Inkjet Printing of Single-Crystal Organic Semiconductors

We have developed a printing technology to manufacture single-crystalline organic semiconductor films. This “double-shot inkjet printing” method introduces a technique of antisolvent crystallization into the micro-fluidic inkjet printing processes. We found that the sequential deposition of an antisolvent and a semiconductor ink that prompts crystallization of the organic semiconductor. Figure 1 presents a schematic of this printing technique. The crystallization ink is first deposited from an inkjet head, and the semiconductor ink is then over-printed from another inkjet head to form an intermingled micro-liquid droplet. Here, C8-BTBT (2,7-dioctyl[1]benzothieno[3,2-b][1]benzothiophene) [2] was used as the organic semiconductor. A supersaturated state of the organic semiconductor is immediately formed in the intermingled droplet, which results in the slow film growth of the organic semiconductor at the liquid-air interface of the droplet. Particularly, it was found that by appropriately designing the deposited pattern on the sheets, the growth direction of the semiconductor layer could be controlled. Thus the technique allows the production of semiconductor thin films with highly uniform thickness at arbitrary positions reproducibly, which is extremely difficult to achieve by conventional printing techniques.

The single crystal nature of the films was investigated by synchrotron X-ray diffraction at the Photon Factory of KEK. It was found that all the diffractions were observed as clear spots [Fig. 2(a)]. The observation of Bragg reflections up to the 14th order indicates that the organic semiconductor single-crystal thin films have a highly crystalline nature. At high incident angles of the X-rays, we observed 16 Bragg reflections including an in-plane component. The refined unit cell including an in-plane component. The refined unit cell based on the analyses of the observed diffractions is consistent with that of C8-BTBT. The films were also investigated by a crossed-Nicols microscope. It was found that the color of almost the entire film uniformly changes from bright to dark when the film was rotated around an axis perpendicular to the film surface [Fig. 2(b)]. This indicates that the whole film is uniformly optically anisotropic. From these results we conclude that the inkjet-printed C8-BTBT single crystal films exhibit high mobility reaching as high as 16 cm^2/Vs on average. The on/off current ratio is larger than 10^5, and the sub-threshold slope is about 2 V per decade. The mobility value is more than 10 times higher than that of amorphous silicon TFTs which are used in conventional liquid-crystal displays, and 100 times as high as that of organic TFTs produced by the conventional printing methods.

The newly-developed double-shot inkjet printing technique will be useful for manufacturing organic semiconductor thin films with high uniformity and for improving the performance of the TFTs, which have been major challenges in the printed electronics technology. This technology will greatly accelerate the research and development of flexible electronic devices.

REFERENCES

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