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Modification of carbon (nano)materials by swift heavy ions

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It is known that ions of different energies interact with materials in different ways, i.e., ions in the keV energy range lose their energy via elastic nuclear collisions, while those with energies higher than 1 MeV/u, so-called swift heavy ions (SHI), transfer their energy predominantly to the electronic subsystem. Given the unique ability of SHIs to deposit huge amounts of energy along a small cylindrical volume surrounding an ion trajectory, a highly localized modification of the material is possible.

This presentation aims at reviewing the radiation effects in various carbon systems, with the main emphasis put on the new phenomena resulting from dense electronic excitation provoked by SHI-irradiation. These effects will be discussed on the example of three different carbon materials: highly oriented pyrolytic graphite (HOPG), graphene oxide (GO), and glassy carbon (GC). The specimens were characterized by the X-ray photoelectron (XPS), X-ray Auger electron (XAES), and Raman spectroscopies. Their surface morphologies were investigated by atomic force microscopy and scanning electron microscopy. In addition, the electrical properties of the GO structures were evaluated by two-contact resistance measurements.

SHI-irradiation of HOPG introduces point-like defects and leads to an increase in the interlayer spacing. At high fluences HOPG is transformed into loosely interacting, damaged graphene sheets that exhibit unusual Raman spectral behavior. One of the most important radiation-induced transformations of GO is its reduction to reduced graphene oxide (rGO) of improved electrical conductivity. Under SHI-irradiation the reduction process is highly localized, leading to the formation of nanometer-sized rGO spots. Assuming the localized reduction occurs along the ion trajectory through several GO sheets, the resulting structures can be considered as arrays of vertically-arranged graphene quantum dots embedded in a non-conducting matrix. For samples irradiated to high fluences with the most energetic ions the presence of sp-hybridized carbon chains was detected. No such structures were formed under low-energy ion bombardment, implying that sp-C formation takes place exclusively at the electronic stopping power regime. This assumption was further confirmed by investigating the cross-sectional damage profile of GC samples.

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