Thrust 3. Two-Dimensional Layered and Hybrid Materials for Nanophotonics and Optoelectronics

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This IFMD thrust aims to exploit the flexibility in two-dimensional layered materials (2DLMs) by taking a vertically integrated approach to design new hybrid materials with greatly improved properties for nanophotonics and optoelectronics applications, in particular, photovoltaics. The group comprises of a multidisciplinary team with a proven track record in all the relevant fields, from theory and computation to synthesis and fabrication to characterization and testing.

2D materials approaching atomically thin planar structures like graphene are emerging as an important alternative to bulk crystals for nanoelectromechanical device applications due to their novel characteristics such as topological phases, large exciton binding energies, and plasmonics. Building on this basic idea and our expertise, the thrust members are developing multi-layer systems in which synergistic coupling between materials and the underlying interface processes create new functionalities. This will enable a materials-by-design approach where the structure can be rationally designed towards desired functionalities, together with a systematic investigation and characterization based on well-developed microelectronic, optical, and surface probing techniques.

Among the many 2DLMs, a primary focus of the group’s research is on hybrid systems where inorganic and organic layers can be intercalated and/or stacked. As an example, a photovoltaic system can be designed with organic layers responsible for capturing higher energy photons and downconverting their energy via singlet fission into long-lived triplet excitons, while inorganic semiconductor layers capture lower energy photons and harvest triplet excitons into electron-hole pairs by resonant energy transfer. Similarly, in biosensing systems, inorganic layers can be used to structure illumination at subwavelength scales for subsequent use in the detection of binding and molecular recognition processes in the adjacent (bio)organic layer, from micro-scale down to single-molecule scale.

Systems such as those described above are also fertile grounds for research into fundamental processes and effects such as photoexcitation, transport, and charge transfer, which may occur both within and across interfaces and phase boundaries. The team has significant expertise to enable this research, with strong assets in established and newly developed investigation methods such as tunable short-pulse lasers, pump & probe time-resolved spectroscopy, photoconductivity dynamics, fluorescence dynamics, single molecule fluorescence, electrochemistry, and photo-thermal AFM imaging. Experiments are supported by strong theoretical modeling and fabrication capabilities. Fundamental research is carried out in tandem with materials development to enable fabrication of proof-of-principle structures and devices to demonstrate and characterize desired performance.