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Low Loss EELS of Lateral MoS_2/WS_2 Heterostructures

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Transition metal dichalcogenides (TMDs) are a class of two-dimensional (2D) materials with a fixed band gap. The fixed band gap limits the usage of these materials in optoelectronics [1], spintronics and valleytronics applications [2]. One of the possible ways to engineer band gap of TMDs is to create lateral and vertical heterojunctions [3].

Lateral TMD heterostructures create atomically thin p-n junctions. These 1D interfaces offer tremendous potential to probe effects such as ultrafast charge transfer, strong coupling and strain at the interface [4–5]. A particularly interesting heterostructure is Type II MoS_2/ WS_2. MoS_2 and WS_2, due to very small lattice mismatch (1.3%), form clean and smooth zig-zag interfaces over large areas [6].

So far, the band gap variation at heterostructure interfaces has been probed by photoluminescence (PL) [6], scanning probe microscopy (SPM) and scanning tunneling microscopy (STM) [5] . PL maps out the excitons present in the heterostructure but the technique is limited by the resolution of light. STS and SPM on the other hand, gives information about the band alignment but has little information about the exciton dynamics in the heterostructure.

Low loss electron energy loss spectroscopy (EELS) in a scanning transmission electron microscope (STEM) gives information about the excitons, plasmons and phonons at high spatial resolution. Recently, low loss EELS at cryogenic temperature has been used to map the excitons in the 2D materials. Tizei *et.al.* have reported the exciton mapping at subwavelength scales in $MoS_2/MoSe_2$ heterostructures in which the excitons broaden at the interface [7]. Using the same approach of low loss EELS at low temperature, the excitons at the interface of CVD grown MoS_2/WS_2 lateral heterostructure have been mapped with higher spectral and spatial resolution.

Figure 1a shows the high-resolution annular dark-field (ADF) image of zigzag interface of MoS_2/WS_2 lateral heterostructure. The higher Z-contrast atoms are that of WS_2 while the darker atoms are MoS_2. After the lateral heterostructure was identified, low loss EEL spectral mapping was done in the same region. (Figure 1c) The corresponding ADF image is shown in Figure 1b. To summarize, three EEL spectra from pure MoS_2, the heterojunction and pure WS_2 are displayed in Figure 1d. In Pure MoS_2, two exciton peaks (1.98 eV and 2.09 eV) were observed separated by 111 meV. On the other hand, in WS_2, the two exciton peaks (2.02 eV and 2.40 eV) are separated by 400 meV. At the heterostructure interface, we find a broadening and a shift in the MoS_2 peak [8].

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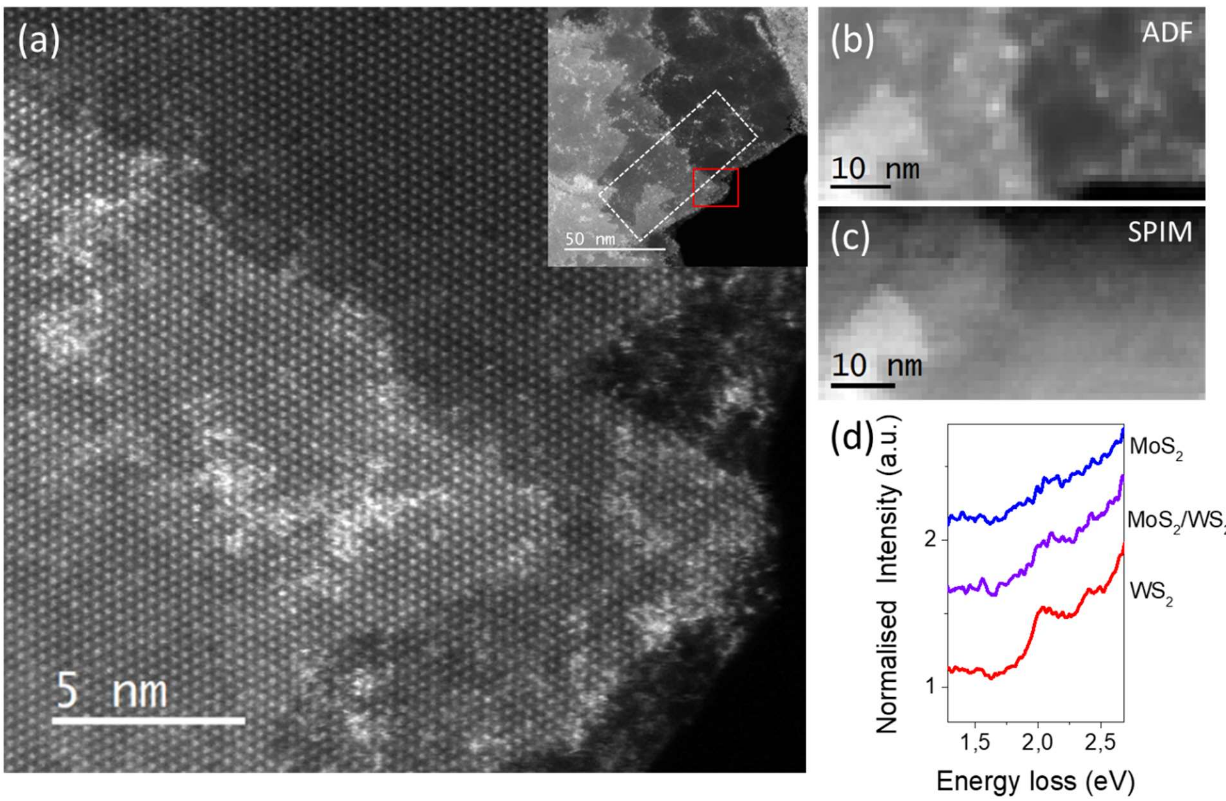

Figure 1. (a) High magnification image of the lateral heterostructure. The higher Z-contrast regions are WS_2 while the dark regions are MoS_2. Inset shows the lower magnification the ADF image in 1a. (b) Scanned ADF image of the heterostructure interface while acquiring EELS spectrum image (spim). (c) Map of the EELS signal integrated at the zero loss tail obtained simultaneously with the ADF shown in (b) indicating the homogenous thickness and confirming the presence of lateral heterojunction. (d) Low loss EELS corresponding to pure MoS_2, heterostructure interface and pure WS_2 regions in the spim.