Project B3: Graphene solution exfoliation by conjugated polymers

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Current state of the research. Graphene is a unique system exhibiting extraordinary electrical, optical, mechanical and thermal properties. Unfortunately, it is a zero band-gap semiconductor, precluding its application as active material in field-effect transistors. Recently, there has also been tremendous progress in the design of new semiconducting polymers (SCPs) possessing better stability and performance for the production of innovative electronic devices. However, these materials suffer from rather modest electrical properties relative to their inorganic counterparts (e.g., the charge carrier mobility is currently still about 2 orders of magnitude lower than for silicon). Thus, the marriage of the properties of these new SCPs with graphene, with its remarkable electrical properties (e.g., charge mobility up to 2000 times higher than for silicon), has the potential to lead to the next generation of flexible electronic devices. In particular, the controlled interaction between graphene and molecules can be harnessed to adapt numerous properties in graphene, including to open a band-gap. To exploit this idea in useful hybrid materials, one must be able to scale up the graphene production significantly and to process the material in the desired manner.

Contributions of the principal investigators. The Freiburg Materials Research Center conducts world leading research in the areas of materials formulation and processing (R. Mülhaupt) and organic SCPs (M. Sommer). The Nanochemistry Laboratory at the *Institut de Science et d'Ingénierie Supramoléculaires* (ISIS) in Strasbourg is a key player in the fields of graphene science and organic electronics, with world class knowledge and facilities for the preparation of new organic electronics devices and their nanoscale characterization. The PIs in Freiburg and Strasbourg will be intimately engaged in this project, proposing an integrated approach involving synthetic chemistry, materials processing, physico-chemical characterization, and device engineering. In this way, the complementary skills both nodes are perfectly matched.

Research project and collaborations. The project targets a breakthrough in graphene science by the increase in graphene exfoliation yields and quality, and the simultaneous production of tailor-made organic SCP-graphene nanohybrid systems. This project relies on the principle that the current state-of-the-art in graphene production through exfoliation has hardly scratched the surface of the potential for high yields and high quality final products, and that the proposed consortium is well placed to tackle these processing and doping challenges, and investigate the electronic and physical properties of the resulting nanohybrid. Thus, the overall goals of the project are: *i*) Optimize the production of graphene by improved exfoliation techniques, aiming at yields of > 8 wt% graphene. *ii*) Simultaneously functionalize the as-prepared graphene and open a band-gap by chemical doping, with organic SCPs physisorbed on the graphene surface. *iii*) Fully characterize the morphological, compositional, energetic and electrical properties of these new organo-graphene nanohybrids. *iv*) Prepare and test FETs constructed from these nanohybrids.

Work plan. The doctoral research includes three work packages:
WP1. Formation of organo-graphene hybrid systems: Graphite exfoliation and simultaneous modification with organic semiconducting polymers. Effects of the chosen polymer and liquid media will be explored. Effects of dry and wet grinding, of high shear mixing, and of processing and post-processing treatment on different substrates will also be studied.
WP2. Nanoscale/multiscale characterization of graphene hybrids. Structural and compositional characterisation (e.g. by SEM-EDX, TEM, AFM, FTIR). Nanoscopic electronic characterization e.g. by conducting AFM (C-AFM) or Kelvin Probe Force Microscopy (KPFM).
WP3. Fabrication of device prototypes based on organo-graphene systems. Electroactive layers in Field-Effect Transistors with channel lengths ranging from 20 nm up to tens of µm.