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RESEARCH ARTICLE

Key electronic parameters of $2H$-stacking bilayer MoS_2 on sapphire substrate determined by terahertz magneto-optical measurement in Faraday geometry

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Supporting Information

We conducted an empirical analysis of the fundamental attributes of bilayer (BL) MoS_2 on a sapphire substrate, employing a suite of techniques including atomic force microscopy (AFM), Raman spectroscopy, and photoluminescence (PL). The AFM-derived topographical data, depicted in Fig. 1(a), reveals a uniformly distributed, pristine MoS_2 thin film. Through measurement of the height differential between the MoS_2 layers and the underlying sapphire as indicated by the white line in Fig. 1(a) we inferred a film thickness of approximately 1.3 nm. This measurement implies a bilayer arrangement for the MoS_2, considering that the thickness of a monolayer (ML) is roughly 0.65 nm [1].

Raman spectral analysis, as shown in Fig. 1(b), was performed using 532 nm laser excitation at ambient conditions, capturing two key vibrational modes intrinsic to BL MoS_2: the in-plane E^1_{2g} mode and the out-of-plane A_{1g} mode [2]. The frequency shift between these peaks ($\Delta = A_{1g} - E^1_{2g}$) is measured at about 21.9 cm^{-1}, which aligns with established properties of BL MoS_2 [1, 2]. Moreover, a detailed examination of the spectrum, achieved by Gaussian fitting (overlaying red, blue, and green curves), allowed identification of a peak "a" near 396 cm^{-1} associated with $2H$-stacking BL MoS_2 [3, 4], alongside a sapphire-substrate-specific peak at approximately 417 cm^{-1} [2].

For PL spectral analysis, we utilized a helium-neon (He-Ne) laser with a wavelength of 532 nm, incorporated with a grating of 1800 lines/mm and an exposure period of 10 seconds; a charge-coupled device (CCD) detector was leveraged for signal capture. We investigated the PL responses of both ML and BL MoS_2 on sapphire, in addition to the bare substrate. By subtracting the native substrate's PL response, delineated in Fig. 1(c), from those of the MoS_2-coated samples, discernible PL characteristics of the $2H$-stacking BL MoS_2 were accentuated, as manifested in the black curve of Fig. 1 (c). For comparative purposes, PL results for ML MoS2 on sapphire, synthesized through a comparable chemical vapor deposition (CVD) process [1–5], are also presented (red curve). The PL spectra were recorded under room temperature using the same 532 nm laser excitation.

From the PL analysis, two eminent emission peaks are seen: Peak A at around 1.86 eV and Peak B at approximately 2.01 eV. These findings concur with reports from prior research [6, 7]. Anticipatedly, the PL emission intensity from BL MoS2 appeared discernibly subdued when juxtaposed with the emissions from ML MoS2.

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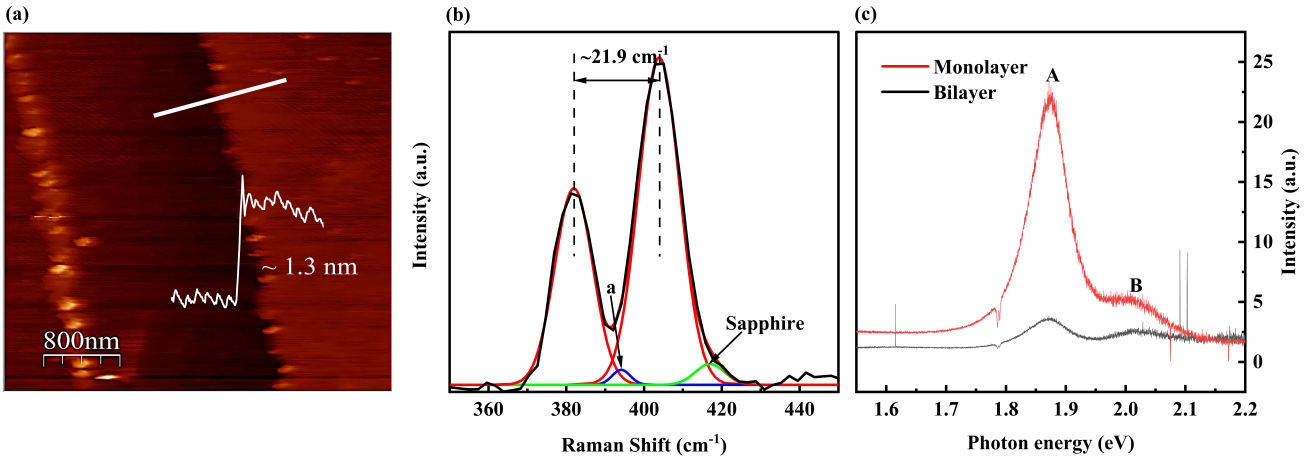

Fig. S1 (a) AFM image of bilayer (BL) MoS_2 on sapphire substrate. The inset shows the hight of the step-change between MoS_2 layer and the substrate along the line marked as white straight line, which corresponds to the thickness of the bilayer MoS_2. **(b)** Raman spectra of BL MoS_2 on sapphire substrate (black curve), measured at room-temperature by a 532 nm laser excitation. Two characteristic peaks for BL MoS_2, A_{1g} and E^1_{2g} with a spacing about 21.9 cm^{-1}, can be clearly identified. By spectral decomposition (red and blue curves), the Raman peaks A_{1g} and E^1_{2g} along with "a" peak induced characteristically by the $2H$-stacking type and the characteristic peak for sapphire can be found. **(c)** Photoluminescence (PL) spectra of monolayer (ML) (red curve) and BL (black curve) MoS_2, measured at room-temperature using a 532 nm laser excitation, where the results are shown after deducting the signals from sapphire substrate.

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