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Electrical stabilization and room-temperature light emission of trions in van der Waals heterostructure

Transition metal dichalcogenides (TMDs) are representative two dimensional (2D) semiconductors with unique electrical and optical properties. Monolayer WSe_2 has inverted sign of spin-orbit splitting of conduction band states at different momentum space, which makes WSe_2 one of the most promising candidates for advanced optoelectronic applications [1, 2]. Various exciton complexes, including charged excitons (trions), have been reported in TMDs, which provide us a playground to investigate exciton complexes and a possibility to fabricate advanced optoelectronic devices. However, trions are generally instable due to small dissociation energy similar to thermal energy at room temperature. Here we demonstrate a light-emitting tunnel device based on van der Waals heterostructure of light emitting monolayer WSe_2 encapsulated by ultrathin hexagonal boron nitride (hBN) with graphene electrodes. In the light-emitting tunnel devices of Gr/hBN/WSe_2/hBN/Gr, charges can be injected into WSe_2 via direct tunneling through hBN. The injected charges (electrons and holes) are recombined at a quantum well of WSe_2 sandwiched by wide-bandgap hBN, leading to a light emission. To increase the doping level in WSe_2, we contacted another graphene electrode directly on light-emitting WSe_2 layer. When more carriers are directly injected to WSe_2 (increase of n-doping level) by changing gate voltage, electroluminescence (EL) from negative trions became more dominant. The calculated dissociation energy of trion increased up to 70 meV, much higher than RT thermal energy (25 meV), which makes trions more stable even at room temperature. Our results shows that trions in light emitting devices can be stabilized by increasing dissociation energy through doping and EL devices based on trion can be operational at room temperature. Our work provides a better understanding for behaviors of the tightly bound excitons in atomically confined systems and shows a novel approach to electrical modulation of the selective generation of excitons or trions, which is essential for potential applications in excitonic electronics.

References

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