Structuring of Organic Semiconductors by Optical Lithography

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Introduction

Organic semiconductors are now in wide use for devices such as OFETs, OLEDs and organic solar cells. However, the transport properties like for example the carrier mobility of these materials are not completely understood. Carrier mobility is usually determined from the dependence of the saturation current on the applied gate voltage of a field effect transistor (FET). These results reflect the mobility under large electric fields. Information about the low field mobility can be extracted from Hall measurements, which have been done for small molecule organic semiconductors [1], but not for conjugated polymers. In order to produce the well-defined Hall bar that is necessary for these measurements, we developed a process to structure a thin layer of an organic semiconductor. In the development of this process, care was taken to protect the semiconductor from oxygen and UV-radiation. In order to monitor the residual influence of the process on the organic semiconductor, FET structures were fabricated by the same process. In addition, Structuring organic semiconductors can also be useful for other applications, for example in a FET where a well-defined structure would reduce the leakage current, or for the definition of pixels in an organic photodetector.

Experimental

Sample Preparation

We start with silicon substrates with a 230 nm oxide layer. Gold contacts are applied by lithography, evaporation and subsequent liftoff (Fig. 1). The organic semiconductor Poly(3-hexyl)thiophen (P3HT) is then spin-coated onto this structure. As the next step, three additional layers are applied on top: photoresist (~1.4 µm), gold (~50 – 100 nm) and a second layer of photoresist (~1.8 µm). The top layer of photoresist is structured by optical lithography and the gold that is not covered by the remaining photoresist is removed by wet chemical etching.

Subsequently, the samples are etched in an oxygen plasma so that all the exposed organic materials are removed. The remaining gold layer acts as an etch mask. In addition, the gold protects the semiconductor form the detrimental influence of UV radiation and oxygen during the whole process. After the etching, the photoresist and gold on top of the polymer layer are removed in a liftoff step with acetone. The smallest feature size that was demonstrated with this process is about 10 µm.

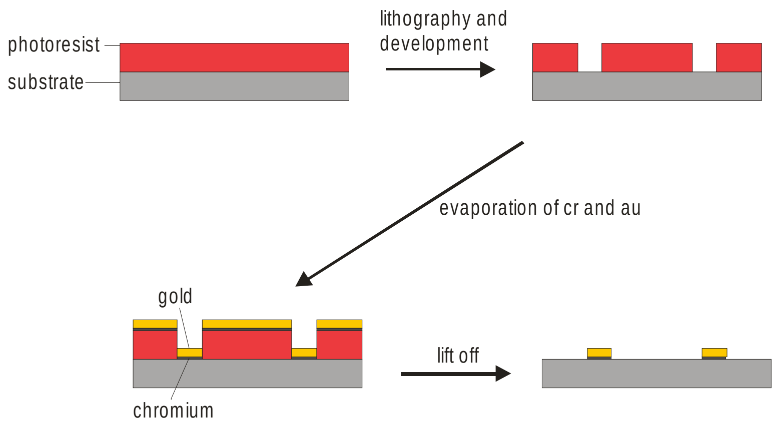

Fig. 1: Process steps for the contacts.

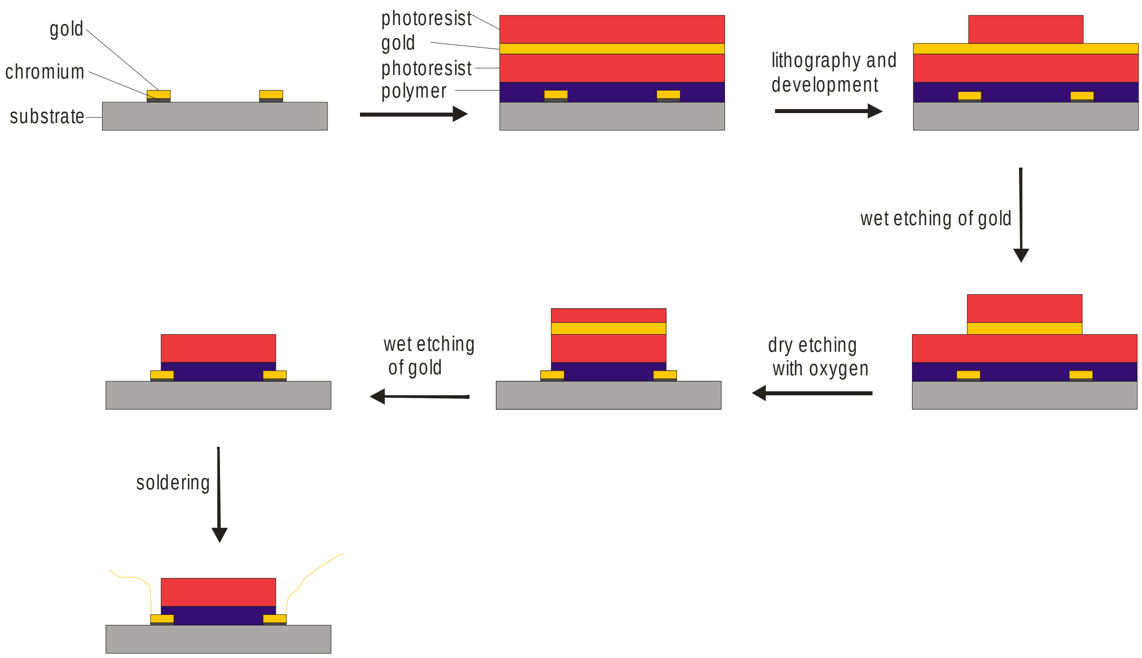

Fig. 2: Process steps for the structuring of the organic semiconductor.

Measurements

To examine the influence of the process steps on the electrical properties of the organic semiconductor, one of the structures on our samples was an OFET geometry with a channel length of 10 µm and a channel width of 1 cm. The transistor characteristics were measured before and after the structuring of the semiconductor layer, the results are shown in Figs. 3 and 4.

These measurements show that the conductivity of the P3HT-layer was increased by one to two orders of magnitude as a consequence of the process steps. The dependence of the source-drain-current on the applied gate voltage decreases accordingly. We interpret these results as being caused by unintentional doping of the P3HT during one of the process steps in spite of the protective gold layer. Up to now, it is not clear during which of the process steps sketched in Fig. 2 the oxygen doping predominantly occurs. The identification and improvement of this step has to be the subject of future work.

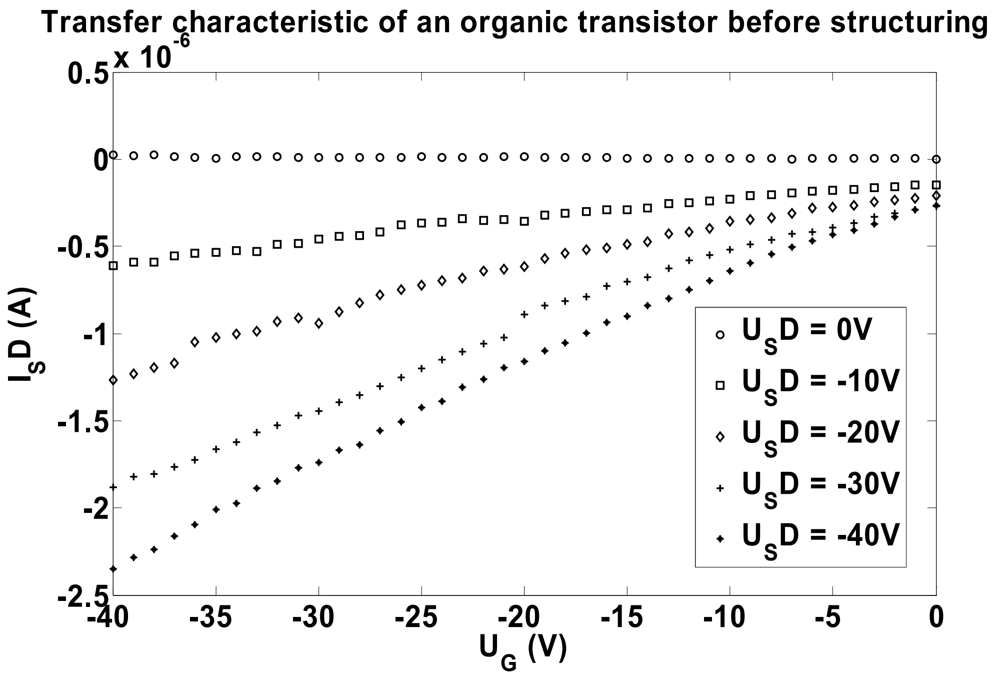

Fig. 3: Transfer characteristics of an organic field effect transistor before structuring the semiconductor.

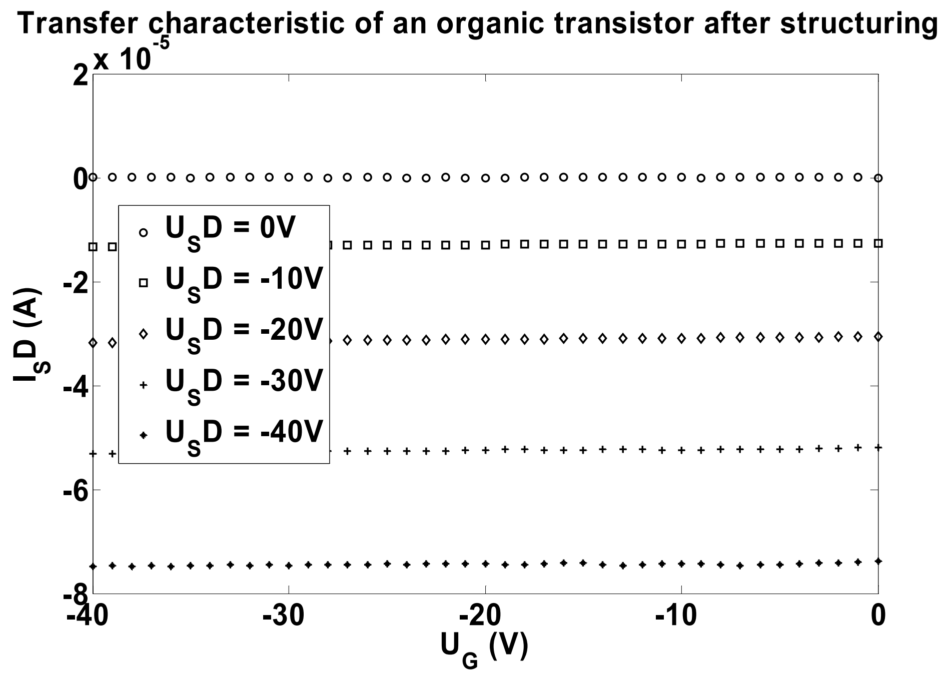

Fig. 4: Transfer characteristics of an organic field effect transistor after structuring the semiconductor.

Conclusion

We have shown that organic semiconductors can be structured by a combination of optical lithography and oxygen etching. Reference measurements on a transistor showed that the semiconductor was doped by oxygen during the process. The influence of the particular process steps has yet to be examined carefully, so that those steps can be modified in order to prevent or reduce the doping of the semiconductor. The experiments were done for P3HT. In principle, this process can be applied to any organic semiconductor, but the influence of the process on the electrical properties of the semiconductor might differ.

References

[1] V. Podzorov et al., *PRL* **95**, 226601 (2005)