Highly charged slow and swift ions interacting with 2D materials

M. Schleberger
Fakultät für Physik and CENIDE, Universität Duisburg-Essen, 47057 Duisburg, Germany;
e-mail: marika.schleberger@uni-due.de)

Ion beams are a proven, versatile and efficient tool for material modification and especially for defect engineering [1,2]. The underlying mechanisms depend strongly on the energy of the projectile and are only partially understood. An ion stores its energy in the form of kinetic (E_{kin}) and so-called potential energy (E_{pot}), the latter corresponding to the energy required to create its respective charge state. The energy stored in the projectile is transferred to a target material upon impact. At low kinetic energy, the so-called nuclear stopping regime, the predominant mechanism is based on elastic collisions leading to linear sputtering cascades or collision peaks in the volume of the material, and ultimately to the emission of atoms. At higher kinetic energies, electronic excitations and ionizations are dominant, the so-called electronic stopping regime. The release of potential energy also occurs via electronic processes that can also later lead to the emission of atoms from the target material. By adjusting these two parameters, E_{pot} and E_{kin}, one can in principle fine-tune the nature of the interaction and thus the corresponding material changes. However, the fundamental mechanisms of defect creation based on electronic excitation are not yet fully understood.

We have introduced 2D materials as target material for the study of ion-solid-interactions. Due to their well-defined thickness, the flexible preparation and last but not least the wide range of available materials, they are an ideal target material for our task. In particular, the TMDCs such as MoS_2 are well suited since they can be easily modified by ion irradiation [3,4] – in contrast to the more famous 2D material graphene [5], see Fig. 1. For the analysis, we have built an experimental setup that can deliver beams of highly charged ions with independently tunable kinetic and potential energy [6]. Our setup allows us to measure yield and velocity distributions of the emitted atoms during HCI irradiation. We have performed a series of experiments with monolayer MoS_2 on different substrates and found that an increase of potential energy leads to enhanced emission of slower particles. By combining these data with STEM measurements [7] of free-standing MoS_2 monolayers, we show that the two contributions can indeed be separated and appear to add up independently of each other. With swift heavy ions even thicker samples can be perforated. This was recently successfully applied to membranes based on graphene oxide that can be used for water desalination. Our work thus contributes to establishing guidelines for defect engineering of 2D materials by kinetic and electronic excitation.

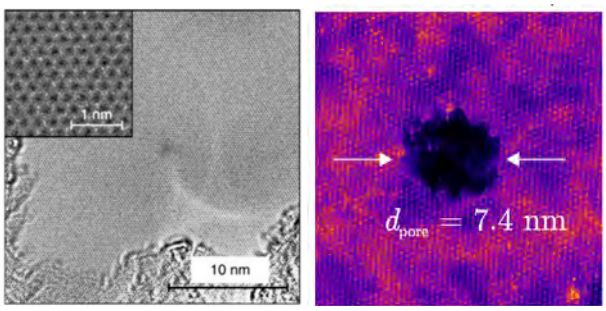

Fig.1: STEM of graphene and MoS_2 after HCI irradiation.

Support by the Deutsche Forschungs Gemeinschaft (DFG) is gratefully acknowledged.

[1] A. Krasheninnikov, F. Banhart, Nature Materials, 6 (2007) 723
[2] J. Kotakoski, M. Schlebergerg, Materials, 11 (2018) 1885
[3] J. Hopster et al., Nucl. Instrum. Meth. B 317 (2013) 165
[4] L. Madauß et al., 2D Materials, 4 (2017) 015034
[5] E. Gruber et al., Nature Communications 7 (2016) 13948
[6] L. Skopinski et al., Rev. Sci. Instr., 92 (2021) 023909
[7] R. Kozubek et al., J. Phys. Chem. Lett., 10 (2019) 904
[8] T. Foller et al., Nano Letters 10 (2022)