Electrical Interfaces for Organic Nanodevices

Optoelectronic applications of organic semiconductor materials is a research field, which recently came to the large scale consumer market in display technologies. Organic semiconductors are mainly applied in amorphous form offering fabrication control on a large scale. Crystalline organic semiconductors, where the molecular packing is more crucial, have not yet had a major impact in commercial products. This thesis describes development of new ways to electrically contact organic semiconductors. In particular, crystalline organic para-hexaphenylene (p6P) nanofibers have been used as a representative component for the organic nanofiber class.

Organic light emitting devices based on nanofibers cannot readily be fabricated by conventional methods developed for thin film devices. A novel design of layered top contacts, separated by an insulating layer, was fabricated using three different approaches. Creating the separator by partly oxidizing an Al cathode anodically is considered the most promising implementation, however further development would be necessary.

During the project a group of collaborators managed to obtain electrically stimulated light emission in organic p6P nanofibers, by using an AC-gated organic field-effect transistor (OFET) implementation. The electrical properties of arrays of p6P nanofibers were investigated as-grown and modeled theoretically. The developed model, assuming hopping-like transport of charge carriers, was used to estimate the distance between hopping sites. A distance of 23±5 nm was extracted and found to be in good agreement with transmission electron microscopy (TEM) studies.

Graphene, a one atom thin 2D crystal of carbon, has several properties relevant for electrodes: it is atomically flat, optically transparent, does not oxidize, and has high electrical and thermal conductivity. In this project the use of graphene as an electrode material for organic electronics was investigated. For this purpose a fabrication process compatible with contamination sensitive cleanroom equipment was developed. First the process was applied to fabricate arrays of OFET templates and p6P applied as the organic semiconductor. The tested devices exhibited large injection barriers and significant hysteresis of the electrical characteristics. Therefore the device design was found unsuitable to elucidate the possible advantages of graphene electrodes in OFETs.

Secondly the electrode fabrication method was applied to realize electrodes for dielectrophoresis experiments. Robust electrodes with multi-layer graphene contact pads and few-layer graphene electrode edges were made. Carbon nanotubes were assembled with dielectrophoresis between electrodes. Optimization of the dispersion prevented the graphitic electrodes from being washed off, and the same samples could be reused for several experiments. During the experiments it was discovered that thin films of p6P on graphitic substrates can form crystalline domains. Molecular orientations on the samples were probed by fluorescence and white light polarization experiments. It was found that blue reflected light has the same polarization as fluorescence from the samples. This can be used to probe molecular orientations in these samples and completely avoid the bleaching effect of UV-excitation. An investigation of the morphological and molecular orientations within the domains, in relation to the graphitic lattice, showed growth of two different crystalline phases. One of the phases was found comparable to the β-phase typically observed on mica substrates. The morphology of the other phase had formed nanofiber-like aggregates on the substrates with typical dimensions up to 500×20 nm2. A possible application was demonstrated by growing nano-aggregates of p6P on a suspended graphene membrane, which could be used for TEM studies of the as-grown crystalline properties of p6P.

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