Soft Matter, Polymers, Composites

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Characterization of the production process of nanoimprinted organic devices by analytical TEM

J. Kraxner[1], I. Letofsky-Papst[1,2], T. Rothländer[3], P. Hütter[3], B. Stadlober[3], W. Grogger[1,2]

[1]Graz Centre for Electron Microscopy (ZFE), Graz, Austria
[2]Institute for Electron Microscopy (FELMI) of the TU Graz, Graz, Austria
[3]Joanneum Research, Materials-Institute for Surface Technologies and Photonics, Weiz, Austria

johanna.kraxner@felmi-zfe.at
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Organic electronics is a field of research with growing interest in the last years. Many applications are already entering industrial commercialization, but the search for new materials and the improvement of the used processes are still in progress. Organic electronics is a promising technology especially for applications, where large-area coverage, diversity in substrates, including flexible ones, and low temperature processing is important. As the device demands emerge to more advanced products such as smart objects and intelligent sensor networks, the performance parameters of the involved circuits become more and more challenging. Parameters like the switching speed, integration density, driving voltage and fabrication yield of circuits are crucial to be optimized. The miniaturization of the structures is a substantial requirement, achieving faster devices with a lower driving voltage and higher integration density.

The organic thin film transistor (OTFT) is a prominent device to optimize the production processes as well as the used materials. The transistor as a key element in logic circuits needs to be controlled as good as possible to be able to build more complex structures. In case of OTFTs the switching speed can be enhanced by an increased charge carrier mobility, and by a decrease of the channel length and the parasitic capacitance. A downscaling of the channel length and also a reduction of the parasitic capacitance is achieved by the usage of the self-aligned process schematically shown in Figure 1. The critical dimensions of the device can be downsized to the sub-micrometer regime and the parasitic capacitance is minimized by a decreased overlap between gate and source/drain electrode, which is the main contribution to the parasitic capacitance. This decrease in overlap can be dramatically enhanced by using the self-aligned technique [1].

The first step in the process (shown in Figure 1A) is to apply a structured gate electrode on the substrate. The gate electrode is either structured by a hot embossing process (HE-NIL) [2] or by an ultraviolet light induced crosslinking of a polymer (UV-NIL) [3]. The process is also suitable for flexible substrates, depending on the different temperature steps involved. In the next steps a dielectric layer and a UV curable positive resist are applied (Figure 1B and 1C). Now the gate structures are transferred into the photoresist by UV exposure through the substrate, using the gate electrode as a photo-mask (Figure 1D). Thereby a precise alignment of the source and drain electrodes with respect to the gate electrode, as well as a minimized overlap can be achieved. This step is followed by a development step, removing the exposed regions (Figure 1E). The source and drain material is applied (Figure 1F) and finally the remaining resist whit the source/drain material on top, is lifted off (Figure 1G) and the semiconductor material is added (Figure 1H).

With regard to the optimization of organic electrical devices, electron microscopy provides an excellent method to systematically study the various manufacturing steps and their influence on the devices. The first challenge is the TEM specimen preparation which is done mainly by using a focused ion beam (FIB) instrument. Due to the fact that soft materials are difficult to be prepared, windows of the regions of interest are milled out, thereby the remaining material provides mechanical stability. In Figure 2A a lamella of one channel can be seen. Figure 2B shows the thinned regions, in this case both sides of the transistor channel. Thereby the overlap of the source and drain electrodes with the gate can be seen easily (Figure 2C, 2D). Experiments with specimens prepared by means of ultramicrotomy were also performed but delamination of the different layers, introduced artefacts, and target preparation are huge problems. Therefore lamellas prepared by using a FIB instrument were analysed by scanning TEM (STEM), energy filtered TEM (EFTEM)as well as Electron Energy Loss Spectroscopy (EELS) and Energy Dispersive X-ray Spectroscopy (EDXS) are in order to gain a deeper understanding of the device (see Figure 1D). Questions concerning the quality of the imprint or the structure transfer of the imprint as well as the identification of any residuals could be answered. Especially with the on-going transformation to all printable materials the analytical methods become more and more important due to the lack of differences (e.g. contrast) between the different materials. At the moment we are using PET (polyethylene terephthalate) as substrate, copper as gate electrode material, PVCi (poly(vinyl cinnamate)) as dielectric material, gold as source/drain material and pentacene as semiconductive layer. Moreover a variety of different resist materials is used during the process. Problems concerning the output of each process step, e.g. the complete removal of the resist in the transistor channel, can be monitored. The tasks get more challenging as the materials get more similar in atomic composition. In these cases questions concerning the layer thickness or shape of the structured features can only be answered by analysing either the plasmon region or the C K edge fine structure to differentiate between the materials. In this study we will present analytical results of organic materials. Despite the low contrast between the different materials we are able to clearly visualize all materials individually. This is possible by careful analysis of the corresponding features in the EEL spectrum: On the one hand the fine structure of the C K edge was used for calculating ratios of the σ* and π* peaks. On the other hand we found that the accurate determination of the plasmon peak energies was very useful to assist the distinction between the different organic materials.

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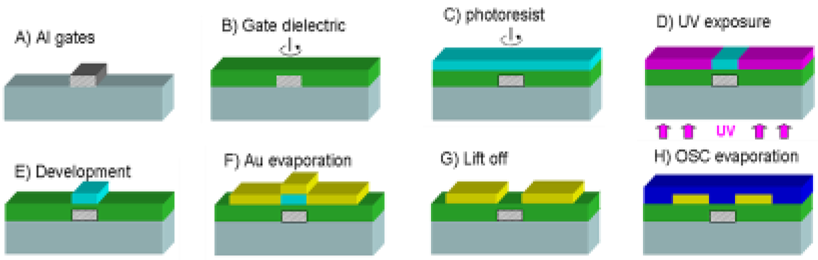

Figure 1. Process scheme of the self-aligned process [1]

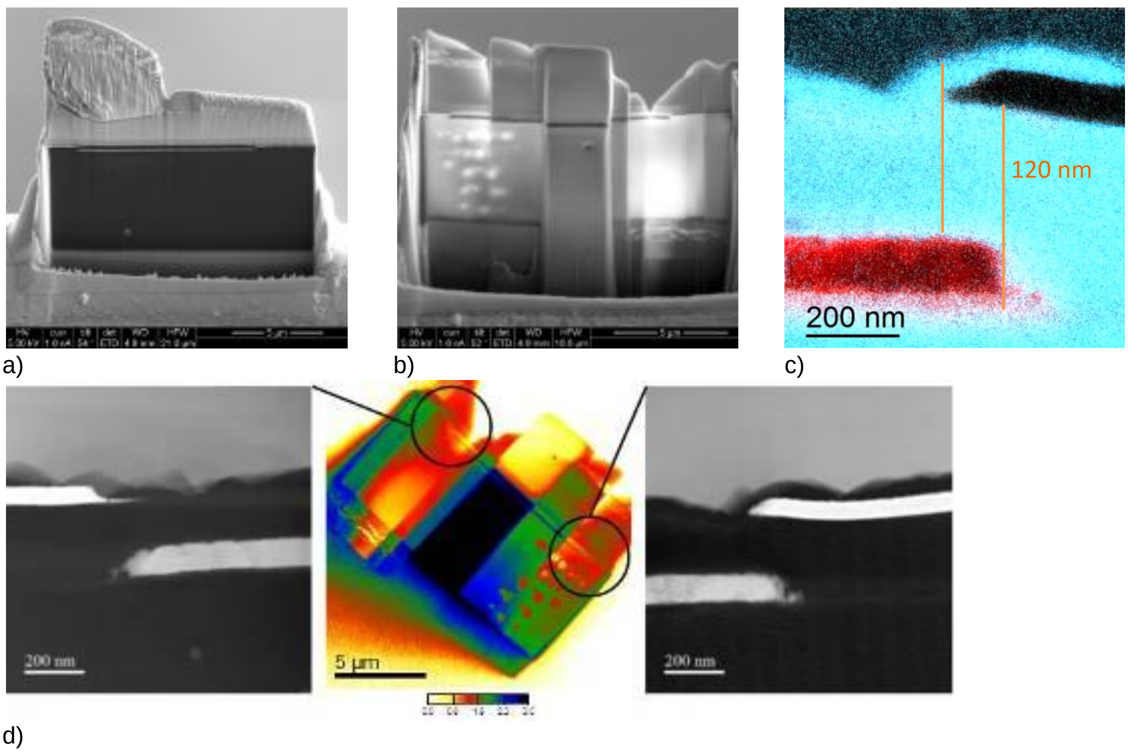

Figure 2. a) FIB lamella of an OTFT channel b) lamella after performing a window milling c) superposition of elemental maps: C…blue, Cu… red O…white, black represents Au and the protecting Pt layer d) relative thickness maps of the whole lamella as well as a close up of the two overlap regions.