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Donor exciton binding energy in ZnSe wide bandgap quantum wells

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ABSTRACT

Positive donor exciton binding energy is calculated as a function of well width for a $Zn_{1-x_{out}}Mn_{x_{out}}Se/Zn_{1-x_{in}}Mn_{x_{in}}Se/Zn_{1-x_{out}}Mn_{x_{out}}Se$ quantum well within the single band effective mass approximation for different Mn content. Exciton bound polaron is investigated for $0 \leq x_{in} \leq 0.06$, on the Mn mole fraction. We determine the interband emission energy with the mean field approximation invoking the exchange interaction between the carrier and the magnetic impurity. The interband emission energy is computed as a function of well width for different Mn content. The valence band anisotropy is included in our theoretical model by using different hole masses in different spatial directions. It is found that the interband emission energy (i) depends on Mn mole fraction and (ii) increases linearly with an increase of the Mn content and the effect is more pronounced for the narrow well showing the quantum size effects. Also the significant increase in interband emission energy is observed due to spin splitting with Mn ion concentration. The interband emission shows a blue shift of the exciton with an increase of Mn content. Our results are in good agreement with the recent published results.

1. Introduction

Diluted magnetic semiconductors (DMSs) generally will have transition metal atoms with partially filled atomic d-shells randomly substituted for a fraction of cation atoms. In these DMSs, a small

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fraction of group II elements will be replaced in a random manner by transition metal ions. The DMSs have attracted considerable attention for the past few decades due to its potential applications in opto-electronic devices, in the blue–green spectral ranges [1]. They exhibit some interesting physical properties from both the semiconductors as well as from the magnetic impurities. Quantum wells constructed on these materials are more interesting than the nonmagnetic semiconductors. It is because of the additional controlled mechanism offered through the strong splitting of electronic energy states caused by magnetic ions. Eventually one can tune the lattice constants and bandgaps by varying the composition of transition metal ions, in a controlled manner; sometimes it may show the phase transition too.

The exciton binding energy for the ZnSe system has been studied by several authors. Excitons play more important roles in quantum wells than in bulk semiconductors with respect to optical and electrical properties. Hetterich et al., [2] have reported the value of 19 meV derived from low temperature magneto-reflectance measurements recently. Thereafter, Lee et al., [3] obtained a measurement slightly greater than 22 meV from magneto-absorption in the presence of the liquid helium temperature. Kim et al., [4] have investigated rather a low value of the exciton binding energy of 13 meV from the fit of room temperature ellipsometry data. The obtained low value may be due to the temperature dependence of the dielectric function and of the effective mass. Very recently, Kvietkova et al., [5] have found the exciton binding energy value of 17 meV for the $ZnSe/Zn_{0.864}Mn_{0.136}Se$ quantum well system. Moreover, they have presented a study of optical properties of cubic $Zn_{1-x}Mn_xSe$ thin films with $x = 0$, 0.136 and 0.21, grown on GaAs (001) substrates by molecular beam epitaxy and they have observed a large negative bowing of the bandgap with an increase in the spin–orbit splitting when the Mn content increases. The exciton binding energy can be manipulated by changing the spatial or the magnetic confinement [6]. Senger and Bajaj [7] presented a calculation of the binding energy of a heavy-hole exciton as a function of well width in a ZnCdSe/ZnSe quantum well structure and exciton magnetic polarons in ZnSe/ZnMnSe quantum well structures were studied by Rossin et al., [8] and they reported the magnetic-field-induced type-I–type-II transition for heavy-hole excitons. Merciline Leonora and John Peter [9] have calculated the effect of magnetic field on acceptor impurity in a diluted magnetic quantum well system such as CdMnTe and the spin polaronic effect was calculated for the acceptor impurity. But all their calculations were reported without the inclusion of interband emission energy with different Mn concentrations.

In Mn-based systems electrons interact with the 3d electrons of the localized magnetic moments of Mn ions via the sp–d exchange interaction. II–VI semiconductors are very suitable for the trion studies due to their strong Coulombic interaction compared with III–V materials. The exciton binding energies of GaAs, CdTe and ZnSe are found to be 4, 10 and 20 meV, respectively. Among these materials ZnSe has the strongest Coulombic interaction. Owing to their relatively large exciton binding energies, they also offer the possibility of realizing quantum wells in which excitonic recombination is dominant even at room temperature [10]. Negatively and positively charged excitons have been studied earlier [11]. Crooker et al., [12] have reported positively charged excitons (trions) for ZeMnSe systems. Excitons and charged excitons (trions) are investigated in ZnSe-based quantum well structures with (Zn, Be, Mg) Se and (Zn, Mg) (S, Se) barriers by means of magneto-optical spectroscopy recently by Astakhov et al., [13]. And they have measured the binding energies of negatively and positively charged excitons as functions of quantum well width, and free carrier density and in external magnetic fields up to 47 T.

In the present work, we investigate the donor exciton binding energy as a function of well width for a $Zn_{1-x_{out}}Mn_{x_{out}}Se/Zn_{1-x_{in}}Mn_{x_{in}}Se/Zn_{1-x_{out}}Mn_{x_{out}}Se$ quantum well within the single band effective mass approximation for different Mn content. Exciton bound polaron is computed for $0 \leq x_{in} \leq 0.06$, on the Mn mole fraction. The energygap is determined with the mean field approximation incorporating the exchange interaction between the carrier and the magnetic impurity. The interband emission energy is investigated as a function of well width for different Mn content. The valence band anisotropy is included in our theoretical model by using different hole masses in different spatial directions. The method followed is presented in Section 2 while the results and discussion are presented in Section 3. Finally, we summarize the main conclusions obtained in this paper in the last section.