In-situ growth characterization of 2D heterostructures: $MoSe_2$ on intercalated graphene/Ru(0001)

Lars Buß[1], Nicolas Braud[2], Moritz Ewert[1], Matteo Jugovac[3], Tevfik Onur Menteş[3], Andrea Locatelli[3], Jens Falta[2], Jan Ingo Flege[1]

[1]Applied Science and Semiconductor Spectroscopy, BTU Cottbus-Senftenberg, Cottbus, Germany
[2]Institute for Solid State Physics, University of Bremen, Bremen, Germany
[3]Elettra-Sincrotrone Trieste S.C.p.A, Bazovizza, Trieste, Italy
Email: lars.buss@b-tu.de

The combination of graphene with other two-dimensional materials in vertically stacked 2d heterostructures gives rise to the possibility of altering the electronic properties of both materials in the attempt of tailoring new structures for the application in electronics, catalysis, or sensors. Despite the great interest, most of the investigated 2d heterostructures were realized by mechanical exfoliation and chemical vapor deposition in the millibar range, and true *in-situ* characterization of the growth process is rarely found in the literature. On *in-situ* prepared samples, Dau et al. [1] have shown that a single layer of $MoSe_2$ grown on few-layer graphene is effectively n-doped and a bandgap of 250meV is opened at the Dirac Point of graphene. To understand the growth process and its significance in terms of electronic properties, here, we have investigated the growth of single-layer $MoSe_2$ on single-layer graphene on Ru(0001) via real-time *in-situ* LEEM and µLEED measurements. The graphene is grown by deposition of carbon from an ethylene precursor at elevated temperatures. After the preparation of graphene, $MoSe_2$ has been prepared via co-deposition of Mo and Se at 250°C as shown in Figure 1a). When only partially covering the Ru(0001) surface with graphene, intercalation of selenium atoms through the edges of the graphene can be observed, which leads to a decoupling of the graphene and the substrate and appears to enhance the subsequent growth of $MoSe_2$ on the graphene. Rotational ordering of the $MoSe_2$ is achieved by annealing at elevated temperatures, which is strongly enhanced by the pronounced mobility of single-domain $MoSe_2$ islands that align with the high symmetry orientations of the underlying graphene (cf. Figure 1b), indicating a non-negligible interaction between the two van-der-Waals materials. XPEEM and µARPES (cf. Figure 1c) prove the monolayer nature of the as-grown $MoSe_2$ as well as the free-standing character of the Se-intercalated graphene underneath. Interestingly, the charge-transfer doping between the graphene and the intercalant is effectively reversed by the charge transfer between the graphene and the $MoSe_2$, leading to a virtually undoped, freestanding graphene inside the selenium-$MoSe_2$ sandwich.

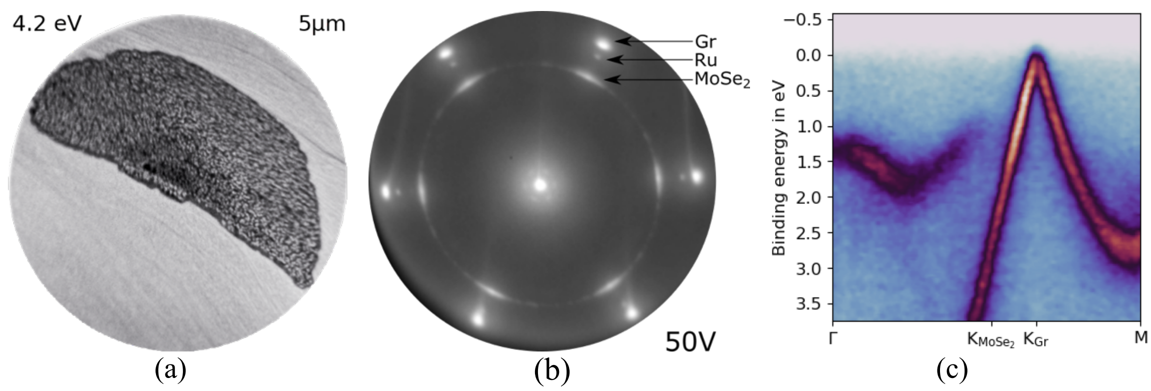

Figure 1. (a) BF-LEEM image of MoSe2/Gr/Ru(0001). The lens-shaped graphene island appears dark while the $MoSe_2$ is visible as bright spots inside the island. (b) µLEED pattern obtained on the graphene island. The reflections of the respective materials are marked. (b) µARPES of MoSe2/Gr/Ru(0001) obtained on the graphene island.

References

[1] M. Dau, M. Gay, et al., ACS NANO **12,** 2319 (2018)