Large-area van der Waals epitaxy of ferromagnetic Fe_3GeTe_2 films on graphene

J. Marcelo J. Lopes[1]
D. Czubak,[1] E. Zallo,[1*] A. I. Figueroa,[2] C. Guillemard,[3] M. Valvidares,[3] J. Rubio-Zuazo,[4,5] J. López-Sanchéz,[4,5] S. O. Valenzuela,[2,6] M. Hanke,[1] M. Ramsteiner[1]
1- Paul-Drude-Institut für Festkörperelektronik, Berlin, Germany
2- Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC and BIST, Barcelona, Spain
3- ALBA Synchrotron Light Source, Barcelona, Spain
4- Spanish CRG BM25 Line at The ESRF - The European Synchrotron, Grenoble, Spain
5- Instituto de Ciencia de Materiales de Madrid (ICMM), Madrid, Spain
6- Institució Catalana de Recerca i Estudis Avançats (ICREA), Barcelona, Spain
**Current affiliation: Water Schottky Institut and Physik Department, TU München, Garching, Germany*
Contact: lopes@pdi-berlin.de

Large-area growth of magnetic 2D materials and van der Waals (vdW) heterostructures is of paramount importance for the development of ultra-compact spintronic devices [1]. Here, we report on vdW epitaxy of the ferromagnetic metal Fe_3GeTe_2 – a 2D crystal with tunable properties and great potential for room temperature ferromagnetism [2] – via molecular beam epitaxy using elemental Fe, Ge, and Te evaporated from Knudsen cells, and growth temperatures around 300 °C. Epitaxial graphene on 4H-SiC(0001) fabricated by high-temperature SiC surface graphitization [3] was utilized as a substrate. Morphological and structural characterization performed with different methods including Raman spectroscopy (see Fig. 1a) and synchrotron-based grazing incidence X-ray diffraction confirmed the formation of continuous Fe_3GeTe_2/graphene heterostructure films with stable interfaces and good crystalline quality. A robust out-of-plane ferromagnetism in the Fe_3GeTe_2 films, comparable to state-of-the-art flakes (e.g., T_{Curie} ~ 220 K) [2], was confirmed by X-ray magnetic circular dichroism (XMCD) and magneto-transport investigations (see Fig. 1b,c). The latter also revealed the occurrence of the quantum Hall effect in the graphene (not shown), underlining the high quality of the epitaxially grown vdW heterostructure. These results are highly relevant for further research on wafer-scale growth of vdW systems containing magnetic 2D crystals for the realization of multifunctional, atomically thin devices.

References

[1] S.O. Valenzuela, S. Roche, Nat. Nanotechnol. **14**, 1088 (2019).
[2] Y. Deng et al., Nature **563**, 94 (2018).
[3] M. Heilmann et al., ACS Appl. Mater. Interfaces **12**, 8897 (2020).

Figures

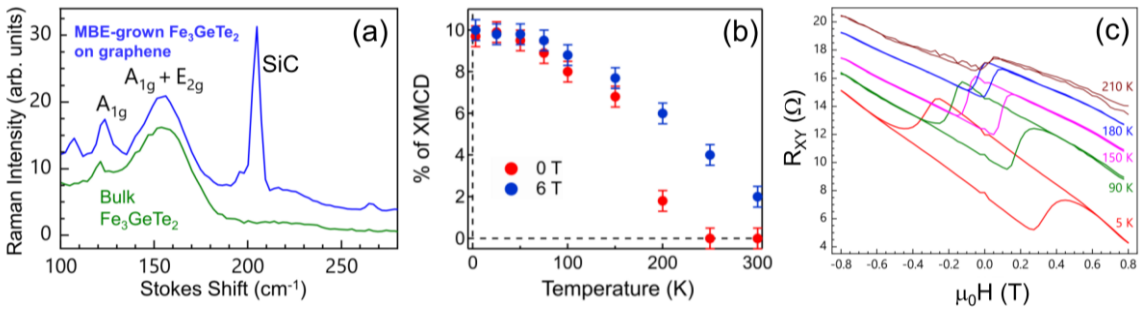

Figure 1: (a) A typical Raman spectrum for a 10 nm thick Fe_3GeTe_2 MBE film showing the associated A_{1g} and A_{1g} + E_{2g} components (blue). A spectrum collected from a commercially available bulk crystal is plotted for comparison (green). (b) Temperature dependence of the Fe L_3 XMCD maximum in saturation (6 T, blue) and remanence (red) for a 20 nm thick Fe_3GeTe_2 film on graphene/SiC. (c) The anomalous Hall effect measured in a 1 cm^2 van der Pauw geometry for a 20 nm thick Fe_3GeTe_2 film on graphene/SiC at different temperatures. From the magneto-transport results, a Curie temperature of about 220 K was obtained, in agreement with the XMCD analyses.