Damage formation in 2D materials due to slow ion irradiation

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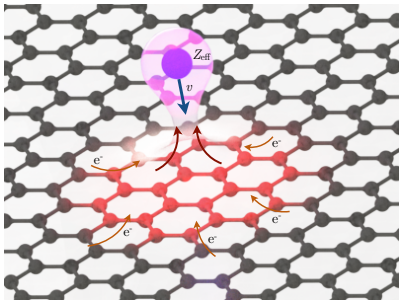
The way in which electrons in low dimensional materials respond to ultrafast external perturbations is at the core of the design of future devices for optoelectronics and photodetection. Highly charged ions - along with femto- and attosecond light sources - provide a unique tool for probing the electronic response of solid materials to an extremely strong electric field, the Coulomb field of an approaching highly charged ion [1]. In our experiments we study the ultra-short time response of different 2D-materials like graphene, MoS_2 and hBN to an incoming highly charged ion (typically Xe^{40+}). In a multi-coincidence setup we measure the charge state and energy of highly charged ions transmitted through suspended 2D-membranes in coincidence with the number of emitted electrons [2]. This allows us to derive the relevant time scales for charge transfer along the 2D-layer, the resulting current densities in the material and lower bounds for the breakdown currents. Depending on electron mobility some 2D materials fail to resupply the lost charges and/or fail to dissipate the absorbed energy on a timescale small compared to lattice vibrations. The resulting Coulomb explosion tears holes of the order of some nanometers into the 2D membrane [3], which are observed in high resolution (S)TEM investigations. The results of our studies are therefore of interest for engineering two-dimensional materials with electrons, ions, and lasers, with many prospective applications like their use as molecular sieves, for desalination or even DNA sequencing.

Figure: *Interaction processes between a freestanding single layer graphene and an approaching highly charged ion, which extracts a lot of charge from a very limited area on a femtosecond time scale. Recharging of the impact area is not instantaneous but retarded due to finite conductivity and allows to probe the local electronic dynamics of the 2D material on this fs-time scale [1].*



[1] E. Gruber, et al., Nature Communications **7** (2016) 13948 (7 pages)
[2] R. A. Wilhelm, et al. Physical Review Letters 119 (2017) 103401 (6 pages)
[3] R. A. Wilhelm, et al. 2D Materials 2 (2015) 035009 (6 pages)