Epitaxial CaF_2: a Route towards Scalable 2D Electronics

Yu.Yu. Illarionov[1,2*], **A.G. Banshchikov**[2], **M.I. Vexler**[2], **D.K. Polyushkin**[1], **S. Wachter**[1], **M. Thesberg**[1], **N.S. Sokolov**[2], **T. Mueller**[1], **and T. Grasser**[1]

[1] *TU Wien, Gusshausstrasse 27-29/E360, 1040 Vienna, Austria*

[2] *Ioffe Physical-Technical Institute, Polytechnicheskaya 26, 194021 St-Petersburg, Russia*

*Corresponding author: *illarionov@iue.tuwien.ac.at*

Two-dimensional (2D) semiconductors can potentially provide a means to overcome the limitations of Si technologies by enabling more than Moore FETs with several nanometer dimensions. However, this target cannot be realized without scalable insulators, which should simultaneously maintain high quality of the interface with 2D channel and low gate leakages for equivalent oxide thicknesses (EOT) below 1nm. Unfortunately, the insulators currently used in 2D FET prototypes do not satisfy these stringent requirements. For instance, oxides known from Si technologies (e.g. SiO_2, Al_2O_3, HfO_2) are amorphous when grown in thin layers, and hBN has unfavorable dielectric parameters and unfortunate band offsets to most 2D semiconductors.

To overcome this bottleneck, we suggest the use of epitaxial fluorite (CaF_2) as an insulator for 2D electronics. Few-nanometers thin CaF_2 layers [1] can be grown on Si(111) by molecular beam epitaxy (MBE) and form F-terminated inert surface with no dangling bonds [2]. This results in a high-quality quasi van der Waals interface with 2D materials (Fig.1a). At the same time, owing to good dielectric parameters (ε = 8.43, E_G=12.1eV), the tunnel leakages through CaF_2 are lower than through most high-k oxides with equal EOT [3], not to mention SiO_2 and hBN.

Recently we fabricated functional CVD-MoS_2 FETs with MBE-grown CaF_2 insulators of record-small thickness only about 2 nm (EOT less than 1nm). Already in the first bare channel prototypes we achieve ultra-low leakage currents (Fig.1b), on/off current ratios of up to 10^7 and subthreshold swings down to 90 mV/dec (Fig.1c). At the same time, our devices exhibit almost no hysteresis, which is likely due to the virtually defect-free MoS_2/CaF_2 interface.

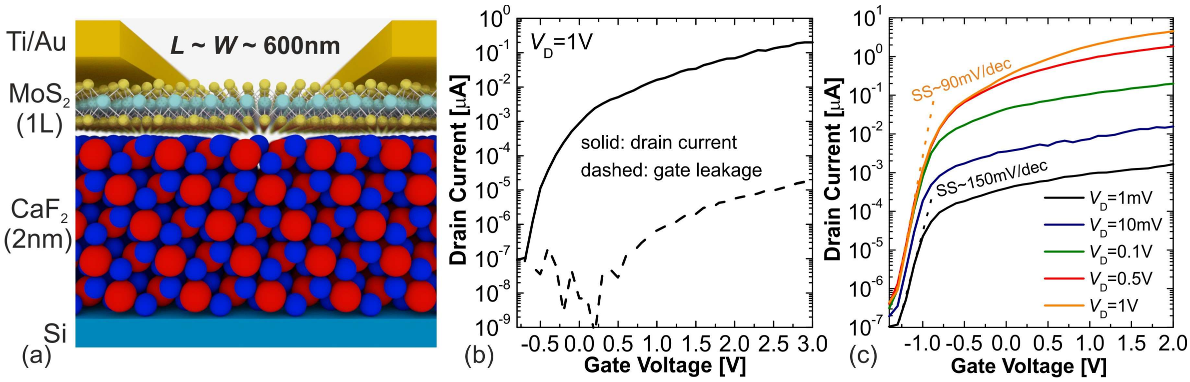

Figure 1: (a) Schematic layout of our device with quasi van der Waals CaF_2/MoS_2 interface. (b) Measured drain current and gate leakage. (c) Typical set of the gate transfer characteristics at different drain voltages.

In summary, we extended the natural stacking properties of 2D materials towards quasi van der Waals heterostructures. Demonstration of competitive MoS_2 FETs with 2nm CaF_2 insulators presents a route towards fully scalable 2D electronics. Our results are especially valuable assuming recent reports on epitaxial growth of $MoSe_2$ [2] and $MoTe_2$ [4] on CaF_2(111) crystals.

[1] M. Olmstead, *Thin Films: Heteroepitax. Syst.* (1999). [2] A. Koma *et al*, Appl.Surf.Sci. **41**, 451 (1990). [3] Y. Illarionov *et al*, Tech.Phys.Lett. **36**, 404 (2010). [4] S. Vishwanath *et al*, J.Cryst.Gr. **482**, 61 (2018).