Giant mechanico-optoelectronic effect in an atomically-thin semiconductor

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Transition metal dichalcogenides (TMDs) are attractive for use in next-generation optoelectronic applications, where atomically-thin components can be made into flexible and stretchable devices. Promising for optical applications, it has been shown that as TMDs scale to a thickness of one monolayer, the photoluminescence response is dramatically enhanced due to emergence of a direct electronic band gap, compared with multi-layer or bulk TMDs exhibiting an indirect band gap. Recently, mechanical strain has also been predicted to enable this transition, where large changes in the photoluminescence response should occur during an indirect-to-direct transition. In this presentation, we demonstrate a two orders of magnitude enhancement in the photoluminescence intensity in uniaxially-strained WSe_2 bilayers with uniform thicknesses. Uniaxial strain was applied through an innovative four-point bending apparatus with the capability of providing up to 3.6 % tensile strain, which is limited by the fatigue behaviors of the flexible poly(ethylene terephthalate) (PET) substrate and poly(methyl methacrylate) (PMMA) encapsulation layers, with strain validation performed through experiments on ultrathin silicon. The transfer of strain to the WSe_2 bilayer was enabled by a novel annealing process performed on the PMMA/WSe_2/PMMA/PET composite to soften the PMMA and increase the adhesion strength at the interface between the PET/PMMA and PMMA/WSe_2. Adding confidence to the high levels of elastic strain experienced by the atomically-thin crystallite, we observe fixed values of mode-dependent Grüneisen parameters over the entire range of strain (1–3.59 %) with no evidence of relaxation through slippage or plastic deformation.

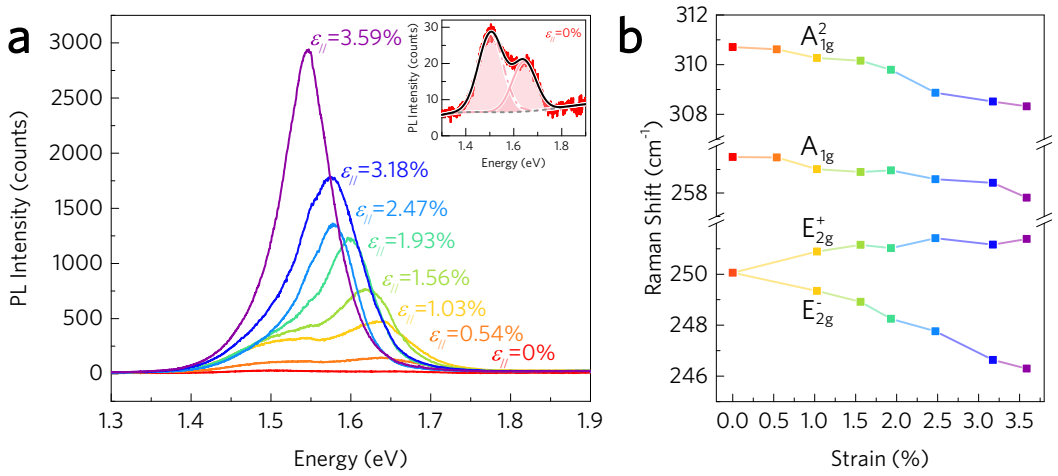

Fig. 1: Amplification of the photoluminescence (PL) emission intensity of bilayer WSe_2 as it is strained up to 3.59%. (a) PL emission spectra resulting from excitation at 2.33 eV as a function of applied uniaxial strain. Inset shows the PL spectra of the unstrained material, $\varepsilon_{//}$=0, where the indirect (dash dotted line) and direct (solid line) electronic transitions have been deconvoluted using Gaussian distributions. (b) Strain dependence of the of the peak Raman Shift of the E^+_{2g}, E^-_{2g}, A_{1g}, and A^2_{1g} modes, obtained by deconvolution of the experimental Raman spectra using Lorentzian distributions. Linear strain dependence of the Raman shift indicates strain relaxation by slippage or plastic deformation is not observed.