Dielectric substrate and capping effects on optical properties of a few atomic monolayer MoS_2 sheets

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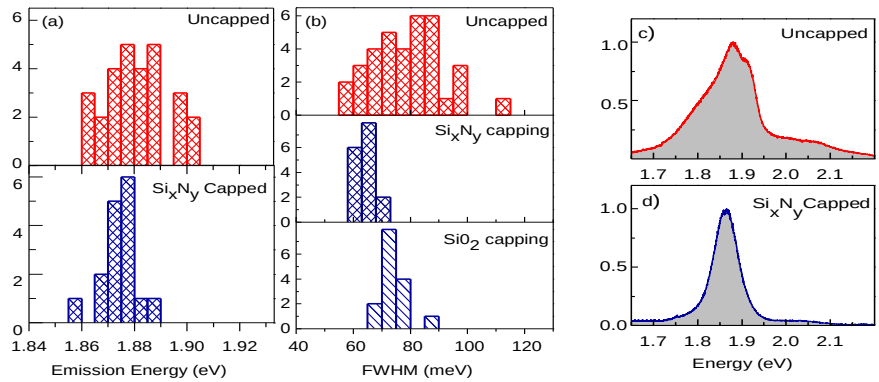
Molybdenum disulfide (MoS_2) is a promising layered material for use in Field Effect Transistors[1]. It also has unusual electronic properties such as an indirect-to-direct band gap transition and strong valley polarization[2]; with mono-molecular layer MoS_2 sheets showing bright photoluminescence (PL) up to room temperature[3]. In order to successfully integrate MoS_2 into opto-electronics devices both accurate control of light emission properties and a better understanding of thin film interactions with the environment are required. Here we use a combination of micro-PL and ultrasonic force microscopy (UFM) to show strong effects of SiO_2 substrate quality (in terms of roughness) and dielectric capping (SiO_2 and Si_xN_y) on the light emission from near-monolayer mechanically exfoliated MoS_2 sheets. In particular we find a notable variation in PL peak energy and lineshape between different sheets on the same substrate. We find that this variation is increased for rougher substrates grown by PECVD. We show, however, that such variation can be markedly suppressed, and in addition narrow PL linewidths obtained, when using atomically flat thermal oxide substrates and Si_xN_y capping (see Figure). Our interpretation of the improved reproducibility of the optical properties is supported by UFM measurements which were used to probe the elasticity of the MoS_2 sheets. We find that the stiffness of the sheet, characterising its adhesion to the surrounding dielectric layers, dramatically increases for smooth thermal oxide substrates, and is further improved by the capping. Based on both PL and UFM data, we relate the variation in the PL lineshape with variation of the strain and charging within the sheets. Thus our results indicate that optical properties can be controlled by appropriate choice of the dielectric substrate and capping, a key result providing a method for producing more consistently fabricated devices.



Histograms showing energy (a) and linewidths (b) of PL from capped and uncapped MoS_2 sheets. PL emission spectra for uncapped (c) and capped (d) MoS_2 sheets showing improved line-widths.

[1]Radisavljevic et. all. Nature nanotechnology, 6, 147–50. (2011)
[2] Zeng, H.; Dai, J.; Yao, W.; Xiao, D.; Cui, X. Nature nanotechnology 7, 490–3. (2012)
[3] Mak, K.; Lee, C.; Hone, J.; Shan, J.; Heinz, T. Physical Review Letters, 105, 2–5. (2010)