Multidimensional sensing of proximity magnetic fields via intrinsic activation of dark excitons in $WSe_2/CrCl_3$ heterostructure

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Monolayers (MLs) of WSe_2 are darkish materials with ground dark (optically inactive) exciton state. The neutral dark excitons exhibit a double (fine) structure comprising so-called grey (X^D) and dark (X^D) complexes. The X^D emission can be observed only due to the applied in-plane and out-of-plane magnetic field [1]. Magnetic layered materials with intrinsic magnetic order [2] are perfect candidates to be used to brighten the dark exciton due to the proximity effect. We employ the polarization resolved photoluminescence (PL) at low temperature (T=5 K) and temperature dependent PL measurement to investigate the proximity effect in two heterostructures (HS1 and HS2) comprising the WSe_2 ML, capped with the $CrCl_3$ layer and encapsulated in hexagonal BN. Fig. 1 (a) displays photoluminescence spectra of 10 nm CrCl3 flake, WSe_2 and HS1 $WSe_2/CrCl_3$ heterostrucure. The spectrum of $CrCl_3$ flake exhibits a broad-band optical response. The spectrum of WSe_2 is analogous to those previously reported and comprises in particular emission lines related to the bright neutral exciton (X^B) and dark exciton (X^D). The PL spectra, measured at the edges of $WSe_2/CrCl_3$ heterostructure (HS1) is dominated by single narrow line, with energies close to the X_D. We attribute this line to the neutral dark exciton (X^D) activated by the in-plane component of the proximity field from the planar ferromagnet, initially based on the emission energy. We base this conclusion also on the polarization-resolved PL spectra which shows a X^D line from the HS1 characterized by two linearly polarized components with emission energy changes with detection angle with energy separation of about 700 µeV and 821 µeV which is shown on Fig. 1 (b) and (c), respectively. We also complete our observation by verifying brightening of the dark exciton by inspection of the temperature dependence on HS2. The X^D feature disappears at the temperature of about 30 K which corresponds to the Cure temperature T_c = 27 K of bulk $CrCl_3$ [3]. We conclude that emission lines in the HSs are related to the dark (X^D) exciton brightened by the in-plane magnetic field due to the non-zero net in-plane magnetization of the $CrCl_3$ layer.

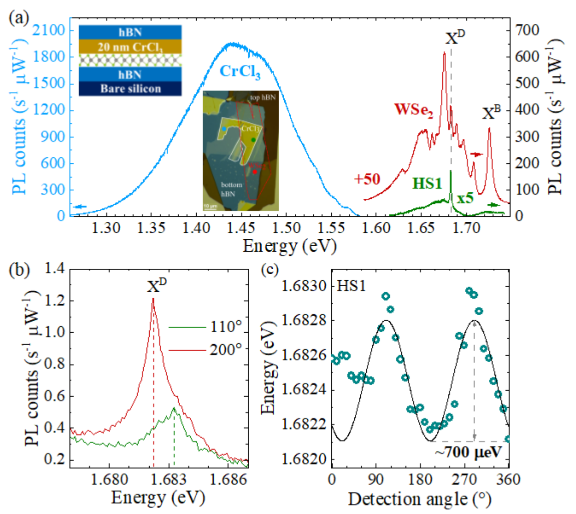

Figure 1: (a) PL spectra of 10 nm $CrCl_3$ flake (blue), ML of WSe_2 (red) and of $WSe_2/CrCl_3$ HS (green). (b) The polarization-resolved PL spectra of X^D line for two orthogonal linear polarizations. (c) Corresponding linear polarization dependence of X^D

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