

Vertical Field-Driven Luminescence Tuning in Layered Heterostructure

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A novel class of atomically thin two dimensional (2D) materials includes the transition metal dichalcogenides (TMDC) exhibiting fascinating properties, such as, superconductivity, non-linear optical phenomena, and exciton-dominated light-matter interaction; an essential requirement for quantum technologies. The utilization of van der Waals heterostructures composed of different 2D materials offers a distinct advantage over conventional III-V semiconductors by eliminating the need for lattice matching. Moreover, these heterostructures enable the creation of artificial systems with novel functionalities absent in nature, paving the way for integrating intricate device features unattainable with conventional materials.

Despite their potential, TMDC-based heterostructures face challenges, including high contact resistance at metal–2D contacts[1] and significant photoluminescence quenching due to ultrafast charge transfer [2], both of which hinder device performance. To address this issue, we consider MoSe₂/NbSe₂ as a prototypical system. Our results indicate that photoluminescence is quenched by an order of magnitude at room temperature in MoSe₂/NbSe₂ heterostructure position (‘on’) compared to the bare MoSe₂ (‘off’), as shown in Figure 1 (b) and (c), respectively. Applying an external vertical electric field counteracts excitonic dissociation, increasing emission four- to twelve-fold across samples, as depicted in Figure 1 (e). The applied field modifies the electron-hole wavefunction overlap, thereby controlling exciton dissociation and photoluminescence in MoSe₂. Both the maximum enhancement of photoluminescence and respective required electric field depend on temperature, attributed to the variation in the band offset between MoSe₂ and NbSe₂. These findings reveal interlayer coupling in van der Waals systems, providing a framework for tuning optical properties in quenching-prone interfaces, and pave the way for advancing 2D optoelectronics.

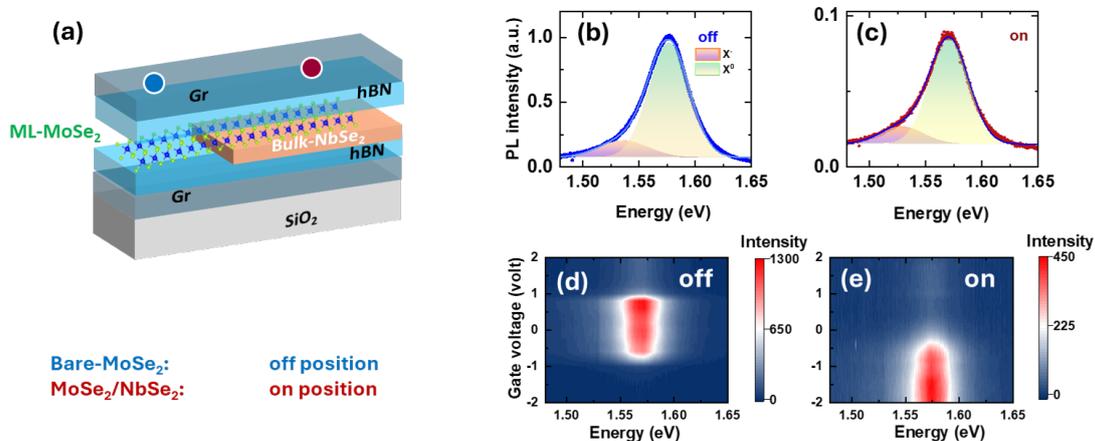


Figure 1: (a) A schematic diagram of a typical MoSe₂/NbSe₂ heterostructure with top and bottom graphene electrodes. The photoluminescence spectra at the ‘off’ and ‘on’ positions are shown in (b) and (c), respectively. The modulation of photoluminescence intensity by a vertical field is illustrated for the ‘off’ position in (d) and the ‘on’ position in (e).

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References

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