Challenges and Requirements for Flexible Displays and Microelectronics

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A range of work over the last decade has developed a new area of technology development: flexible microelectronics. Flexible microelectronics can be defined as integrated circuits built on a flexible substrate. The critical difference between this technology and that of conventional, or even advanced flex, is that the active devices (those containing semiconductors) are formed together with the lines and interconnects (rather than fabricated separately and then attached), providing great promise in terms of product cost and form factor. This concept is not new: it has been conceived and proposed for over 40 years. It is only more recently, in the wake of the AMLCD industry and it's related technologies in thin film transistor manufacturing, that flexible microelectronics has become a realistic goal.

There are dozens of R&D efforts around the world which are gradually demonstrating useful results in this area. The fabrication methods range from organic to inorganic semiconductors, from additive to subtractive patterning, from direct to transfer methods, from using plastic to metallic foil substrates. Though progress has been slower than hoped, some of this work is nearing manufacturability. One example is the EPLaR technology by Philips, a transfer method which is now running in a commercial-grade factory. Almost all of the work done in this area involves fabrication on panels of material, and given the large infrastructure of batch processing equipment for display manufacturing, the most convenient path forward will likely be batch mode manufacturing.

So, why do we wish to pursue Roll-to-Roll (RTR) manufacturing? The AMLCD industry has shown great success in lowering cost of production by increasing the panel size and improving yield through a variety of methods, and one would expect flexible microelectronics to benefit from this infrastructure. The answer to the above question lies in the path to commercialization. The evidence is strong that the many product advantages of flexible microelectronics, flexibility, form factor, ruggedness, low weight, etc., are not something for which the consumer will pay extra. In fact, since we are generally talking about replacing glass with plastic in a display, the consumer will expect to pay less! This presents a big barrier for display and other applications to adopt the flexible technology in a batch mode since they can expect the manufacturing costs to be even higher than with conventional substrates for some time to come. RTR manufacturing offers a way around this barrier by lowering manufacturing costs. Several efforts to model manufacturing costs have produced conservative estimates that, even with similar manufacturing methods the cost of production of a display backplane could be lowered by a factor of 50% to 67%. This is very attractive to an industry with margins of a few percent.

Even more exciting are the use of new approaches to manufacturing which are based more directly on conventional RTR methods like printing. Two projects which are taking this approach, the HP SAIL method, and Microcontinuum's Advance Surface Nanoforming method, are showing very promising results. Using these types methods, the cost of production could be expected to go down an order of magnitude or more. Other (publicly available) work in this area is work toward developing barrier layers for OLEDs, also being conducting in RTR pilot production.

In spite of these efforts, realizing a commercial RTR line remains a daunting task. Most of the RTR technology in use today was developed for products and applications with very different demands in terms of product value and yield. Significant challenges remain in particle and defect management, chemical contamination, substrate distortion, base material preparation and supply chain management. The concepts are not new to the converter industry, but the magnitude of the numbers involved and impact on product yield and cost is much higher than before experienced and requires a new effort and look at these issues.

The most dramatic challenge is in particle and defect detection and mitigation. For an AMLCD backplane, a typical requirement for a process is less than 0.1 per cm-2 for defects between 0.5 and 1 micron, down to 0 per cm-2 for defects 5 micron or greater. In AMLCD production, these defects are detected with direct imaging with high resolution, allowing Statistical and Pareto methods for managing the defects. Commercial RTR technologies today can detect such defects down to 5 microns at best, and even then without the desired resolution. New approaches and tools will be needed in this area.

Related to generating and detecting these defects is perhaps the second most challenging demand for flexible microelectronics: the supply chain. If material suppliers wish to participate in the emergence of this industry, the material supply will also need to be qualified to these specifications. Suppliers need to incorporate methods to clean and handle material to achieve these specifications. Webs which are wound without interleaf are prone to pick-up material originating from the rollers, etc.

On first pass it may appear that the costs of achieving these levels of cleanliness are too high to be practical. This assumption ignores the lessons of history: the move of the display industry to Asia two decades ago was largely a matter of production yield: investment and focus in achieving higher yield led to the more competitive costs achieved in Asia. This relates to the high value of the product being produced and will apply to flexible microelectronics.

Chemical contamination is another likely challenge toward RTR production. This is related to the incorporation of semiconductor devices in the process flow. Semiconductor properties are very sensitive to most contaminants to levels of only a few PPM. This sensitivity has driven the need for UHV (pressures of low 10-7 Torr or lower) as the operating conditions for many AMLCD and IC production tools. This is also true of all layers which come into contact with the semiconductor layer in a device, demanding in-vacuum transfer between processes. This level of contamination needs to be kept in mind for equipment vendors who wish to propose tools in this area. Out-gassing of web materials needs very high levels of isolation from processing areas, as well as complete separation from other process zones.

The majority of work on flexible microelectronics assumes the use of plastic (PET, PEN, PI, PC) substrates. These materials pose a significant challenge for many flexible microelectronic methods which often require micron-scale alignment of pattern layers over meter lengths. There are three general approaches to solving the problem of substrate distortion: 1) managing the thermal, hygroscopic and chemical schedule of the process to minimize the distortion. Practical experience from several labs suggests that this can be expected to reduce the distortions to within 100 ppm between process steps. 2) Adjusting the patterned images so that they compensate for the distortions. Optical projection can meet or exceed the 100ppm goal, and in fact the USDC is sponsoring such a tool now being installed at the CAMM. 3) providing self-alignment within your process. There are many examples of this in even conventional AMLCD manufacturing, and the HP SAIL process, is a great example of implementing this in a RTR format. In addition, just as with the defects, much of the challenge for material stability could be mitigated with an improved material supply.

The establishment of the Center for Advanced Microelectronics Manufacturing (the CAMM) at Binghamton University was motivated by the general need to study and advance the technology in RTR-based manufacturing. Tool installation is underway to establish 2.5 micron patterning on webs up to 2 ft width, defect inspection to 3 microns or less, high purity and low particulate vacuum processing, examine different methods of cleaning and web handling. Application areas envisioned range from flex circuitry, large area lighting, RFID, optical films and active matrix displays.

In summary, there is steady progress in developing flexible microelectronics that integrate semiconductor devices into the manufacturing flow. The path to commercializing this technology demands the development of new RTR manufacturing technology. Significant technical challenges remain in the areas of particle and defect management, chemical contamination, substrate distortion, base material preparation and supply chain management. While these challenges are not new to the converting industry, there needs to be a much higher emphasis and investment in this area to realize commercial success for flexible microelectronics. The CAMM at Binghamton University was established to bring a focused effort to just these needs.