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# Two-dimensional $WSe_2/WO_X$ Quantum Well realized by Monolithic Phase Engineering

Two-dimensional (2D) transition metal dichalcogenides (TMDs) as an emerging semiconductor have been attracted enormous attention because of exceptional optical properties such as large exciton binding energy and direct bandgap transition at the monolayer limit. Such remarkable properties make them promising for high-performance light-emitting devices such as LEDs, LASERs, and single-photon quantum emitters. However, highly efficient luminescence in the 2D semiconductor heterostructures is inherently limited due to the indirect band-gap transition at the multilayer regime as well as low quantum yield of constituent monolayers. In addition, it is still challenging to construct the 2D-based quantum well structures for exciton confinement because most of TMDs results in the type II alignment when forming heterostructures. Here, we propose a new approach to fabricate a high-efficiency luminescent 2D quantum well structure by monolithic phase engineering and van der Waals stacking. To achieve that, first, the bilayer $WSe_2$ was converted to the $WO_X/WSe_2$ heterolayer by the layer-by-layer oxidation. Then, by multiply stacking the monolithically-phase-engineered $WO_X/WSe_2$ building blocks, we successfully achieve the 2D oxide/selenide superlattice structure. Unlike the case of stacking monolayers only, the photoluminescence (PL) characteristic was not quenched in this stacked heterostructure. As the number of the stacked $WO_X/WSe_2$ structures increases, PL intensity increases several times more than the simple sum of the single $WO_X/WSe_2$. This is presumably because the $WO_X$ layer acts as a decoupling layer between two adjacent monolayers, allowing to preserve the direct bandgap nature of monolayers even in the staked heterostructure. Additionally, by examining the band alignment between the $WO_X/WSe_2$, we found that the phase-engineered 2D heterostructure formed the type I quantum well structure, leading to efficient radiative recombination. This work suggests new approach to fabricate 2D-based quantum heterostructures for high-performance light emitters.