Faster transistors for large, high-resolution displays

New inorganic metal oxide semiconductors that increase image resolution and reduce production costs are set to revolutionize the display industry. Resource Efficiency’s Electronic Solutions Team was awarded the 2014 Evonik Innovation Award in the New Products/New System Solutions category for an innovation it pioneered under the brand name iXsenic®.

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Display performance depends on thin-film transistors

Cross-section of a liquid crystal display (top), backplane and thin-film transistor (bottom)
Controlling whether pixels transmit light requires an additional electronic component located between the backlight and the pixel matrix: the TFT backplane (TFT stands for thin-film transistor, fig. 2). Each subpixel needs this kind of transistor, which acts as a switch regulating light transmission between fully opaque and fully transparent in response to the voltage applied. A Full HD television requires roughly six million TFTs (approximately two million for each of the three primary colors).

The TFT backplane has a critical influence on the quality of video that can be shown on the display—the bigger the screen, the faster the TFTs have to switch on and off. If not, video sequences with rapidly changing scenery will appear blurred. The standard technique that manufacturers currently use for producing TFT backplanes is to apply thin films to glass plates via vapor deposition—specifically via chemical and physical vapor deposition (CVD and PVD, respectively). Sputtering is an example of the latter.

CVD involves a chemical reaction causing silicon to precipitate out of the gas phase and onto the surface of a heated substrate. In sputtering, high-energy ions eject individual atoms from a solid silicon body, and these then precipitate onto the substrate. Both methods require a high vacuum. Etching processes involving the use of shadow masks and photoresists strip away unwanted material from the resulting deposition layers, thereby creating structures on the backplane.

Amorphous silicon is the base material for over 80 percent of TFT backplanes, and display manufacturers have decades of experience with the technology. In order to create large displays and produce these kinds of backplanes economically, the industry has developed larger and larger facilities over the years for each new generation of display. Whereas the maximum backplane that could be produced in 2000 had an edge length of roughly one meter (GEN 4 and GEN 5), the first facilities able to handle GEN 10 substrates—i.e., glass plates covering an area of approximately 2.90 m x 3.10 m—came online about five years ago. The use of amorphous silicon in TFT backplanes is nearing its limit for large displays. This is due to its material properties, as the speed at which a thin-film transistor can switch on and off ultimately depends on the charge carrier mobility. A large, high-resolution LCD television requires charge carrier mobilities between one and ten square centimeters per volt per second—values that amorphous silicon simply cannot achieve without considerable technical difficulty, if at all. This will pose major technological challenges for the display industry over the coming years.

This was the starting point for Evonik’s Electronic Solutions Team, an Innovation Management unit within Resource Efficiency. Instead of amorphous silicon, future TFTs could be made using inorganic metal oxide semiconductors, which, in turn, can be applied to the substrate using a coating process—and Evonik developed a toolbox for this approach. Marketed under the brand name iXsenic®, this new product is based on metal oxide semiconductor materials, to which other materials needed for TFT production have been added.

Development of iXsenic® began about seven years ago at Creavis, Evonik’s strategic innovation unit. In 2012 the team that had developed the metal oxide semiconductor materials moved over to the Coatings & Additives Business Unit (Resource Efficiency as of 2015) in order to prepare for the market launch. Today’s Electronic Solutions Team consists of approximately 30 employees who come from nine different countries and a variety of backgrounds, representing the disciplines of chemistry, physics, electrical technology, engineering, business, and more. In addition to its homes in Marl (Germany) and Shanghai (China), the team also runs an Applied Technology Center in Hsinchu (Taiwan) starting in 2014.

The metal oxide semiconductors that the Electronic Solutions Team developed exhibit charge carrier mobilities of 15 square centimeters per volt per second, regardless of the specific application involved. Under laboratory conditions, that figure rises to as high as 40 square centimeters per volt per second. These properties make these materials perfect for the TFT backplanes used in the large, high-resolution displays of the future.

High charge carrier mobility values are not the only way that metal oxide semiconductors break new ground: as solvent-based materials, metal oxide semiconductors can simply be coated onto substrates to form thin-film transistors. While this process requires clean-room conditions, it does not—unlike CVD or sputtering—require high vacuum, and that lowers display manufacturers’ energy and equipment costs. In addition, a process based on deposition from a liquid is relatively easy to scale up—an important property given that display size is constantly growing (think GEN 10). Evonik now intends to work with its key customers to develop production-ready iXsenic®-based TFT backplanes.
The specialty chemicals company has acquired sufficient patent protection for both the product and the process, and the Electronic Solutions Team has industrial-grade clean rooms and coating systems at its disposal. Production processes in the display industry can vary greatly from one manufacturer or plant to another, and when addressing these issues the team collaborates with two research partners: the Belgian-Dutch Holst Centre and the Industrial Technology Research Institute (ITRI) of Taiwan. At the same time, the team is also working on a ready-to-use solution that will significantly reduce the amount of adjustment that display manufacturers have to undertake in order to make the switch to metal oxide semiconductors.

The metal oxide semiconductor is basically suitable for all common display technologies (fig. 3): in addition to LCDs, this includes displays made from organic light-emitting diodes (OLED), electrophoretic displays (such as those used in e-book readers), touch screens, and flexible displays. The production of the latter is possible because—unlike CVD and sputtering—processes for applying metal oxide semiconductors can be run at temperatures low enough to prevent damage to polymer-based substrates. Evonik and Holst Centre, for instance, joined forces at SID 2014, a respected display industry trade show, to present a flexible OLED display on a polyimide foil.

If printing technology was advanced enough, Evonik’s metal oxide semiconductors would allow manufacturers to print electronic components, fulfilling the ultimate dream of the electronics industry. The chemical company also collaborated with Panasonic to present an 8-bit thin-layer microprocessor at the 2014 ISSCC Semiconductor Conference—a demonstration that vividly illustrated the suitability of iXsenic® for printing. An article about this microprocessor has been published in the Scientific Reports section of the distinguished journal “Nature.”

Evonik has already achieved a major milestone with the coating technology existing today, with initial customers now developing market-ready displays using iXsenic® technology. iXsenic®, in other words, gives Evonik a presence on the display market—a market currently estimated to be worth roughly US-$150 billion—opening up an entirely new business area for the company.