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NANO SPOTLIGHTS

Micrometer- and Nanometer-Sized Organic Single Crystalline Transistors

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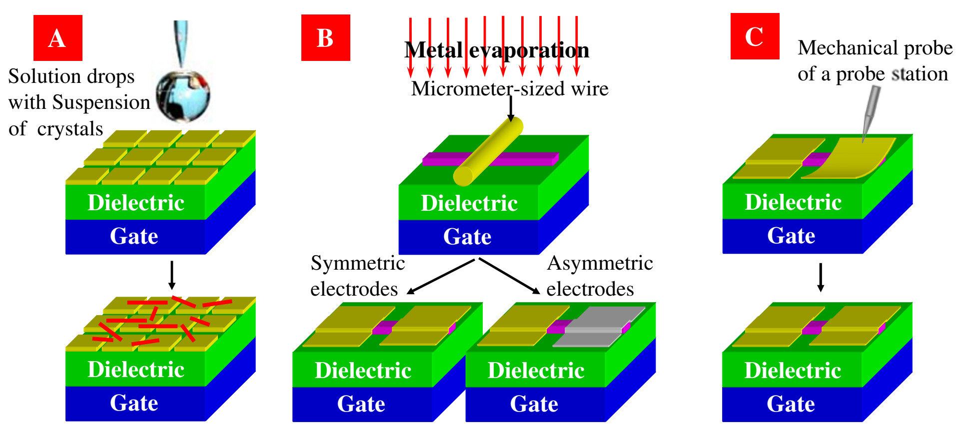
Single crystal devices of organic semiconductors have attracted worldwide attention due to (i) the high performance of organic single crystalline devices and (ii) the possibility of single crystals to reveal the intrinsic charge-transport properties of organic semiconductors. Normally, organic crystals exist as nanometer- or micrometer-sized "small" crystals because of the weak interaction between the molecules of organic semiconductors, and it is challenging to grow large size organic single crystals for devices, even the crystals at millimeter size. Hence, if devices could be fabricated by using the "small" organic crystals directly, it will be beneficial to not only keep all the advantages of organic single crystals and avoid the challenge for the growth of large-sized crystals, but also provide a way to characterize organic semiconductors more efficiently. Furthermore, the effective using of the "small" crystals will be meaningful for the integration of organic single crystals to micro- and nanoelectronic devices. Unfortunately, traditional inorganic microfabrication techniques such as electro-beam/focused ion beam depositions will damage or pollute organic crystals, which limit the application of the inorganic microfabrication techniques for organic single crystalline devices. So, new technologies to fabricate devices with "small" organic crystals must be developed. Recently, the researchers in Institute of Chemistry, Chinese Academy of Science, explored several



Crystals were dispersed on bottom-contact electrodes via drop-casting, spin-coating, or spraying coating from the solution with the suspension of crystals.

One single micrometer-sized wire was applied as the shadow mask. By multi-movement of the micrometer-sized wire, the channel length was decreased and asymmetric electrode devices could be fabricated.

A technique was developed to make drain and source electrodes with mechanical process. Thin Au layers were transferred onto the micro /nanometer sized crystal as electrodes.

novel methods to realize the fabrication of devices and study the transport properties of the "small" crystals.

Prof. Wenping Hu and prof. Hongxiang Li, who lead the research group from Beijing National Laboratory for Molecular Science, Institute of Chemistry, Chinese Academy of Science, reported several novel methods to overcome the challenge in Research News titled "Micrometer and Nanometer-Sized Organic Single-Crystalline Transistors" in *Advanced Materials* published online on July 4, 2008. "By traditional physical vapor transport and chemical solution growth process, micrometer and nanometer-sized organic single crystals can be obtained more easily than large-sized crystals. Using these micrometer- and nanometer-sized organic single crystals not only retain all the merits of single crystals, but also provide more effective ways to characterize organic semiconductors," said Hu and Li. "We have opened up some new techniques to make small sized organic single-crystalline devices, for example, the multi-time gold microwire mask moving method." Hu and Li explained to Nanospotlight, "We placed the gold microwire above the small crystals, fixed the gold wire with silver glue, and then deposited the electrode. The gold wire serviced as mask to obtain the conducting channel with the length equal to the diameter of gold wire. After that, we slightly moved the gold wire, and deposited the metal again. The channel width can be decreased further. If a gold wire with width of 20 micrometer was used, the channel length can be decreased till 5 micrometers." "Another advantage of this technique is the fabrication of the asymmetric electrodes, which is difficult to realize by other mask technique." With this technique, high-performance copper phthalocyanine (CuPc) devices with Au/Au symmetric electrodes (published separately on November 21, 2005, online edition of *Advanced Materials*, "Low threshold voltage transistors based on individual single-crystalline submicrometer-sized ribbons of copper phthalocyanine"), and copper hexadecafluoro phthalocyanine ($F_{16}CuPc$) devices with Au/Ag asymmetric electrodes (published separately in October 26, 2006, online edition of *Journal of the American Chemical Society,* "High-Performance Air-Stable n-Type Transistors with an Asymmetrical Device Configuration Based on Organic Single-Crystalline Submicrometer/Nanometer Ribbons") have been achieved. "We are also exploring other device fabrication techniques." Hu and Li said. "By simply using a mechanical probe to scratch the polymer layer on a Si substrate to create a gap as an air dielectric, using single-crystalline ribbon as semiconductor layer, and stamping the thin Au layers to form electrodes, the air-dielectric devices could be fabricated." The results achieved by their group demonstrated excellent photo/air stability and good performance of single-crystalline $F_{16}CuPc$ devices (published separately on February 28, 2008, online edition of *Applied Physics Letters*, "Air/vacuum Dielectric Organic Single Crystalline Transistors of Copper-hexadecafluoro phthalocyanine Ribbons"). Another exciting result was the ambipolar single-crystalline devices with the high mobilities and good balanced carrier injection realized with this technique (published separately on April 1, 2008, online edition of *Advanced Materials,* "High-Performance Air-Stable Bipolar Field-Effect Transistors of Organic Single-Crystalline Ribbons with an Air-Gap Dielectric"). "On the other hand, the practical application requires the controlled growth of these small crystals, which is also very challenging." Hu and Li told Nanospotlight, "We developed a seed-induced vapor growth process to obtain in situ patterning of organic nanoribbons." The compared results proved that the clean environment of the physical transport system and the high temperature of the substrate excluded the possibility of interface contamination, and the *in situ* patterned nanoribbons formed perfect interface with dielectric (published separately on November 14, 2006, online edition of *Advanced Materials*, "In Situ Patterning of Organic Single-Crystalline Nanoribbons on a SiO_2 Surface for the Fabrication of Various Architectures and High-Quality Transistors"). "Alternatively, we also explored the growth of organic small crystals with chemical solution method. Precise size-controlled crystals have been obtained by carefully adjusting experimental parameters (published separately on February 29, 2008, online edition of *Journal of the American Chemical Society,* "Single-Crystalline, Size, and Orientation Controllable Nanowires and Ultralong Microwires of Organic Semiconductor with Strong Photoswitching Property")." Hu and Li said, "We are now working to integrate these high-performance devices into micro/nanoscale single-crystalline circuits. The experimental results have showed that the complex circuits can be constructed with these micro/nanocrystals."

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