Optoelectronics and optomechanics in hybrid two-dimensional heterostructures

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The recent rise of a large family of two-dimensional crystals with unique electronic and optical properties has opened exciting perspectives for the design and study of new devices based on van der Waals heterostructures [Gei13]. At the same time, a variety of low-dimensional semiconductor nanostructures with size- and shape-tunable optical properties can be routinely synthesized using colloidal chemistry methods.

In this PhD project, as an original attempt to develop the field of low-dimensional heterostructures, we propose to combine i) two-dimensional crystals (as atomically thin electrical channels) with ii) colloidal semiconductor nanostructures (as active optical materials). We will focus on i) graphene (as a 2D semimetal with extremely high carrier mobility) or "monolayer" transition metal dichalcogenides (MX_2, with M=Mo,W and X= S, Se, Te, as direct bandgap semiconductors [Mak10]) and ii) CdSe-based nanoplatelets (*i.e.*, colloidal quantum wells [Ith11]). **The rich photophysics of these hybrid two-dimensional heterostructures will be thoroughly investigated with the aim to fabricate hybrid optoelectronic and opto-electromechanical devices** [Gei13**,** Kop14]. This research project builds upon our recent investigations of energy transfer in graphene-nanoemitter hybrid systems [Fed15], the mechanical properties of suspended graphene [Met14], the photophysical properties of MX_2 layers [Fro15] and on our expertise in device fabrication [Fro15b].

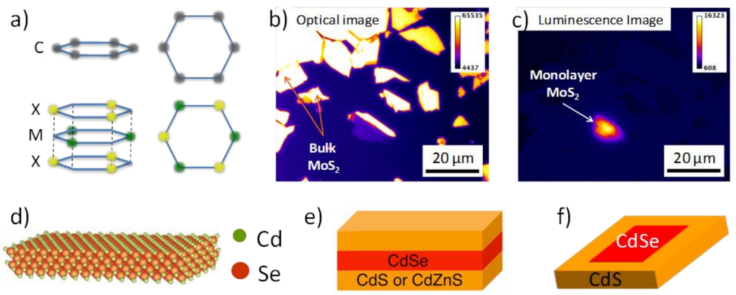

Fig. 1: Crystal structure of a) graphene and b) MX_2 (M=Mo,W and X= S, Se, Te). c) optical and d) photoluminescence (PL) images of MoS_2 layers, showing bright PL only from monolayers (S. Berciaud et al., unpublished). Schematic of a d) CdSe nanoplatelet (NPL), e) core/shell NPL, f) core/crown NPL. The NPL are provided by the team of B. Dubertret at LPEM (ESPCI).

We will first address Förster-type energy transfer and photoinduced charge transfer at the heterointerface between a single nanoplatelet and a graphene or MX_2 layer. These interface phenomena will be probed using a combination of optical (including time-correlated single photon counting) and electrical measurements at variable temperature (4K-300K).

In a second step, we will fabricate nano-resonators [Cas15] based on a suspended monolayer of graphene or MX_2 and study individual nanoemitters located directly onto or in the immediate vicinity of the atomically thin membrane. We will focus on strain coupling and on the electro-mechanical control of light emission in these hybrid systems.

We are looking for a motivated PhD candidate interested in nanophotonics, condensed matter physics and nanofabrication (in the StNano clean room). The research will be performed within the nano-devices team at IPCMS.

References: [Cas15] A. Castellanos-Gomez *et al.*, Ann. der Physik **527**, 27 (2015), [Fed15] F. Federspiel *et al.*, Nano Lett. 15, 1252 (2015), [Fro15] G. Froehlicher *et al* Nano Lett. **15** 6481 (2015), [Fro15b] G. Froehlicher *et al* . PRB **91**, 205413 (2015), [Gei13] A. Geim & I. Grigorievea, Nature 499 419 (2013), [Ith11] S. Ithurria *et al.,* Nature Materials 10, 936 (2011), [Kop14] F.H.L. Koppens *et al.*, Nature Nanotechnology **9** 780 (2014), [Mak10] K.F. Mak *et al.* PRL 105,136805 (2010), [Met14] D. Metten *et al.*, Phys Rev. Applied **2**, 054008 (2014)