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The Fractional Dimensionality of Excitons in II-VI Ultra-Thin Quantum Wells

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ABSTRACT

II-VI semiconductors and related alloys present very attractive properties for application in optoelectronic devices such as lasers, LEDs, photodetectors, solar cells, etc. The use of quantum wells (QWs) in the active region allows the optimization and precise tuning of the optical properties of those heterostructures. Due to the quite small critical thickness of epitaxial layers of CdSe on ZnSe and of CdTe on ZnTe, the associated QWs can be grown only with a maximum thickness of 3 to 4 monolayers. These ultra-thin quantum wells (UTQWs) present very interesting optical properties and in spite of its reduced thickness present strong excitonic emission. We have shown that CdTe/ZnTe and CdSe/ZnSe UTQWs, grown by atomic layer epitaxy (ALE), cover most of the red-blue spectral region [1], and demonstrated that their emission can be fine-tuned by a convenient choice of the substrate temperature due to the Cd substitution by Zn atoms during the epitaxial growth [2]. Recently, we have shown that the spectral response of ZnSe/GaAs(001) heterostructures increases significantly when subnanometric CdSe UTQWs are inserted in the ZnSe layer [3] of a ZnSe/GaAs(001) heterostructure, this finding results very attractive for the elaboration of novel photodetectors and solar cells. In principle, as the thickness of the QWs is reduced a closer 2D behavior is expected. However, for the case of the UTQWs this is not necessarily the case. We observed that the thinnest the UTQW, the largest the penetration of the electron and hole wave functions within the barrier; this penetration depth can be considerably larger than the width of the UTQW. Then, we can expect that for the thinner wells the excitons evolve towards a 3D behavior. In order to have a quantitative description of this change, we determined the dimensionality of the excitons (αD), with $2 \leq \alpha \leq 3$, using the model of fractional-dimensional space [4]. In this model, the highly anisotropic QWs (in principle 2D systems in 3D heterostructures) are treated as isotropic systems in an effective fractional-dimensional space where the fractional dimension is a measure of the anisotropy of the QW system. We found a minimum value of $\alpha \sim 2.4$ for the CdSe/ZnSe UTQWs. The results are explained in terms of the structural and electronic properties of the UTQWs and are used to explain some peculiar characteristics of their excitonic emission.

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