Supplementary information for Identifying defect-related quantum emitters in Monolayer WSe_2

Jianchen Dang,[1,2] Sibai Sun,[1,2] Xin Xie,[1,2] Yang Yu,[1,2] Kai Peng,[1,2] Chenjiang Qian,[1,2] Shiyao Wu,[1,2] Feilong Song,[1,2] Jingnan Yang,[1,2] Shan Xiao,[1,2] Longlong Yang,[1,2] Yunuan Wang,[1,3] M. A. Rafiq,[4] Can Wang,[1,2,5] and Xiulai Xu[1,2,5,*]

[1]*Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China*

[2]*CAS Center for Excellence in Topological Quantum Computation and School of Physical Sciences, University of Chinese Academy of Sciences, Beijing 100049, China*

[3]*Key Laboratory of Luminescence and Optical Information, Ministry of Education, Beijing Jiaotong University, Beijing 100044, China*

[4]*Department of Physics and Applied Mathematics, Pakistan Institute of Engineering and Applied Sciences, P.O. Nilore, Islambad 45650, Pakistan*

[5]*Songshan Lake Materials Laboratory, Dongguan, Guangdong 523808, China*

[*] xlxu@iphy.ac.cn

Supplementary Figure 1

(a) The optical microscopy image of the WSe_2 obtained by mechanical exfoliation. P1, P2 indicate different measurement positions. We also measured other samples and observed similar phenomena in which narrow peaks occur at the edge of monolayer or few layers, as shown in (b). The scale bar is 5 μm. (c) The comparison of the narrow emission line induced by defects and the intrinsic valley exciton spectrum, corresponding to P1, P2 in (a). (d) PL spectra as a function of temperature. With increasing the temperature, the intensity of these emitters decrease until disappearing with linewidth broadening dramatically. The evolution of PL intensity with temperature further confirms that these narrow peaks are derived from the defects.

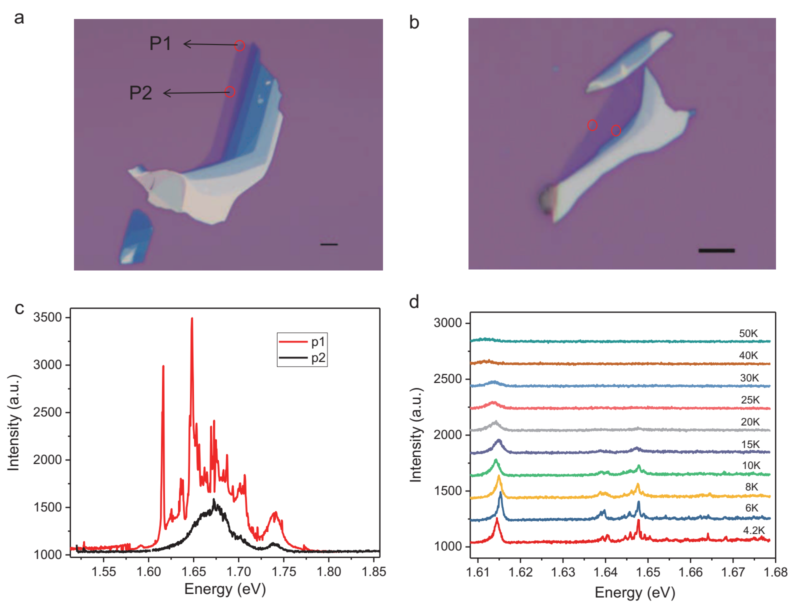

Fig. 1

Supplementary Figure 2

Magneto-optical measurement of another emission lines which have the same behaviour with QD1. (a) PL spectra with different magnetic fields. The emissions arise from type I transition and the electron-hole recombination occurs assisted by electron and hole trapping. The peak energy as a function of magnetic field is shown in (b). The extracted g factor and FSS are about 2.17 and 336 μeV, respectively, as shown in (c).

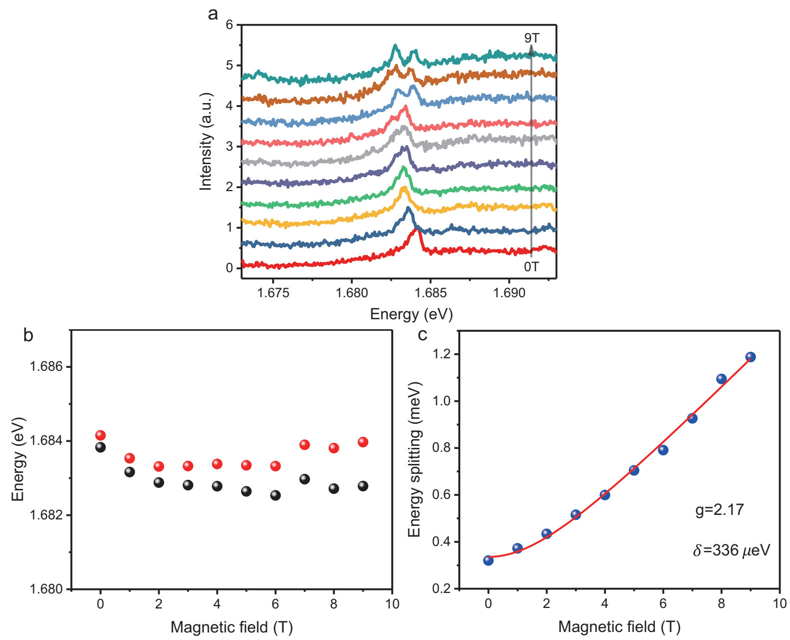

Fig. 2

Supplementary Figure 3

Magneto-optical measurement of QD2 in vector magnetic field. (a) Schematic of the relative angle of vector magnetic field. θ is the angle between the vector magnetic field and the normal of the sample. (b) PL spectra as a function of magnetic field in Faraday configuration. A g factor about 7 and FSS about 730 μeV can be observed. (c) PL spectra as a function of magnetic field in Voigt configuration, in which no obvious changes are observed. The energy splitting of the doublet as a function of magnetic field in Voigt configuration is shown in (d). The energy splitting of the doublet basically remains same, indicating a small g factor in the plane of sample, similar to III-V quantum dot[1, 2]. (e) PL spectra with different θ. The total strength of the vector magnetic field remains 4 T. The energy splitting as a function of θ is shown in (f). The evolution of splitting with angle θ is similar to III-V quantum dot[1, 2]. The Zeeman splitting exceeds the exchange energy and becomes dominant with applied magnetic field perpendicular to the sample.

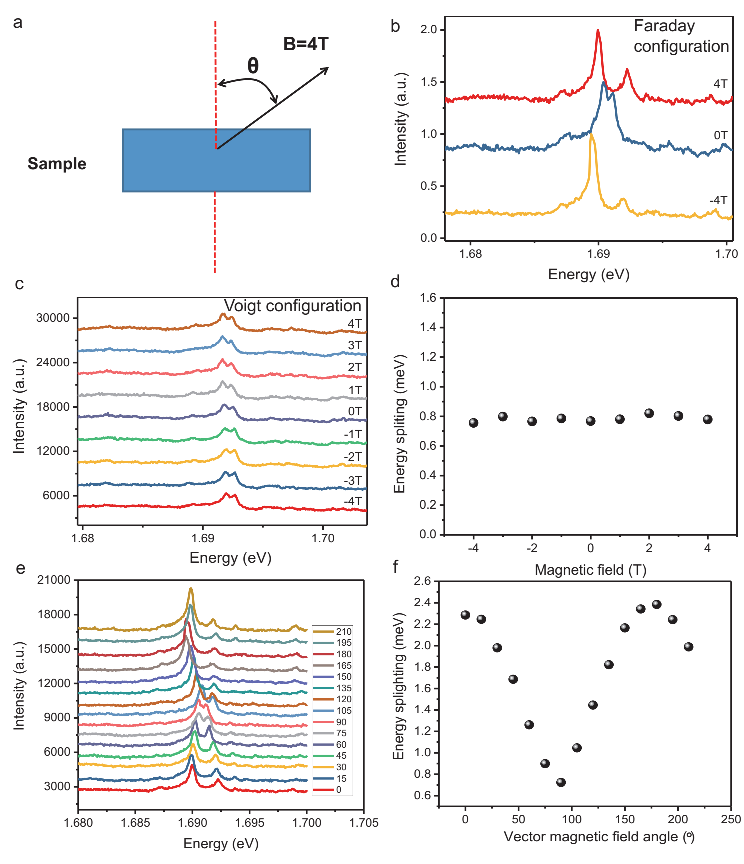

Fig. 3

Supplementary Figure 4

Magneto-optical measurement of other emission lines for type III. (a) PL spectra with different magnetic fields. (b) Energy of peaks as a function of magnetic field. Both two emission lines arise from type III transition which exhibit unobservable FSS and Zeeman splitting. Spectral wandering can be observed for both emission lines.

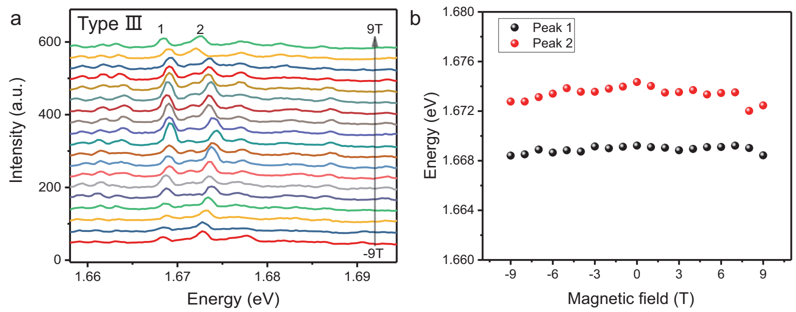

Fig. 4

Supplementary Figure 5

The contributions of valley magnetic moment to three types of quantum emitters under magnetic field are shown in Figure S5. Under positive magnetic field (B > 0), all bands will experience a large upshift (downshift) in the K (-K) valley. The electrons in different valleys will have energy difference, resulting in unequal distributions in the two valleys following the case near thermal equilibrium. That is to say, the electrons tend to occupy the conduction band in -K valley. And the case for the negative magnetic field (B < 0) is the opposite. The unequal distributions in the two valleys lead to the magnetic field dependence of intensity with different helicity. For QD1 and QD2, in which the electrons are trapped by defect levels, the dependence of PL intensity on magnetic field is not obvious compared to QD3.

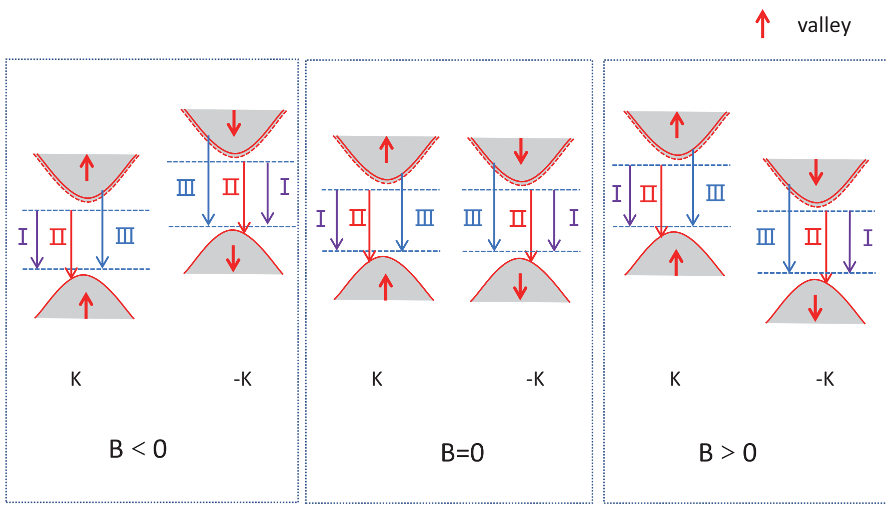

Fig. 5

REFERENCES

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