Electrical Control of Hybridized Exciton in Moiré $WS_2/MoSe_2$ Heterostructures

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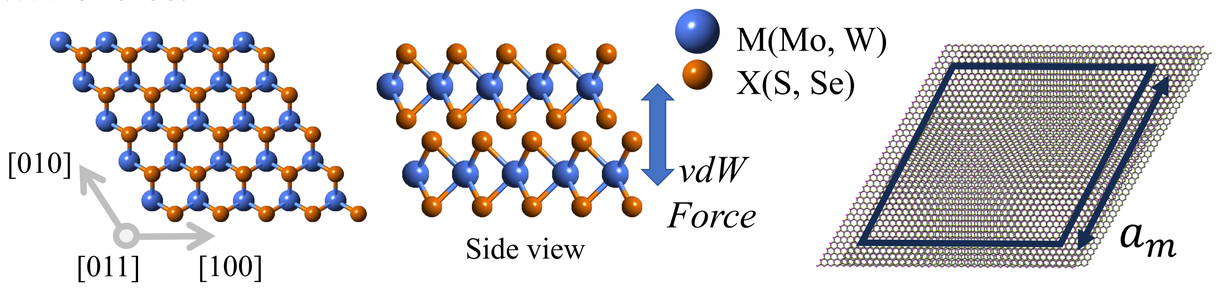
Abstract

Two-dimensional semiconductor heterostructures provide a rich platform for exploring strongly bound excitons and interlayer coupling phenomena. In particular, moiré superlattices formed by stacking transition metal dichalcogenide (TMD) monolayers enable tunable hybridization between excitonic states across layers. We investigate the electrical-driven band evolution in $WS_2/MoSe_2$ heterobilayers using photoluminescence (PL) and differential reflectance (DR) spectroscopy on dual-gate devices. Because the conduction band edges of $WS_2/MoSe_2$ are nearly degenerate, the applied electricity strongly mixes their electronic states. As a result, the DR spectra exhibit pronounced Stark redshifts and clear splitting of the $MoSe_2$ exciton resonances, evidencing the formation of hybridized inter- and intralayer excitons. These excitons further experience moiré potential modulation, giving rise to additional fine structures and localization behavior within the superlattice. Our findings highlight the moiré superlattice as a versatile platform for engineering hybridized excitonic states with tunable coupling, offering new opportunities for exploring correlated exciton physics and electrical-controllable quantum optoelectronic phenomena.

Key words : moiré superlattice , $WS_2/MoSe_2$ Heterobilayers, electrical tuning , interlayer coupling

Transition Metal Dichalcogenides (TMDs)

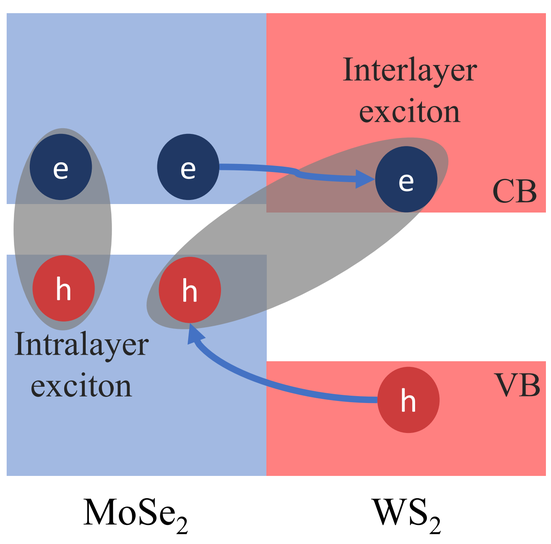
TMDs (MX2) are semiconductor with layer and layer bonded by van der Waals force.

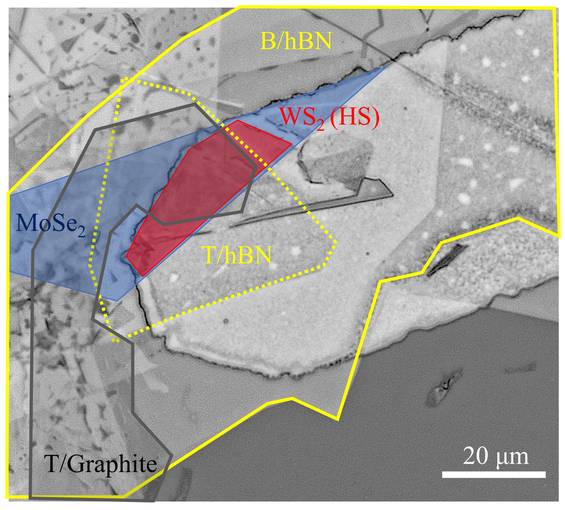


$WS_2/MoSe_2$ heterobilayer

- Nearly degenerate CBMs
- R-stack lattice mismatch ≈ 4.3 %

$$a_m = \frac{a_{WS_2} a_{MoSe_2}}{|a_{WS_2} - a_{MoSe_2}|} \approx 7.6 \text{ nm}$$

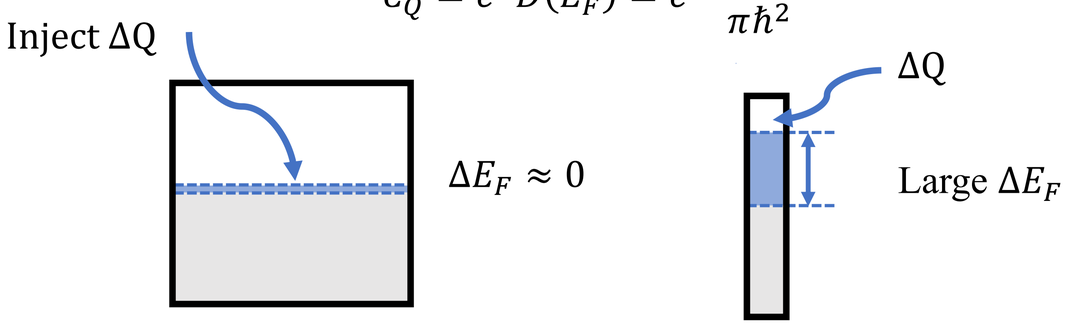




Quantum capacitance and model

Because Pauli exclusion principle, the extra kinetic energy cost in of raising Fermi level can be viewed as quantum capacitance:

$$C_Q = e^2 D(E_F) = e^2 \frac{g_v m^*}{\pi \hbar^2}$$



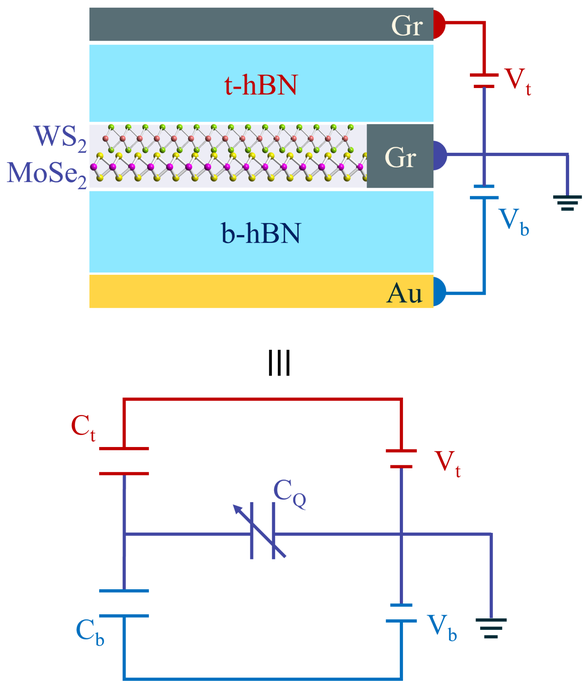
The equivalent capacitance :

$$\frac{1}{C_{tot}} = \frac{1}{C_{\text{geom}}} + \frac{1}{C_Q}$$

Then carrier concentration n will be:

$$n = \frac{1}{e} \frac{C_t(V_t - V_t^0) + C_b(V_b - V_b^0)}{1 + \frac{C_t + C_b}{C_Q}}$$

When E_F inside bandgap, DOS→ 0, n must be 0.



Result

All experiment was measured at 4K.

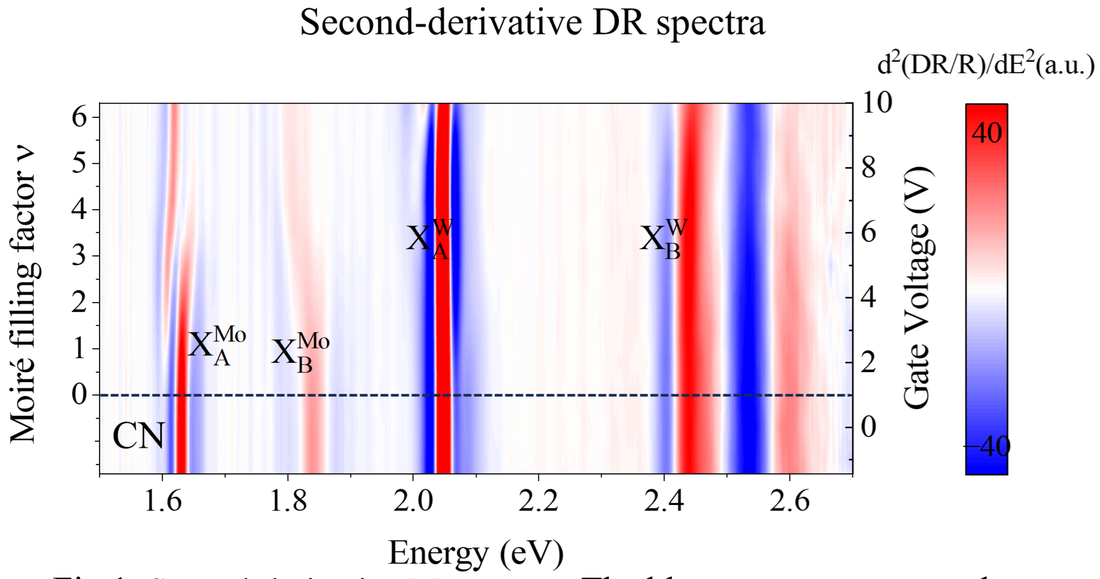
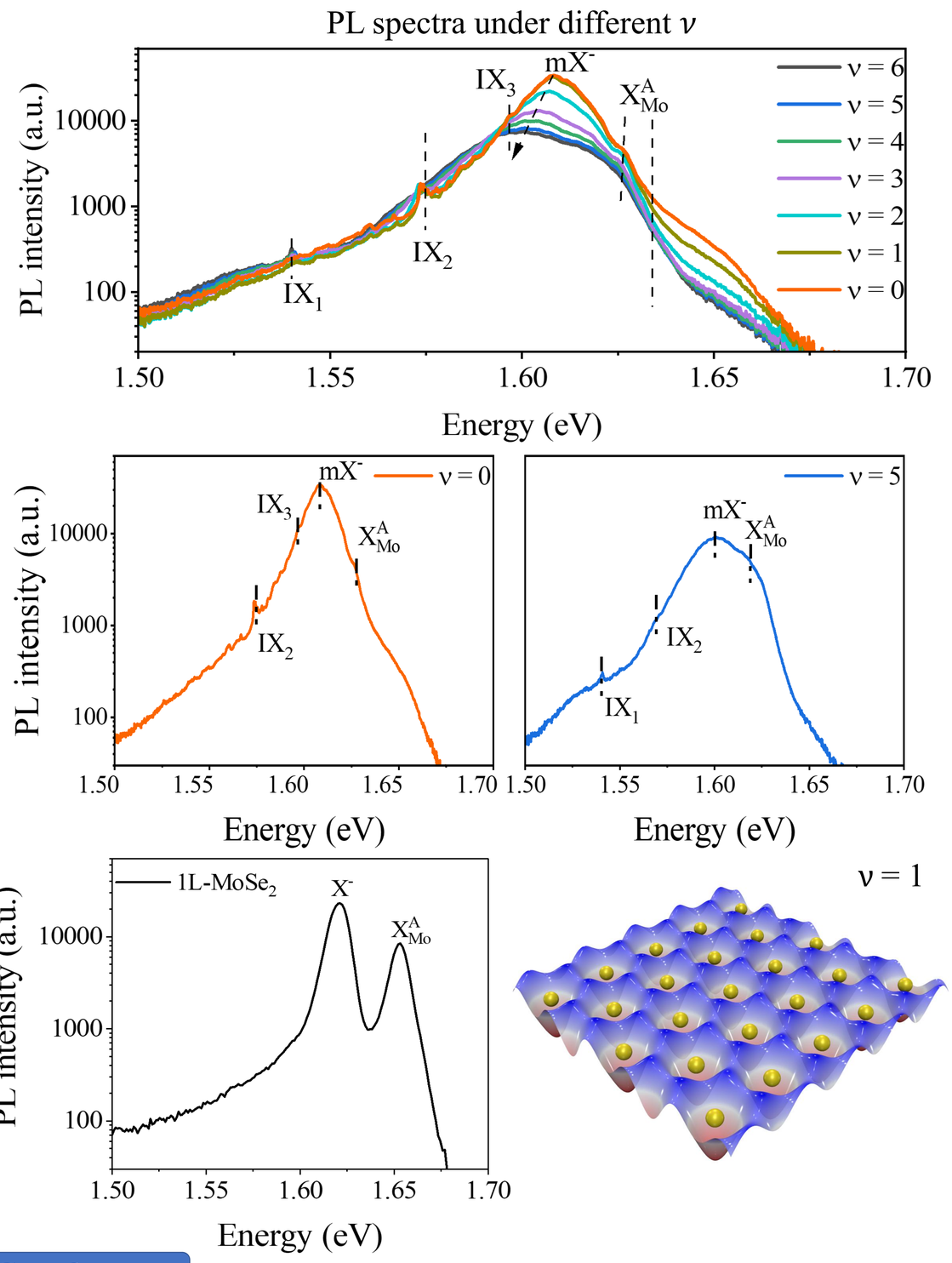


Fig.1. Second-derivative DR spectra. The blue part represent peak position. 4 excitons has splitting at different filling factor.



Conclusion

1. At high ν, DR spectra exhibit pronounced Stark redshifts and clear splitting with electron filling.
2. In contrast, PL spectra show that interlayer excitons are tunable by doping.

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