Magnetic proximity interactions in the $CrCl_3$/hBN/WSe_2 heterostructures

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Monolayers (MLs) of WSe_2 are part of the semiconducting transition metal dichalcogenide (S-TMD) family, which low-temperature (T=5-10 K) photoluminescence (PL) spectra are composed of a series of excitonic lines, which have been widely investigated in the literature [1]. On the other hand, chromium chloride belonging to the family of magnetic layered materials is characterized by the ferromagnetic order with layers and the antiferromagnetic coupling between the layers with the in-plane spin alignment [2]. The combination of these two materials allows the study of the proximity effect [3].

In this work, we performed the photoluminescence (PL) experiment on the $CrCl_3$/hBN/WSe_2 heterostructure (HS), composed of a thick $CrCl_3$ layer, hBN spacer and WSe_2 ML. The spacer plays a crucial role in preventing charge transfer from WSe_2 to $CrCl_3$, as we presented in our previous work [3]. Measurements were performed at low temperature (T = 5 K), using 2.41 eV excitation energy in an out-of-plane magnetic field.

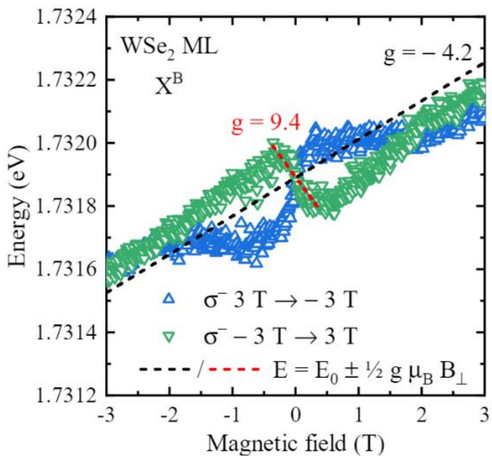

Figure 1: The magnetic field evolution of the neutral exciton (X^B) measured in the HS. The black line represents the Zeeman splitting function for the WSe_2 ML embedded in hBN flake based on the literature [1], while red dashed line is the fir using Zeeman splitting equation.

The Figure represents the energy dependence of the neutral exciton (X^B) measured on the HS in magnetic fields. Green and blue triangles denote the $\sigma-$ polarization of the magnetic field course form 3 T to -3 T and from -3 T to 3 T, respectively. Within the range of small magnetic fields, an unusual behavior of the X^B transition is observed. The energy values exhibit non-linear dependence as a function of magnetic fields. Around |0.2| T, a sudden change in energy of approximately 3 μeV is observed. Using the standard equation for the Zeeman effect, describing the splitting into two circularly polarized components of the transition in the magnetic field [1], *i.e.* $E^{\sigma^{\pm}}(B) = E_0 \pm \frac{1}{2} g \mu_B B_{\perp}$, we found a g-factor of around 9.4 in this region. Furthermore, in magnetic field ranges of |0.2| T - |2| T and |2| T - |3| T, the data points form linear lines, each with different slopes. The magnetic field dependence of the X^B emission in the WSe_2 ML encapsulated in hBN flakes is characterized by the g-factor of around -4.2, which is represented by the dashed black line in the Figure. At the same time, the PL intensity of $CrCl_3$ shows a minimum at around |0.1| T. This is followed by the flattering of its intensity above |2| T, ascribed to a critical field [4], due to the change of the spin orientation in $CrCl_3$ from the intrinsic in-plane to along the applied out-of-plane magnetic field.

We propose that the departure from the linear dependence of the X^B energy in external magnetic fields can be understood in terms of the interaction between the magnetic $CrCl_3$ and the WSe_2 ML. It is conceivable that the unusual energy dependence at small magnetic fields is due to the presence of the $CrCl_3$ magnetization, while the increase in external magnetic fields causes the disappearance of the coupling between $CrCl_3$ and WSe_2. Finally, the change in the orientation of the spin alignments in $CrCl_3$ above the critical fields results in the standard Zeeman splitting of the X^B line. Our results emphasize the complexity of the magnetic coupling between magnetically ordered $CrCl_3$ and the WSe_2 ML due to the proximity effect, which understanding is key for future possible applications.

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