Defect Creation in Graphene by Swift Heavy Ion Irradiation

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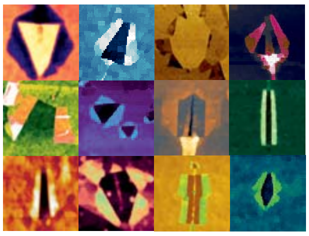
Goals

- Investigation and quantitative characterisation of energy dissipation processes during and after swift heavy ion (SHI) irradiation [1]
- Tailoring of morphological and physical properties of ultrathin films (e.g. graphene, MoS_2, Mica) [2]
- In situ mechnical exfoliation and characterisation of graphene on arbitrary substrates [3]

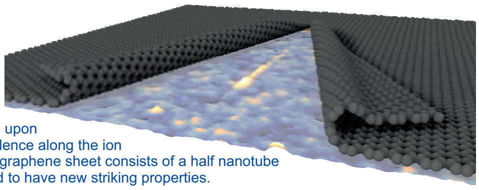


Experiment

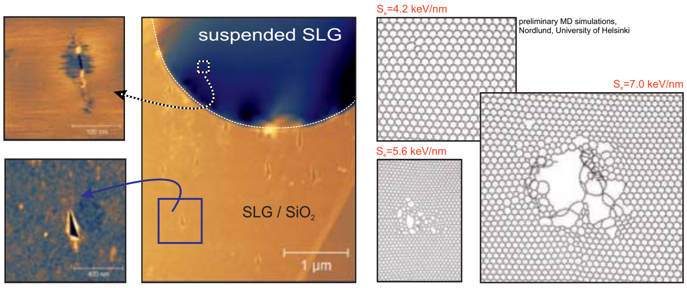
- Irradiation experiments at the IRRSUD beamline of the GANIL (Caen, France) and at the M1 branch at the GSI (Darmstadt, Germany)
- Sample characterization in ambient with atomic force microscopy (AFM) in tapping mode
- UHV-measurements with non-contact (NC) AFM system (including in-situ measurements of work function with Kelvin probe force microscopy (KPFM)

Tailoring the Morphology of Graphene by SHI Irradiation

Introducing closed bilayer edge (CBE) structures into single layer graphene sheets



- Single layer graphene (SLG) flakes exfoliated in ambient fold upon SHI impact under glancing incidence along the ion trajectory. The resulting bilayer graphene sheet consists of a half nanotube like structure, which is predicted to have new striking properties.
- The folding efficiency of SLG is typically around 100%. This can be used to test for successfull irradiation. Furthermore, the actual ion fluence can be determined allowing the exact calibration of the incidence angle [4].



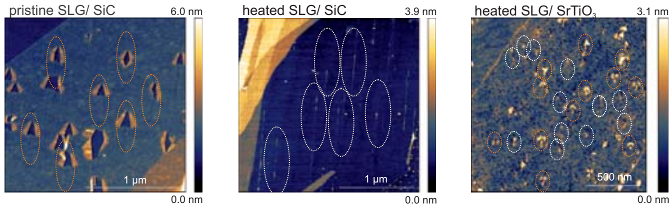
Formation of CBE

- **1st step:** SHI creates a line of defects in the graphene sheet by direct damage due to electronic excitation
- **2nd step:** Material from the substrate and/or the interfacial layer between SLG and the substrate is ejected

Defect creation

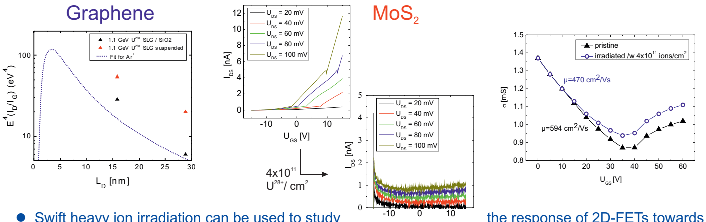
- **Treshold** for defect creation directly by the SHI projectile determined experimentaly to be around S_e=5 keV/nm

Role of the interfacial layer (IFL)



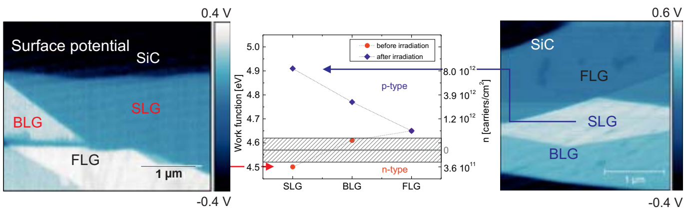
- SHI irradiation of exfoliated SLG on SiC leads to the formation of CBE and foldings. Size and form may vary depending on the ions incidence angle. Each ion produces one folded structure.
- Heating the sample in ultra high vacuum (UHV) for several hours @ 800 K removes interfacial adsorbates (e.g. H_2O, O_2, N_2, ...). Those samples show surface tracks after irradiation.
- After mild heating (~500 K) in UHV, a SLG/$SrTiO_3$ sample shows a mix of ion induced foldings and surface tracks. Here, the interfacial adsorbate layer has not been completely removed.

Radiation hardness of graphene



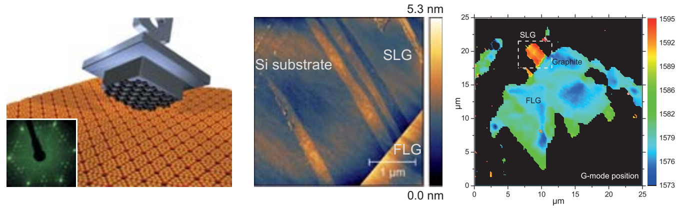
- Swift heavy ion irradiation can be used to study the response of 2D-FETs towards ionizing environments like e.g. outer space. After SHI irradiation (up to $4x10^{11}$ ions/cm²), graphene devices remain operational while MoS_2 devices show severe degradation and become unoperational [5].
- The ratio of the D-peak and G-peak intensity in the Raman spectrum can be used to measure the defect density. Compared to Ar^+ (90eV) ions from literature [6], SHI lead to a much higher I_D/I_G ratio on

Doping Graphene with SHI



- Irradiation after heat treatment (600 °C, UHV) prevents folding in the graphene lattice and surface track formation in graphene can be observed
- Surface tracks are formed by a combination of defects created by the SHI in graphene directly and material emitted from the SiC (0001) substrate
- The implementation of foreign material into the graphene crystal causes a shift in the work function observed by KPFM in situ. The shift can be explained by a transition from n-type to p-type doping [7].

UHV Exfoliation



- Exfoliation of HOPG in UHV on a well perpared Si(111)7x7 surface [3]
- Single layer graphene flakes with size in the order of several microns can be located, µ-Raman mapping shows a strong shift in the G-mode position for SLG.
- Atomic force microscopy in ambient reveals that the Si(111) substrate undergoes oxidation while Si(111) underneath graphene still shows smooth terrace steps.

References

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