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Deeply-submicron confocal photoluminescence spectroscopy and edge recombination in WS_2-WSe_2 lateral heterostructure monolayer crystals

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Abstract: We conducted confocal micro-photoluminescence spectroscopy to scan a WS_2-WSe_2 lateral heterostructure sample using oil emerged microscopy method. We observed enhanced PL lines at the edges of WSe_2 and spatially enhanced PL at tip of the v-shaped areas.

OCIS codes: (250.5230) Photoluminescence; (160.6000) Semiconductor materials; (300.6250) Spectroscopy, condensed matter

1. Introduction

The monolayer transition metal dichalcogenide (ML-TMDC) has a single atomic layer in thickness with direct band gap properties and weak screening of charge carriers that enhance the light matter interactions [1], which are attractive optoelectronic properties and promising for emerging applications. To realize these applications using TMDCs, we need to understand the structural defect effects on the surface, edge and boundary state of the material. The recently developed chemical vapor deposition (CVD) grown method allows the creation of uniform thickness, large size, and multiple TMDC materials' heterostructure [2], but these synthesized 2D materials can still have structural defects, such as intrinsic lattice structure defects [3], which can in turn effect their optical properties. The μ-PL optical properties of TMDCs have been studied, but imposing diffraction limits to observe its properties has not been possible due to lack of resolution. Therefore, in this paper, we present our work using μ-PL to scan the sample via oil emerged microscopy method, which allows a beam size ≈ 200 nm , and thus enabled us to observe enhanced PL lines at the very edges of the WSe2 flakes and spatially enhanced PL at the v-shaped parts of the sample.

2. Material and Method

The WS_2-WSe_2 lateral heterostructure sample was prepared using CVD growth method on SiO_2(300nm)/Si substrate. As shown in Figure 1**a**, the material of the center of the quasi-triangle area was tungsten disulfide (WS_2) and that of the darker edge area was tungsten diselenide WSe_2 with 4 to 9 um width. Raman spectroscopy of the lateral hetrostructure with a 514nm wavelength laser clearly showed the monolayer characteristics of each region. The monolayer WS_2 had E_{2g} peak around 350 cm^{-1} and A_{1g} peak around 420 cm^{-1} and the intensity of E_{2g} peak was much higher than that of A_{1g} peak. The monolayer WSe_2 had a single maximum peak around 250 cm^{-1}. The two monolayers had a peak around 520 cm^{-1} from the SiO_2/Si substrate (Figure 1**b**). Spectrums of photoluminescence (PL) were observed by the confocal setup. The WS2 center region and WSe2 edge region had an emission peak at 1.95 ev and 1.61 ev, respectively, and WS_2 emission intensity was brighter than that of WSe_2 by more than twice (Figure 1**c** and **d**). For these experiments, we used an excitation laser with 594 nm wavelength and around 50uW power, and we were successful in getting μ-high resolution PL from a beam size as small as ~200nm. In addition,

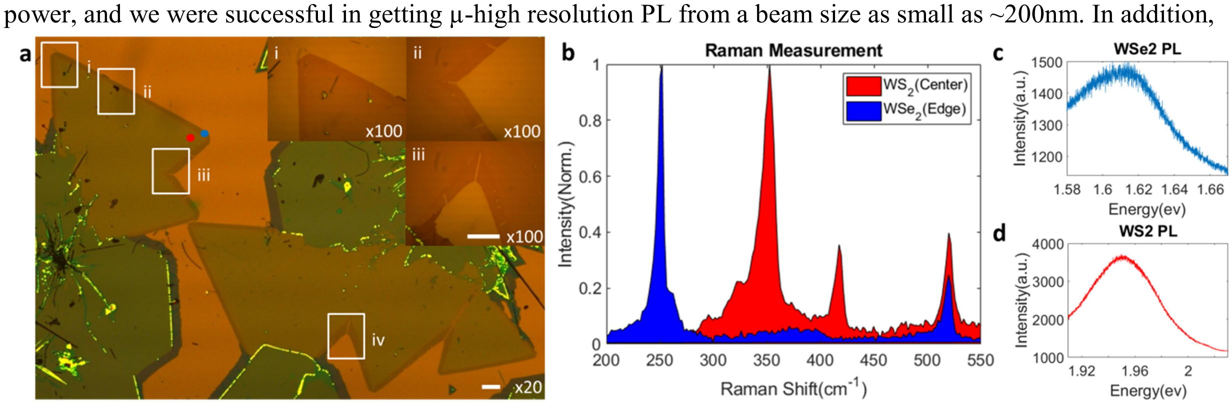

Figure 1 │ a, Flake areas in WS_2-WSe_2 lateral heterostructure sample. i~iv are the areas of interest. i and ii are edge enhanced recombination areas and iii and iv are the v-shaped regions. A scale bar in 20x and 100x are 5um and 10um, respectively. **b**, Raman measurement of WS_2-WSe_2 lateral heterostructure. Blue line is the WS_2 region(center), and red line is the WSe_2 region(edge). The red and blue dots on **a** are the areas of measurement, the color corresponds with those of **b**, **c**, and **d**. A 514nm laser was used for Raman measurement. **c** and **d** Measurement of the wavelength of the photoluminescence at WS_2 and WSe_2 regions. WS_2 was much brighter than WSe_2 region. A 532nm laser was used for PL spectrum measurement. The measurement was performed at room temperature.

we used two detectors to detect each wavelength at the same time with the WS_2 detector set to 632 to 638 nm window (1.96 to 1.94 ev), and the WSe_2 detector set 750 to 780 nm window (1.65 to 1.59 ev).

3. Results and discussion

Figure 2**a**, shows the bright field microscopic image (100×) of the flakes corresponding to the areas of interest given in Figure 1**a,** and Figure 2 shows the results of applying μ-high resolution PL. By comparing the bright field images with those of μ-PL, we can clearly see that they overlap on the cracks and some oxidation areas that have no PL to show the accuracy of μ-PL. Simultaneously, the μ-high resolution PL experiment successfully found unexpected bright lines and spots. As shown in Figure 2**a** and **b**, μ-PL experiment mapped out that the most edge region of WSe_2 which had a bright line of a width of ≈ 300 nm. Correspondingly, as seen in inset of each figures, the intensity of WSe_2 PL had the highest point at both edges with the dimer area in the middle. These results were completely opposite to that of the WS_2 center quasi-triangle area whose intensity increased far away from the edges. Furthermore, the μ-PL experiment mapped out a very bright spot on the tip of v-shaped structure for each of the two different parts of the WSe_2 area (Figure 2**b** and **c**). These results were corroborated by that of the spatial profile where these two micrometer spots were much brighter than other WSe_2 regions. These two interesting phenomena may have been caused from defect state on the edge and v-shaped parts of the flakes. These defects state on areas is effect on the edge recombination so that the enhanced PL observed not only single edge area but also boundary edge between two materials heterostructure. In future study, TEM measurement, μ-Raman, and spectrum measurements at enhanced area will be included.

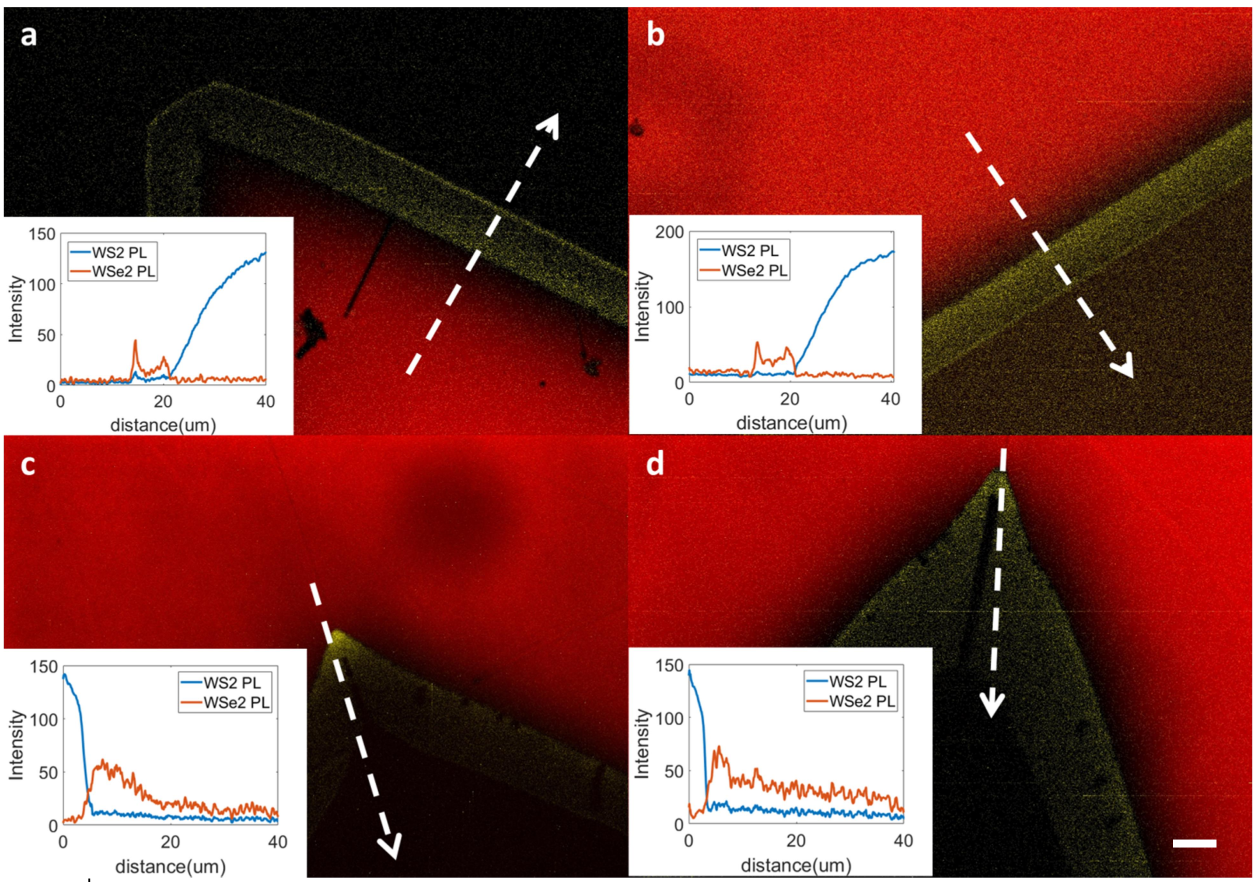

Figure 2 | μ-PL image of interested area on Figure 1**a**. Red color is WS_2 PL, and orange color is WSe_2 PL. Insets in each μ-PL are the respective spatial intensity profile of the dash lines. **a** and **b** are enhanced PL from edge recombination. **c** and **d** are tip enhanced PL area at the v-shaped parts. The scare bar at figure **d** is 5um.

4. References

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