Light-Emitting Tunneling Van Der Waals Heterostructures In Magnetic Fields

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The toolbox of available two-dimensional (2D) crystals comprises a variety of materials with different electronic properties (metallic, semiconducting and insulating). By vertically stacking different types of 2D crystals one can create more complex systems, which are referred to as *van der Waals heterostructures* (vdWs) [1]. Lately, vdWs were fabricated using ultrathin layers of graphene, hexagonal boron nitride (hBN) and transition metal dichalcogenides. The first successful demonstration of devices like field-effect tunneling transistors [2] or light-emitting tunneling diodes [3] highlight the great versatility of the approach.

(a)
(b)

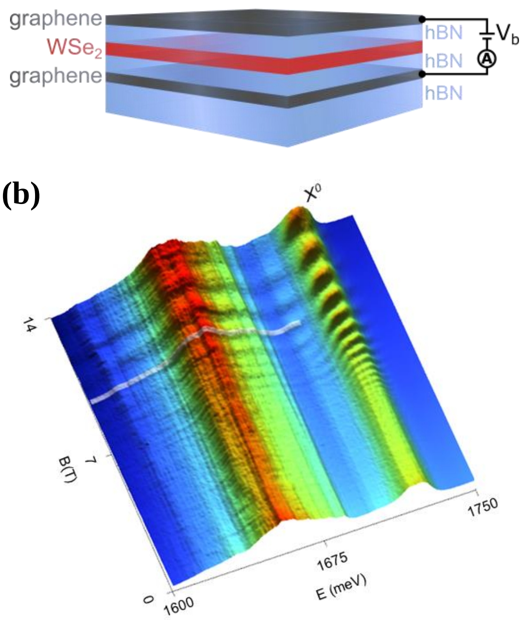

Fig.1: (a) sample structure, (b) 3D false color plot of the EL of the vdW as a function of magnetic field

Here, we report on magneto-optoelectronic measurements of a light-emitting tunneling structure based on a WSe_2 monolayer (ML) as the active emission material. The actual stacking sequence for the samples was hBN / graphene / hBN / WSe_2 / hBN / graphene (Fig. 1 (a)). Remarkably pronounced magneto-oscillations were observed for the electroluminescence (EL) of the free exciton emission line (X^0) of the WSe_2 ML (Fig.1 (b)). The results can be interpreted in terms of a modulation of the tunneling injection processes into the WSe_2 caused by the Landau quantization of the graphene electrodes. These oscillations can be used to deduce an effective valence band offset for the graphene / WSe_2 / hBN system.

Surprisingly, the EL signal was registered even at sub-bandgap voltages, which can be explained by taking into account tunneling into exciton states, which are situated well (~ 0.4 eV) below the bandgap of the WSe_2 ML. These findings indicate the great potential of vdWs for optoelectronic applications. The sheer number of materials and combinations for vdWs should allow to tailor many more device schemes suitable for a plethora of applications.

[1] A. K. Geim et al. *Nature* **499**, 419 (2013).
[2] L. Britnell et al. *Science* **335**, 947 (2012).
[3] F. Withers et al. *Nature materials* **14**, 301 (2015).

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