Analytical Characterization for NIL production of Organic TFTs by Energy-Filtered Transmission Electron Microscopy

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The field of organic electronics moves on from purely laboratory based development to standard production procedures which require high throughput at low costs. Therefore individual manufacturing steps are being intensively studied to systematically improve the production of organic electronic devices. Among the investigation techniques to analyze the specimens' appearance at individual steps of production, transmission electron microscopy (TEM) of cross section lamellae has turned out to be an essential tool.

Within this study the production of organic thin film transistors (TFT) with sub-micron channel lengths by applying Nanoimprint Lithography (NIL) is studied. The principle of this procedure is shown in Figure 1a. A silicon stamp, containing source and drain pattern, is pressed onto a stacked system of substrate (glass or flexible substrates), gate electrode, dielectric and an imprint resist. During imprinting the resist is cured and thereby the pattern is transferred irreversibly into the resist. After the release of the stamp the resist has to be etched away so that no residual layer is left at the imprinted areas. Subsequently the electrode material can be sputtered, lifted off and finally the active material is applied to complete the device. The etching process is particularly delicate because it is costly, hard to control, and it might be harmful to an organic layer underneath.

Here we present an improvement of the imprinting step, resulting in a completely residue-free imprint making the etching step obsolete [1]. The key component of our NIL process is a novel imprint resist (NImpR). The residue-free imprint is facilitated by the use of an adjustment of the stamp's surface energy to maximize the contact angle.

To evidence the residue-free imprint, cross section lamellae were prepared using a focused ion beam instrument (FIB) and analyzed by analytical TEM investigations. Since the specimens are multi-layered compositions of inorganic and organic layers on glass or soft matters both, the preparation as well as the TEM investigation turned out to be quite challenging. However, bending of the lamella was kept under control by thinning only regions of interest and thus leaving the major part of the lamella as a static support as shown in Figure 1b. This way the lamellae could be prepared successfully and thinned to a suitable value for energy filtered TEM (EFTEM) as evidenced by a relative thickness map shown in Figure 1c. A zero-loss filtered bright field image is shown in Figure 1d where the substrate, the gate electrode, the polymers and the protective layers can clearly be distinguished. However, a distinction between the individual polymer layers could not be achieved. In the presented case three polymer layers are involved, benzocyclobutene (BCB), poly-(vinyl cinnamate) (PVCi) and NImpR. Since on the one hand BCB contains silicon and on the other hand NImpR contains nitrogen, and both elements are detectable with electron energy loss spectroscopy, elemental mapping enables the visualization of the spatial distribution of the involved polymers. Figure 1e shows a superposition of four differently colored elemental maps, where the different polymers can clearly be distinguished. NImpR is obviously

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completely removed in the imprinted areas, even small pumps, as indicated by the white arrow, can clearly be identified as PVCi.

In summary we could improve the NIL procedure by eliminating the etching process. This is realized by a residue-free imprint step enabled by a novel imprint resist. The residue-free imprint could be evidenced by TEM investigations. Reactive ion etching is known to damage organic layers and it is hard to be implemented in a standard printing line. Moreover, it is costly and time consuming. The cancellation of this step is a huge improvement with respect to the whole process. Furthermore, the authors want to emphasize that NImpR allows a lift-off with deionized water, which is a big advantage with respect to ubiquitous availability, the potential for immediate recycling and environmental sustainability, resulting in a further decrease of production costs and an increase of process safety. [2]

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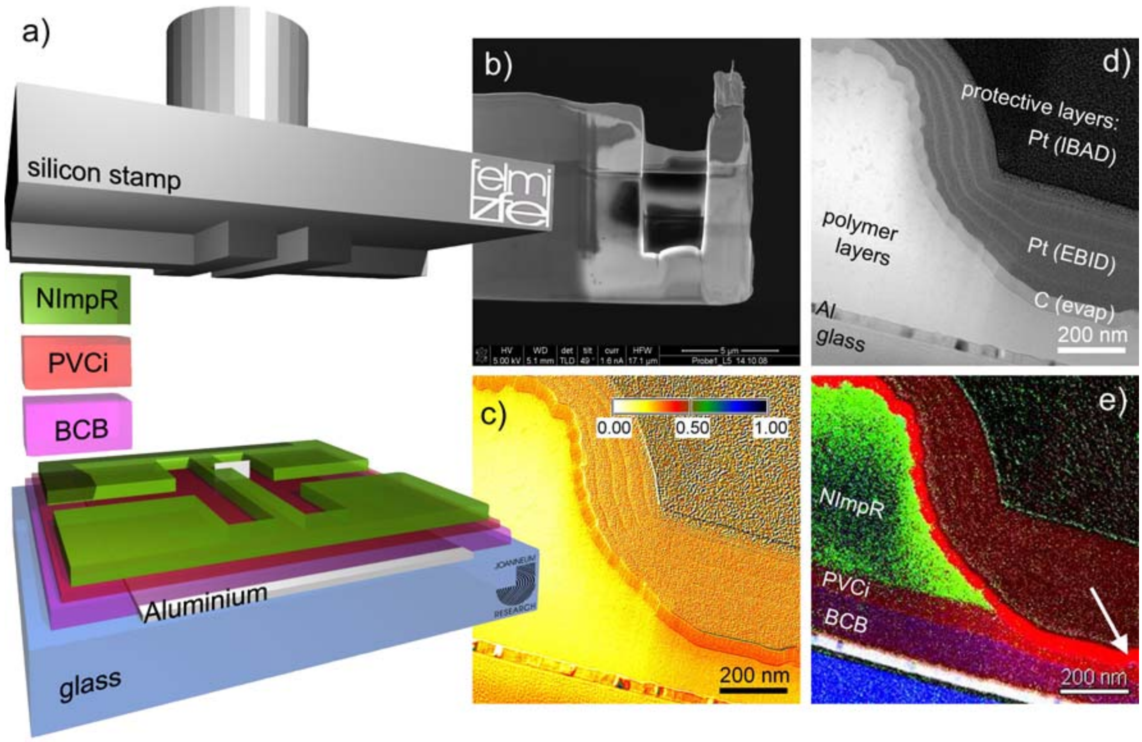

Figure 1. a) scheme of the NIL process after the residue-free imprint step. The white plane in the center indicates the investigated area. b) FIB preparation: only the important part is thinned for further investigation to avoid bending. c) TEM relative thickness map (t/λ). d) TEM bright field image, zero-loss filtered. e) superposition of elemental maps: C…red; N…green; Si…blue; Al…white. The white arrow indicates a bump in the imprinted area, residues can be excluded.

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