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Nanostructuring of monolayer graphene by highly charged ions

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Upon impact on a surface, slow highly charged ions (HCIs) deposit large amounts of their potential energy within the first few monolayers of the material. Depending on material properties relaxation processes can lead to nanosized material modifications, e.g. hillocks and craters in bulk samples or pores in 2D materials - often in a similar manner as after swift heavy ion (SHI) impact. For atomically thin graphene, so far no pore formation could be observed after irradiation with HCIs (up to charge states of typically 40+), while the formation of cracks was reported after SHI irradiation. A possible explanation could be the existence of a potential energy threshold which needs to be exceeded in order to enter the nanostructuring regime. Such thresholds have previously been found for bulk samples, with CaF2 being a particularly well investigated case. Studies with slow ions in very high charge states (» 40+) so far are rather scarce —both for bulk samples and 2D materials —which makes HITRAP perfect for exploring this uncharted territory.

There are two scenarios where we could perform our measurements: Either we use the existing diagnostics chamber in-between RFQ decelerator and cooling Penning trap on the ground floor of the HITRAP facility or we install an ultra-high vacuum system consisting of an experimental chamber, a sample holder (for bulk and atomically thin materials) and a pumping stage at the HITRAP platform on the second floor. In the second scenario, an alignment of the new setup for perfect sample irradiation conditions will be achieved prior to the beam time with ions from the present EBIT ion source.

In the first scenario, we will irradiate a freestanding single-layer graphene sample with 6 keV/u U92+ from HITRAP and for comparison also one CaF2 single crystal of 1cm x 1cm size. Considering a 60s repetition rate and 105 ions per pulse, which is a conservative assumption, the samples will have to be irradiated for 3 days each to achieve a total fluence of 4x108 ions/cm2. For 6 keV/u U92+ the potential energy of ~1 MeV is in the same order of magnitude compared to the kinetic energy of 1.4 MeV ≙ 1.07x106 m/s ~ 0.5v0 with v0 being the Bohr velocity, which is considered a slow highly charged ion. Even regarding an energy width of ~ 2keV/u, the maximum velocity stays < 0.6v0. In the second scenario, the cooled HCI beam extracted from the cooling Penning trap is expected to have a transport energy of 5keV/q with narrow energy distribution and an intensity smaller compared to the first scenario due to the efficiency of the cooling Penning trap.

After the irradiation, the samples will be taken out of the vacuum, stored under protective atmosphere and shipped to TU Wien, where we will analyse ion-induced material modification via STEM and AFM.

We therefore want to apply for one week of HITRAP beam time, i.e., 21 shifts à 8 hours.

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