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In-situ Characterization of MoS_2 Based Field Effect Transistors during Ion Irradiation

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MoS_2 is one of the important materials for possible future electronic applications using atomically thin layers of semiconductor materials. Different to other 2D materials it posses a bandgap and can be used for logic as well as photonic and optoelectronic applications. This bandgap can be tuned using ion irradiation via the induced defects. This allows for interesting applications including but not limited to memristive devices based on single layer MoS_2 [1].

Helium Ion Microscopy [2,3] is a versatile method for modifying and imaging a wide range of materials including insulating and biological materials. A Carl Zeiss Orion NanoFAB equipped with in-situ probes from Kleindiek, a heater and a TOF-SIMS [4] setup has been used in this work. It allows the irradiation of individual MoS_2 flakes using a focused He ion beam with a diameter of only 0.5 nm or a focused Ne ion beam with a diameter of only 2 nm. Simulations and experiments have shown that at the typical HIM ion beam energies, between 5 keV and 30 keV, damage to the 2D material monolayer happens mostly via recoiling substrate atoms [5].

Here, in-situ Helium Ion Microscopy (HIM) has been used to electrically characterize single layer MoS_2 field effect transistors. These devices have been fabricated via chemical vapor deposition (CVD) and transferred onto $SiO_2/Si(p^{++})$ chips for EBL contacting and further characterization. The oxide thickness is in the range of 200 nm to 300 nm.

Individual flakes where than exposed to increasing fluences of 7.5 keV He ions. The energy has been chosen to maximize the efficiency of the vacancy creation process on the one hand and still provide a good lateral resolution on the other hand. The fluence range extended from $1x10^{11}$ 1/cm² to $5x10^{13}$ 1/cm². Transfer curves where recorded at selected intervals. In addition several samples have been checked with low temperature photoluminescence (PL) to analyze the type of defects formed during ion irradiation.

Results show an initial increase of the current and a reduction of the threshold voltage with increasing ion fluence. However, at higher fluencies the maximum current in the channel drops as expected. At about a helium fluence of $1x10^{13}$ 1/cm², the highest value of current was measured. This correlates well with results from PL spectroscopy for the sample irradiated with $1x10^{13}$ He^{+}/cm² which showed the highest intensity of bound exciton emission. This peak could be related to the creation of sulfur vacancies since they require the lowest formation energy. In addition sulfur vacancies could increase the density of n-type carriers in MoS_2 resulting in a lowering of the threshold voltage.

We explain this behaviour by a combination of several effects including defect mediated changes in the electrical properties, ion beam induced removal of contamination and formation of trapped charges in the underlying substrate.

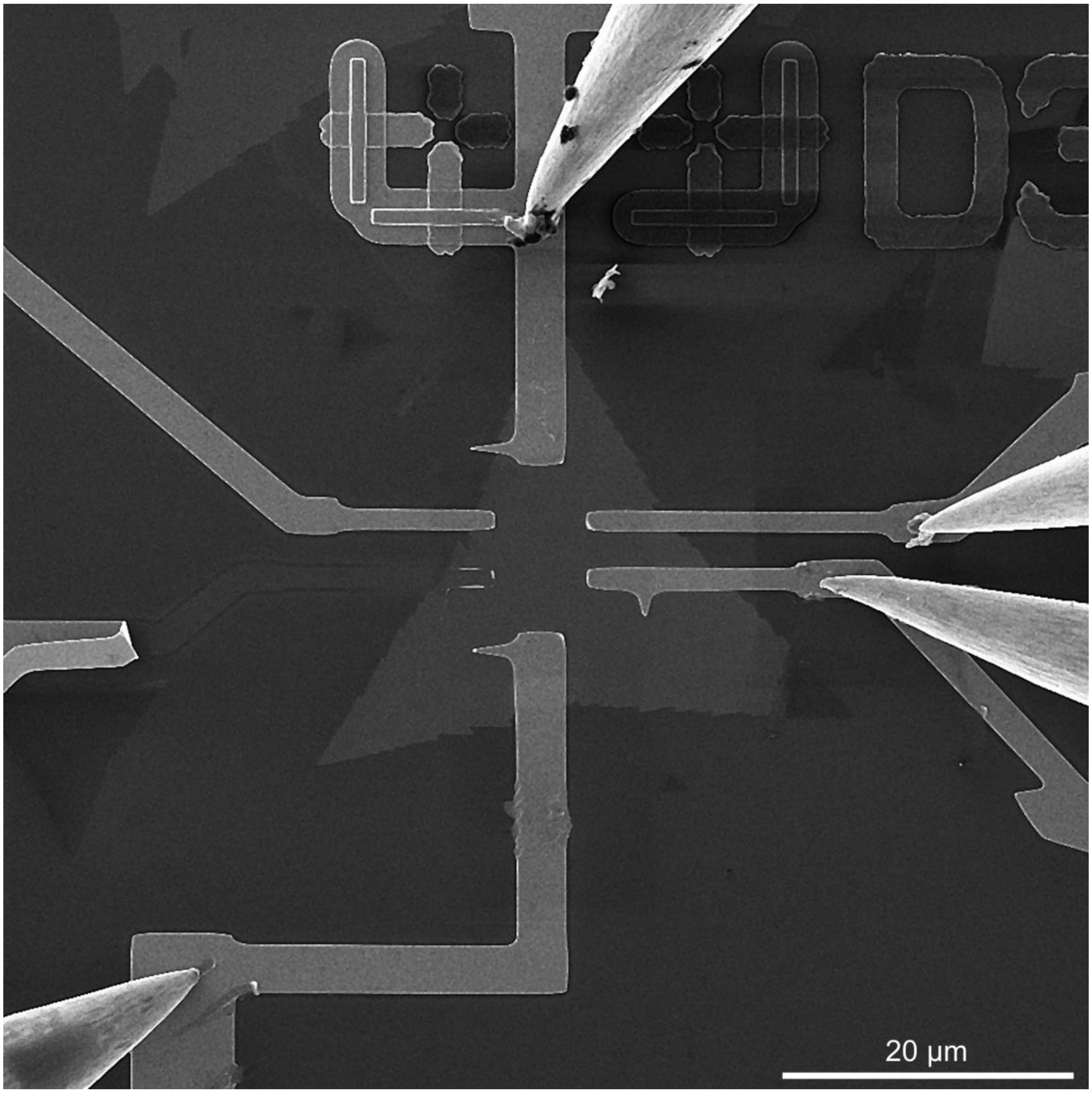

Figure 1. MoS2 flake with contacts and probes attached after in-situ electrical characterization.

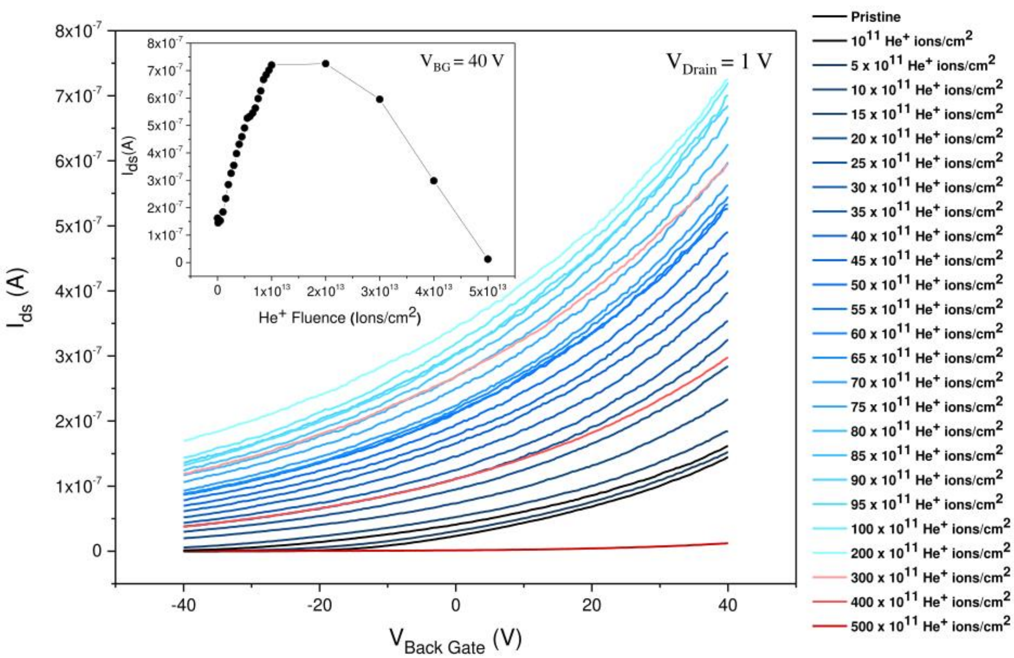

Figure 2. In-situ transfer curves at various He ion fluencies and Ids behaviour at VBG=40V (inset).

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