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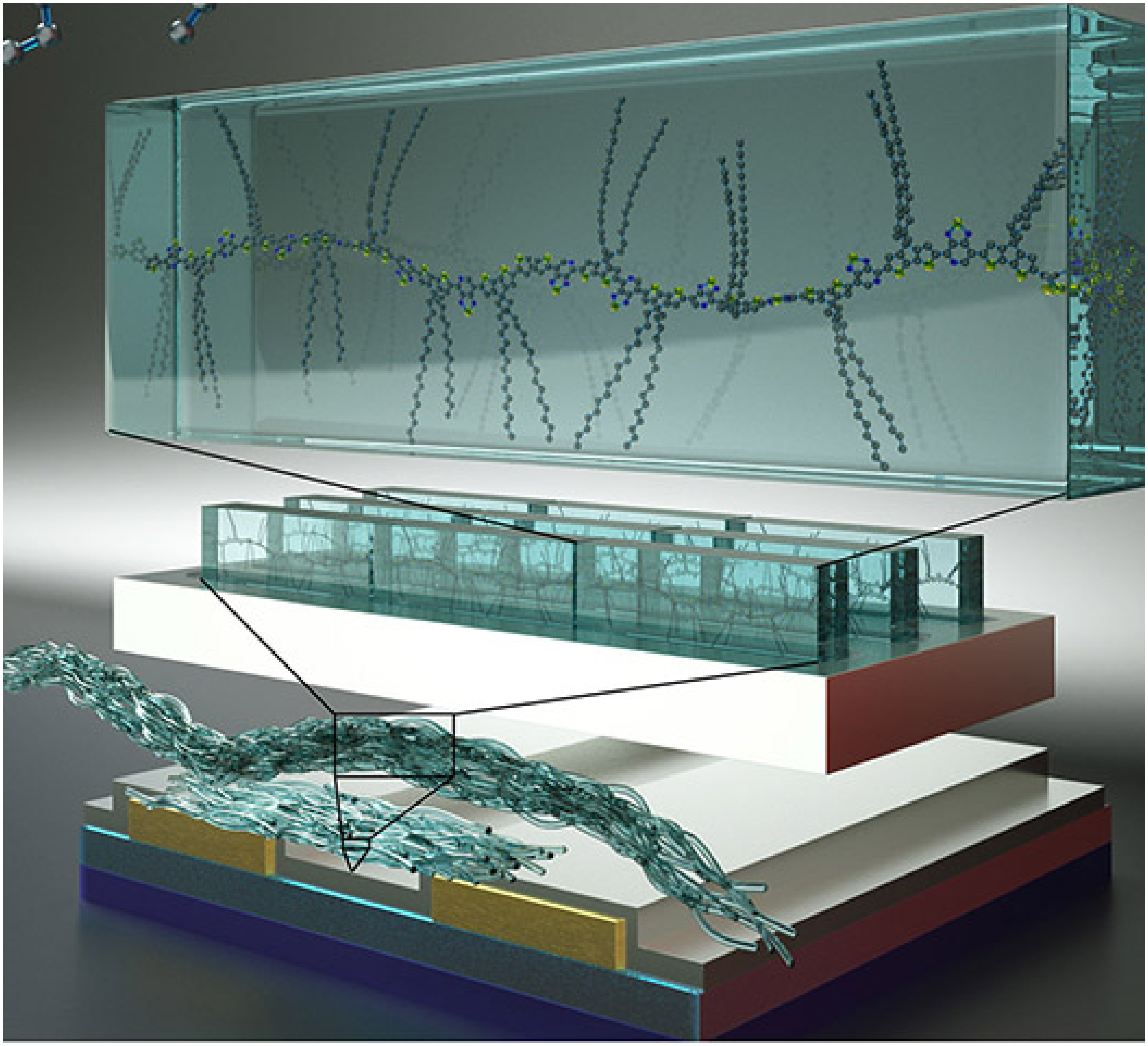
UCSB Researchers Develop Polymer Transistors with High Carrier Mobility

A collaborative team at University of California, Santa Barbara?s Mitsubishi Chemical Center for Advanced Materials has demonstrated commercially-viable, high carrier mobility for transistors made from semiconducting conjugated polymers

Display technology as we know it is rapidly changing thanks to the development of flexible electronics and a new generation of thin-film transistors. Transistor manufacturing technology can make or break the limitations of what?s possible with electronics. Researchers battle the challenges of energy and cost: whether the transistor material can be fabricated efficiently in sheets or arrays, and if the process temperatures are low enough to allow manufacturing without the use of high temperatures and high energy use.

Recently, researchers with the Mitsubishi Chemical Center for Advanced Materials, and the Departments of Materials, Chemical Engineering, Chemistry and Biochemistry, and Physics at University of California, Santa Barbara, have demonstrated that thin film transistors made from semiconducting conjugated polymers are unexpected contenders for the race toward flexible, scalable, and low-cost electronics. The results of their research, in a paper titled ?High Mobility Field Effect Transistors Fabricated with Macroscopic Aligned Semiconducting Polymers,? were published recently in Advanced Materials.



Artist's concept demonstates semiconducting polymer chains are closely packed to each other along the fiber direction, and individual fibers are aligned within the fiber bundles from electron source to drain in the channel of the thin film transistor, which leads to predominant intrachain charge transport and record high OFET hole mobility. *Credit: Peter Allen, UCSB*

?This is the first time someone can claim that polymer transistors could be a viable, low-cost material for the backplanes needed in display manufacturing,? explained Hengbin Wang, Senior Scientist with Mitsubishi Chemical USA, Inc. The key to an organic semiconductor that makes it a strong candidate, they found, is a high carrier mobility made possible by alignment of the semiconducting polymer chains in the channel of the thin film transistor.

A polymer is a chain of repeating hydrocarbon molecules with alternating single and double carbon-carbon bonds. One might think of the shape it takes as forming a backbone ? and along this backbone there?s a path perfect for fast and easy charge transport. Getting this molecular structure just right is critical to the performance of a polymer transistor, and thus for developing ?plastic electronics.?

?A huge benefit of a polymer transistor is flexibility,? commented Hengbin Wang, who is a visiting scientist at UC S anta Barbara. ?But only this past year have researchers been able to show that polymer transistors reaching a ch arge mobility of 10 cm^2/Vs. Now, this team has demonstrated good thermal stability and a record hole mobility as high as 23.7 [cm^2/Vs] and we believe that?s only the beginning of the system?s full potential.?

On a basic level, a transistor is an electronic switch and mobility determines how much current can be switched ? and how fast. Charge carrier mobility is therefore critical for efficient electronics of any kind. Until this point, po lymer semiconductors have only been demonstrated at carrier mobilities typically below 1 cm^2/Vs. The higher the mobility, the more useful the transistor and, in the case of displays, it means less voltage is needed for illumination.

UC Santa Barbara professor and Nobel laureate Alan Heeger, in collaboration with former postdoctoral researcher Hsin-Rong Tseng, initially proposed the model behind the high mobility polymer transistor based on a concept that Heeger first imagined thirty years ago: obtain high mobility via well-aligned polymer chains. He teamed up with materials professor Guillermo Bazan?s lab to produce an excellent candidate polymer.

?I think we?re on a pathway to an even higher mobility,? commented Heeger. ?Plastic semiconductors are attracti ve to manufacturers because they?re soluble and can be printed. They?re flexible materials, an advantage for many applications, and the entire process is scalable.?

The UC Santa Barbara team is the first to demonstrate a high carrier mobility along a polymer chain. ?I ho nestly think it?s a major breakthrough,? commented Heeger. ?People talk about the plastic electronics revolu tion, and the transistor is the most critical element. Once you reach carrier mobility values of 25 or 50 [cm^2 $/Vs$], a material can be used to make backplanes for electronics. We?re nearly there.?

The group of materials professor Guillermo Bazan, known for his polymer research in high-efficiency flexible solar technology, stepped up to the challenge of designing a series of polymer chains that met the requirements, and honed the process of applying the polymer to a nano-structured substrate with 200nm grooves to guide the formation of aligned polymer chains in a way that would achieve the highest carrier mobility.

?The materials design of the polymer stems from basic science considerations on how to take advantage of di fferent monomer symmetries in order to achieve highly regioregular backbones,? Bazan explained. Structural sy mmetry is important, he says, to maximize the carrier mobility of the polymer. The processing approach was to align the polymer molecules from electron source to drain, forming ?fiber bundles? that enable electron flow alon g the polymer chain instead of hopping molecule to molecule as in traditional pi-pi stacking.

Using electron diffraction and high resolution Atomic Force Microscopy, researchers in the groups of professors Edward Kramer of materials and chemical engineering, and Thuc-Quyen Nguyen of chemistry and biochemistry, respectively, affirmed that the crystalline structure on the polymer in the high mobility films was highly aligned with the conjugated polymer backbone along the desired direction of current flow. ?The pi-pi st acking direction of the crystals was in the plane of the film. This high alignment of the crystalline structure is believed to be responsible for the high mobility,? commented Kramer.

The promise of polymer transistors lies in a scalable, lower-cost, and energy-efficient manufacturing process. The polymer used by the UC Santa Barbara team is soluble in organic solvents and prints out like a coating or an ink in a roll-to-roll process. In comparison to manufacturing metal oxide or silicon transistors which require high energy ? and a batch process ? polymer transistors offer a ?cleaner and greener fabrication process,? describe d Wang.

As viable leads in the race to improve upon traditional silicon based transistors, other materials have proved hopeful?such as printable carbon nanotube transistors, and polycrystalline silicon or metal oxide materials. Po lymer transistors, however, offer potential advantages over these materials in a number of ways, including fabrication at lower temperatures, and a low cost process. One big advantage is that they can be produced on flexible, light weight substrates covering larger areas.

?Manufacturers have tried to use organic transistors for smaller flexible applications, such as barcodes, RFIDs, or lightweight cards,? said Wang. ?This discovery opens doors for applications like bigger, flexible displays using OLED technology.?

?This research is an example of the success that can come from a long-standing academia-industry pa rtnership,? commented Glenn Fredrickson, professor of materials and director of the Mitsubishi Chemical Center for Advanced Materials at UC Santa Barbara.

?The expertise of UCSB in organic synthesis and molecular electronics has been paired with Mitsubishi Ch emical Corporation?s industry knowledge to create polymers and process techniques leading to materials with un precedented carrier mobilities that should impact future lighting, display, and flexible electronics technologies,? added Fredrickson.

"These polymers are a new concept compared to conventional thin film transistor materials, including silicon, metal oxide and organic small molecule semiconductors, which achieved high mobility by their high crystallinity, but associated grain boundaries limited homogeneity of large area devices,? added Dr. Akira Oh no, Senior Researcher with Mitsubishi Chemical Group Science and Technology Center. ?The polymer fiber bu ndle structure realizes high mobility at much lower crystallinity that these materials, resulting in expectation of high homogeneity throughout large area and durability against a small curvature when the device is bent. They are indispensable features for large area and/or flexible devices in the future.?

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