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## Army-Backed Flexible Display Effort:

# A Symbol of Public-Private Partnership

*Greg Goth*

The promise of pervasive military networks featuring devices issued to each soldier or sailor has circulated for some time. These individuals would have rugged, lightweight displays that roll or fold up that they could use to access crucial and perhaps life-saving information in real time.

Contributing to an interesting "big picture" for this technology, the defense sector along with academic research and manufacturing interests have collaborated comprehensively to establish a viable mass-market foundation for flexible displays. Drawing on decades of experience in which military users have broken in new technology, the US government and industry consortia have invested in facilities such as the Flexible Display Center at Arizona State University (http://flexdisplay.asu.edu). This US$43.7-million-dollar center provides the Army with flexible display prototypes while also developing key manufacturing processes that will make flexible displays commercially viable.

"The Defense Department, particularly the Army, has really taken a strategic position here and invested in the FDC, with what seems to be a very feasible charter for it," says Janice Mahon, vice president for technology commercialization at Universal Display Corporation, a New Jersey-based company specializing in new display technology. "I think this is another element that, 20 years from now, we'll look back and say it really served its purpose as a catalyst to get a number of things demonstrated and really did efficiently help bring the technology into the marketplace."

### FEATURES AND APPLICATIONS

For both proponents of flexible display technology and dispassionate observers, the military funding of prototypes and the manufacturing process behind them might embody an entity with a critical need driving a market with widespread, if amorphous, hopes.

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The primary driver behind the Army's interest in promoting flexible displays is that the technology's physical properties offer vastly superior, if unquantifiable, advantages in safety for its frontline troops.

Soldiers have access to many of the networking capabilities they need for real-time information in form factors similar to civilian PDAs and laptops. However, the glass displays' physical properties mandate many extra pounds of protection around the glass to protect it from the occupational hazards of frontline duty as well as batteries to power the LCD glass interface. According to material prepared by analysts at the Combined Arms Center at Ft. Leavenworth, Kansas, the typical soldier carries weapons and gear weighing up to 100 pounds (www.globalsecurity.org/military/library/report/call/call_01-15_ch11.htm); such overloading often leads to mission-threatening and life-threatening fatigue.

The flexible organic light-emitting diode displays' salient physical properties are key to the defense sector's investment. Since OLEDs don't need a backlight as LCDs do, they're thinner and lighter. Bistable OLEDs, which the FDC is currently investigating, also don't need to receive power except when the user changes the display's image, meaning the soldier will need to carry fewer batteries into the field. As for durability, OLEDs are estimated to be 10 times more impact resistant than plastic LCDs and 100 times more impact resistant than glass LCDs. This combination of low power requirements and high durability dovetail well with the frontline soldier's needs.

David Morton, the Army Research Laboratory's flexible display program manager, says the Army envisions an initial application of the flexible displays as a credit-card-sized device, about 2.5 by 4 inches, on a foil substrate.

"Around that display there is a host of thin film transistor (TFT) test structures, where we're attempting to understand what else you can do with flexible transistors," FDC Director Greg Raupp says. "At a minimum, we'd love to put



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the driver circuit on the substrate. That will reduce the cost and also reduce the number of connections to the outside nonflexible world, which will make not just a lighter device, but also a more rugged device. Ultimately, we're asking if we can we put communications circuitry on there, or a complete wireless system on the substrate, or at least some components."

The device might attach to the soldier's uniform via a Velcro-type fastener, Morton says, or slip into a fatigue pocket.

## TECHNOLOGICAL CHALLENGES

The optimistic focus on what these devices will do has often overshadowed the nascent status of the industrial foundation that will realize them. In some cases, display manufacturers can adapt processes and materials from existing technologies such as LCDs. However, other aspects of display manufacture—such as fabrication temperature and lamination reliability—present challenges never before attempted under the constraints of flexible materials.

An example of the painstaking details the FDC must examine with its partners is finding a reliable adhesive. In April, the US Display Consortium (www.usdc.org), an industry-led group charged with managing supply-chain projects and sharing the results with member organizations, awarded the National Starch and Chemical Company a US$600,000 contract to develop an adhesive that can tolerate a wide range of temperatures and stresses. In the USDC release announcing the contract, National Starch executive Don Herr explained the project's goals. According to the USDC, most microelectronics development activities leverage existing semiconductor manufacturing tools, which were developed to handle rigid substrates of glass or silicon in a batch mode.

"Flexible substrates, however, cannot be handled by most of these tools without resorting to many undesirable or cumbersome methods, such as adding extra metal carrier plates, taping substrates into place, or manually picking and placing by tweezers," Herr said in announcing the contract (the company declined to make further comment about the project).

"This project will enable adhesives and processes to be developed that will increase the range of process conditions that can be used, thereby improving the FDC's chances of success. Furthermore, this project will create a source of bonded plastic substrates available to USDC member companies."

Additionally, the uncertainty about which substrate material—foil or plastic—might best lend itself to cost-effective flexible-display technology has meant that basic processes and toolsets are still being designed. The FDC plans to launch its first production-capable demonstrator line later this summer, Raupp says. Up until now, its work has been done on semiconductor wafer lines, which don't transfer to the needs of production-quality display lines.

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The effort to design a commercially viable process around these substrates has consumed much of the FDC's effort, according to Raupp.

"There is no drop-in manufacturing-ready replacement for glass and, therefore, that requires us to do two things," Raupp says. "First, we have to work with materials suppliers and developers to define requirements and develop new flexible materials that are display ready, and secondly, we have to develop modified processes from the traditional LCD processes to enable us to make high-quality transistor arrays on that substrate."

Several popular press stories have focused partially on the economic advantage that roll-to-roll flexible display processing—a process similar to newspaper and magazine publishing—would give manufacturers. However, Raupp says one of the most promising factors in ramping up flexible display manufacturing relatively quickly will be the ability to modify existing LCD techniques and lines to provide competitive prices for flexible units.

"It's safe to say I'm a skeptic on roll-to-roll," Raupp says. "First, roll-to-roll technology, for what we need, is immature and not ready. What we need to do is produce high-information content displays à la the quality of your desktops and cell phones, and there are too many process and toolset issues surrounding implementing roll-to-roll. Secondly, you're not going to get a better display out of roll-to-roll. You might, and notice I said might, potentially get lower costs, but it's not going to get you higher quality."

Raupp says flexible-display lines will benefit directly from the fast growth of existing LCD substrate lines. According to LCD manufacturer Corning, Inc., LCD substrate size has roughly doubled every 18 months since 2000. This increase in size lets manufacturers either make larger displays or make more smaller displays out of a single substrate, thereby increasing efficiency. To remain competitive in the LCD industry, these companies will have to adopt these bigger lines, although the older, smaller lines will still have usefulness. Raupp says the FDC is almost ready to launch a 370 mm × 470 mm (approximately 14 inches × 18 inches) Generation 2 demonstration line; he estimates it will be ready sometime in the third quarter of this year. By contrast, the latest LCD industrial lines can yield anywhere from 12 17-inch panels to 12 32-inch panels.

"It's very reasonable to assume that as the LCD industry goes to Gen 6 and above, they will retire some of their older lines," Raupp says, "and those lines, which will be fully depreciated, will still be working toolsets, and they will be modified appropriately and adapted to a

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flexible display application. In fact, one of the reasons we're doing Gen 2 is that we will then be able to transfer the technology to someone who has an existing line, Gen 2 to Gen 4 perhaps. It's not going to be the exact same toolset, but it will be mostly the same. They'll need a few new tools and a few modifications of existing tools, but the point is, we're not talking about the capital investment for putting in a whole new line. For a relatively modest investment, it will make sense for people who have made a big investment in new lines to keep the old runs running flex."

Morton says one of the big questions surrounding any substrate candidate, metal or plastic, is its ability to withstand various processing temperatures. Ultimately, he says, a material capable of tolerating low, medium, and high processing temperatures would go far in assuring an off-the-shelf reliable product. The move from low to medium and finally to a high TFT-processing temperature will mean, Morton says, that manufacturers will be able to fabricate some of the electronic circuitry directly onto the substrate—"which means you can reduce the interconnects, and the interconnects are going to be one of the first places the flexible display may fail."

## DUAL USE PRINCIPLES, PROMISE, AND PERILS

The current state of the research around flexible display manufacturing processes demonstrates the promise around the public-private partnership behind the FDC and the USDC. While a potentially life-saving military device offers obvious benefits, other industries are keenly interested in what flexible displays will mean for their futures. For example, mainstream publishing has seen revenue and circulation declines as online content vies with paper for readership. A lightweight flexible display might greatly reduce publishers' dependence on paper while retaining a newspaper or magazine's convenience and portability. As healthcare information technology becomes more ubiquitous at the point of care, doctors and nurses will also want lightweight devices that don't weigh them down or bulge out of their pockets as they make rounds through hospitals or offices. Just as defense-related research led to mass-market technologies, including global positioning systems in use on everything from automobiles to golf carts and the Internet itself, flexible display pioneers say the Defense Department-led investment in new processes and tools will mean more market opportunity and lower costs per unit.

"There's no question that what the military wants is not a small volume of very high-cost specialized displays," Raupp says. "They want to go to a major manufacturer of flexible displays for commercial applications, buy the COTS technology, and integrate it into military systems."

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Moreover, the idea that the military can pay any price for flexible displays—or any cutting-edge technology—is simply not feasible, according to a veteran of industry and government who warns that the free-spending era for the military establishment won't go on forever.

"We've been living in a rich man's world the last six years, ever since September 11," says Jacques Gansler, vice president of research at the University of Maryland; Gansler served as Undersecretary of Defense for Acquisition, Technology and Logistics from 1997 to 2001. "I suspect we won't be living in that world for long."

In fact, the Defense Science Board Task Force for Manufacturing Technology, which Gansler chaired, issued a comprehensive assessment of the military's development of critical new technologies in February (www.dodmantech.com/pubs/dsb_2006-02_Mantech_Final.pdf). The report didn't mince words in evaluating what members felt were some salient shortcomings of the development process:

"Today's high-technology weapon systems cost too much to buy, take too long to field, and are expensive to sustain. Systems proceed through the acquisition process with immature technology and unstable designs, which result in higher costs, longer development times, and even reduced order quantities—all detrimental to the ultimate goal of enhancing warfighting capabilities."

While, on a per-unit basis, flexible displays don't cost nearly as much as ballistic missiles or jet aircraft, the industry's nascent state bears watching as public, private, and academic experts align military and commercial marketplace goals to achieve scalable, affordable, and reliable flexible display products.

"The Army has always been among the first users, if not the first, for new technology, and with flex displays, there's an obvious advantage in a number of ways for us," Morton says. "We understand, even if we gave every solider two flexible displays, that it would take up a couple days of the production of a real display plant, and because of that we want the technology commercialized. We want to be able to buy it."

Morton says the eventual advent of mass-market flexible displays is taken for granted, yet enough questions about the most cost-effective way to enter the market still abound. This leads to hesitancy among manufacturers to jump in headlong—"So, by demonstrating the manufacturing capability for this as well as some of the applications, we're hoping to get over that." P