Seminar announcement

Tuesday, April 25, 2023
1.30 pm
WSI, Seminar room S 101
Exclusively in person

"Dome-shaped two-dimensional crystals: A playground for the study of the crystal mechanical and optoelectronic properties"

The variegated family of two-dimensional (2D) materials comprises crystals with exceptional characteristics. Amongst them, hexagonal boron nitride (hBN) is a thermally stable and mechanically robust insulator, and semiconducting transition-metal dichalcogenides (TMDs) possess alluring optoelectronic and spin properties when reduced to the single layer. In particular, TMD monolayers are characterised by a direct bandgap, resulting in an efficient light emission in the visible/infrared range, and by a strong spin-orbit coupling, which makes them interesting candidates for opto-eletronics and valleytronics. Importantly, 2D materials are also characterised by an exceptional mechanical flexibility and robustness.

Here, we explore new strategies to tune the peculiar properties of 2D TMDs and hBN by mechanical deformation. We show a novel procedure to engender localised strains in monolayers or multilayers of TMDs and hBN, based on low-energy hydrogen-ion irradiation of bulk flakes. More specifically, protons penetrate through the topmost layer(s) of the crystal, leading to the production and accumulation of molecular hydrogen in the interlayer region. The trapped gas coalesces, leading to a local blistering of the material, and thus to the formation of one- (or few-) layer-thick micro/nano-domes filled with pressurised hydrogen [1,2]. The domes host complex strain fields that reach high values. Mechanical modelling of the dome shape and strain, and nano-indentation measurements allow us to obtain precious information on the adhesion energy and on the elastic properties of the material [3,4].

The domes are durable and incredibly robust, and in most TMDs their thickness is of just one layer [1,5]. In turn, TMD domes behave as efficient light emitters. The high strain fields they host cause dramatic changes in the TMD opto-electronic properties, and photoluminescence (PL) steady-state and time-resolved studies enabled the characterisation of the strain-induced band-structure modifications and revealed intriguing phenomena, such as a strain-induced direct-to-indirect bandgap crossover [6]. Magneto-optical measurements allowed us to study the effect of strain on the gyromagnetic factor of the TMD, and to pinpoint hybridisation phenomena between direct and indirect excitons [7].
Low-temperature PL studies further revealed single photon emission from the strained domes [8].

Finally, the strain-induced band structure tuning observed in the domes can be exploited to couple the material with other 2D materials to enable new functionalities through the creation of selectively strained 2D heterostructures.

[1] D. Tedeschi, E. Blundo et al., Adv. Mater. 31, 1903795 (2019).
[2] E. Blundo et al., Nano Lett. 22, 1525 (2022).
[3] E. Blundo et al., Phys. Rev. Lett. 124, 046101 (2021).
[4] C. Di Giorgio, E. Blundo et al., ACS Appl. Mater. Interfaces 13, 48228 (2021).
[5] B. Liu et al., Nat. Commun. 14, 1050 (2023).
[6] E. Blundo et al., Phys. Rev. Res. 2, 012024 (2020).
[7] E. Blundo et al., Phys. Rev. Lett. 129, 067402 (2022).
[8] S. Cianci et al., Adv. Opt. Mater., in press, DOI: 10.1002/adom.202202953 (2023).

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