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Organic Transistors Speed Up

By Alexander Hellemans

Experimental single-crystal devices overcome fabrication problem

3 December 2003—Engineers working with organic electronics dream of cheap, ubiquitous carbon-based circuits printed on plastic sheets. But for that to happen, scientists must find a way to get current to flow faster in organic field-effect transistors (OFETs). Now, two groups have tweaked the manufacturing process of single-crystal OFETs to boost their switching speeds.

At present, organic semiconductors don't measure up to their inorganic counterparts, notably silicon. Mainly that's because of their low charge carrier mobility: the electrons or holes typically move three orders of magnitude more slowly than the charge in inorganics. It's a drawback that severely limits the currents that devices can switch, as well as the frequency at which they can operate, observes Moritz Sokolowski, a physical chemist at the University of Bonn in Germany.

The big problem of low carrier mobility has to do with the fact that experimental OFETs still are almost always deposited as a film on a substrate of silicon dioxide, leading to imperfections in the first organic layers laid down. But now several research teams are investigating ways to circumvent this deficiency by using freestanding single organic crystals—crystals grown from a vapor rather than deposited in layers on the surface. The crystals therefore have perfect lower layers for the channel through which charge flows. The two groups are making OFETs with mobilities that compare not too badly with the mobility of amorphous silicon used to control the pixels in flat-panel displays, 1 cm2/ V-s. Researchers at Rutgers University (Piscataway, N.J.) have reported a mobility of 8 cm2/ V-s in rubrene crystals, while a group at Delft University of Technology in the Netherlands has achieved a mobility of 0.4 cm2/ V-s in tetracene crystals.

Getting around glass

In some of today's experimental OFET designs, the source and gate electrodes of gold, silver, or doped silicon are deposited on the organic semiconductor film; in others, the organic film is deposited over electrodes that are prefabricated on the insulating silicon dioxide layer. A charge applied to the gate creates a channel by attracting electrons or holes, thus increasing the charge carrier density in a few molecular layers adjacent to the material insulating the film from the gate.

The reason silicon dioxide is still so widely used as an insulator despite the imperfections it generates in the layers deposited on it is that it has a much higher dielectric constant than common organic insulators—it transmits the electric field created by the gate much better to the organic channel. Yet, for reasons imperfectly understood, the structural defects in the layers of molecules closest to the gate strongly hamper mobilities, evidently because the initial layers are critical in allowing current to flow.

Bypassing the dilemma, Vitaly Podzorov and his colleagues at Rutgers created single-crystal rubrene OFETs using a gate-insulating layer of parylene, instead of silicon dioxide, and directly depositing silver contacts on the crystal to form the source and drain electrodes. Parylene has a dielectric constant comparable to that of silicon dioxide (~3 versus 3.9) and allows the creation of very thin insulating films without defects. Though the way the OFET was constructed helped, the major factor in achieving a record-high mobility of 8 cm2/ V-s was the choice of the semiconductor, says Podzorov, who has submitted his team’s work to *Applied Physics Letters*.

Alberto Morpurgo and his colleagues at Delft stuck with silicon dioxide as a dielectric and used tetracene as a semiconductor. By growing a single crystal atop the substrate instead of depositing the tetracene as a noncrystalline film, "we limited the damage done to the organic material," Morpurgo says. Besides making a single crystal, the technique made the tetracene stick close to the gate dielectric and bond with the gold source and drain contacts already deposited on the silicon dioxide, both important for making fast transistors. Thus their best crystals were able to achieve a mobility of 0.4 cm2/ V-s, which is the fastest speed reported for tetracene so far.

A field revived

Closely following the latest developments in organics is Christoph Wöll, a physicist at the Ruhr University of Bochum in Germany. Wöll believes that the ongoing research with single crystals will be extremely important in understanding how electric charges travel through these materials. Although the big differences in the measured mobilities may depend on experimental conditions, such as the quality of the electrical contacts with the organic material, "they may indicate that the mobilities depend more on the choice of molecules than was thought before," he says.

At the same time, anticipating the day when commercially viable organic devices will be made, Wöll points out that low mobilities will be less of a problem if the devices can be kept very small, on a nanometer scale, minimizing the length of the channel. In other words, the charge does not have to move so quickly, because it does not have far to go. Summarizing the tradeoffs, Wöll says that "either you have an expensive technology for making small devices, and you don’t need to bother with mobilities, or you use conventional technology to make fairly large and cheap structures, and then you need high mobilities."

The new field of organic electronics got a nasty blow last year with the discovery that a star researcher at Lucent Technologies Bell Labs (Murray Hill, N.J.), Jan Hendrik Schön, had faked a large number of papers reporting spectacular results with organic materials. (Tetracene’s allegedly becoming a superconductor in a very strong electric field was one of them.) Yet paradoxically, the affair may also have had some positive impact—as Wöll sees it, anyway. "Schön was in a sense very clever in proposing the use of mobilities in organic materials before anybody had measured them. It became clear [after the debacle] that we had to understand the fundamentals first," he concludes.

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