Splitting of Dark and Bright Exciton States in Monolayer $MoSe_2$

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Introduction

Excitons in monolayer transition metal dichalcogenides (TMDCs), depending on the spin configuration of the conduction and valence band, can be either optically bright or dark. Even though spin-forbidden transitions are optically dark, these dark excitons have been observed in tungsten based TMDCs by adding in-plane magnetic field or via near-field coupling to surface plasmon polaritons [1,2]. However, in $MoSe_2$ where the lowest excitonic states are optically bright, the direct observation of dark excitons and the measurement of the bright-dark exciton splitting are still missing.

Experimental

We have performed low temperature magneto-photoluminescence (PL) and broadband reflection contrast (RC) measurements on BN encapsulated monolayer $MoSe_2$. The experiments were performed in Voigt geometry using a direct-optics micro-spectroscopy setup coupled to the 17.5T superconducting magnet or using a fiber-based probe and a 31T resistive magnet.

Results and Discussion

Our experiments reveal the dark exciton brightening and energy shift of both bright and dark exciton branches in monolayer $MoSe_2$ by in-plane magnetic field. In the weak-field limit, the intensity of brightened dark increases quadratically with the magnetic field. The zero field bright-dark exciton splitting and conduction band g-factor are accurately determined from the analysis of the field evolution of exciton branches using a simple two-band model. The separation of bright and dark exciton is found to be just 1.5 meV, nearly an order of magnitude smaller compared to previous theoretical studies [3].

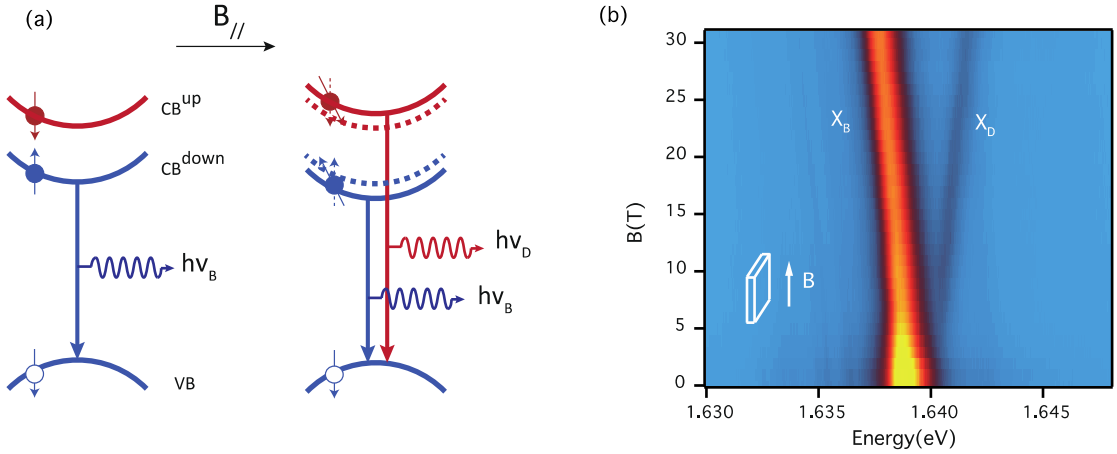

Fig.1. (a) Simplified picture of field-induced dark exciton brightening and bright-dark exciton splitting. (b) PL intensity color plot of micro-magneto-PL spectra revealing splitting of bright and dark excitons in monolayer $MoSe_2$.

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References

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