displays gas flow of one gas N_2, O_2, or Ar. Pressure is measured between the sputter target and the process drum in the plasma zone of each sputter cathode. Gas flows into the cathode body through a distribution manifold. Gas flow rate controls the plasma zone pressure. The system includes a Ferran Scientific RGA controller. The sensor supplied with the system will be the 2-100 AMU range sensor. All process zones and vacuum chambers have a mini flange for RGA head installation.

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References

1. http://camm.binghamton.edu/
2. http://www.flextech.org/ and http://usdc.org
3. K. Jain, M. Klosner, M. Zemel and S. Raghunandan, “Flexible Electronics and Displays: High-Resolution, Roll-to-Roll, Projection Lithography and Photoablation Processing Technologies for High-Throughput Production,” *Proceedings of the IEEE,* 93(8), 1500, 2005.
4. K. Allen, “Reel to Reel: Prospects for Flexible Displays,” *Proceedings of the IEEE,* 93(8), 1394, 2005.
5. R. Ludwig, R. Kukla and E. Josephson, “Vacuum Web Coating – State of the Art and Potential for Electronics,” *Proceedings of the IEEE,* 93(8), 1483, 2005.
6. D. Cairns and G. Crawford, “Electromechanical Properties of Transparent Conducting Substrates for Flexible Electronic Displays,” *Proceedings of the IEEE,* 93(8), 1451, 2005.
7. S. Lacour, J. Jones, S. Wagner, T. Li and Z. Suo, “Stretchable Interconnects for Elastic Electronic Surfaces,” *Proceedings of the IEEE,* 93(8), 1459, 2005.
8. http://flexdisplay.asu.edu/

Figure 1: Clean room view of GVE tool vacuum chamber showing (bottom half) three independently pumped process zones.

Figure 2: Service core side of GVE tool showing winding mechanism (top). The plasma pre-process zone and dual rotating cathode are shown clockwise on the right hand side.

Figure 3: CHA Industries Mark 80 roll coater with web winding and process zones mounted on the front door. The entire assembly moves on floor mounted rails into the vacuum chamber.