A- and B-excitons in MoS_2, $MoSe_2$, WS_2 and WSe_2 monolayers

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Excitons in monolayers (MLs) of semiconducting transition metal dichalcogenides (S-TMDs) are of major interest from different viewpoints. They exhibit large binding energies of few hundreds of meV and the Bohr radius of the ground state of $1-2$ nm. Understanding excitons in S-TMDs monolayers invokes a special form Coulomb potential imposed by the two dimensional geometry of the monolayer surrounded by distinct dielectric environments.

Here, we report on low temperature (T=5 K) reflectance contrast (RC) and photoluminescence (PL) experiments, aiming at clarifying the nature of excitons in monolayers of four different S-TMDs, *i.e.* MoS_2, $MoSe_2$, WS_2 and WSe_2, encapsulated in hexagonal boron nitride. High quality of the investigated structures allows us to trace both the ground (1s) and first-excited (2s) states of excitons in all four materials. PL spectra display the emission peaks due to A-excitons (see Figure) whereas the RC spectra show the 1s and 2s resonances of A- as well as of B-excitons. With these observations, the exciton binding energies in different materials and for A- and B-excitons are evaluated. A-excitons are found to be most (least) bounded in MoS_2 (WSe_2) monolayers, what likely reflects a different dielectric response inherent of these monolayers. The apparent difference between binding energies of A- and B-excitons correlates with the reduced effective mass associated with the corresponding intersubband transitions. Our findings provide a new input to quantify the energy ladders of excitons in S-TMD monolayers.

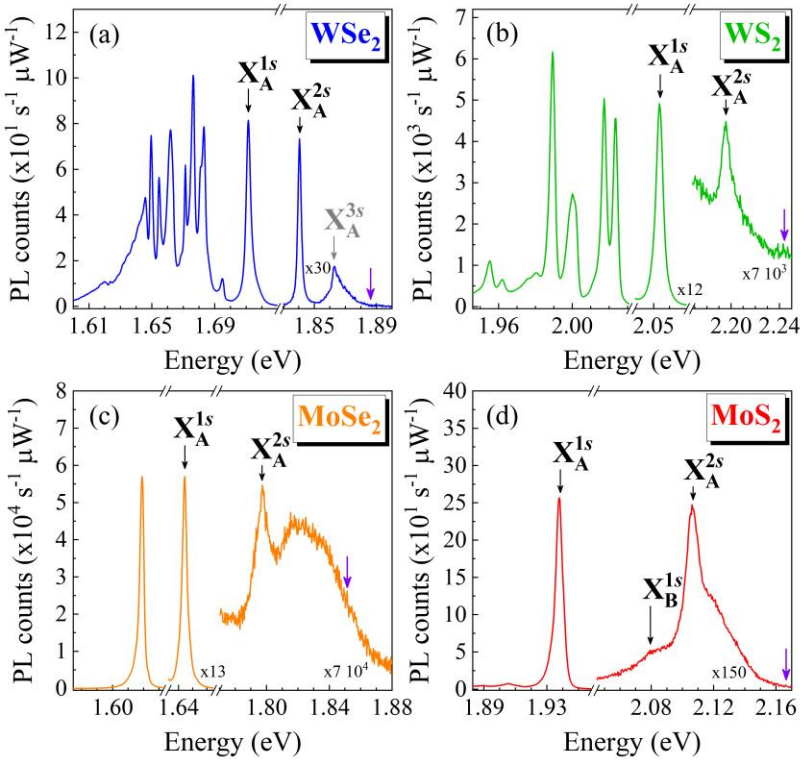

Figure: Low temperature (5 K) photoluminescence spectra of four representative monolayers of semiconducting transition metal dichalcogenide. X_A^{1s} (X_A^{2s}) denotes the emission peak due to the ground state 1s (the first excited 2s) exciton state. Arrows indicate the onset of the continuum states (single particle bandgaps associated with A-resonances). In WSe_2 monolayer, the emission peak associated with the 3s exciton state is also observed. Note that in MoS_2 monolayer, the 1s resonance of the B-exciton (X_B^{1s}) appears in a close vicinity of the 2s resonance of the A-exciton.