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Experimental Evidence of ZnCdSe Quantum Wires Achieved by Strain-Induced Lateral Confinement

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1. Introduction

In the past few years, an increasing attention has been paid to one-dimensional semiconductors, due to their predicted attractive properties (increase of the oscillator strength, lower laser threshold). Nevertheless, progress has been rather slow due to the difficulty in achieving the growth of good quality quantum wires (QWR). One of the most promising techniques is the so-called *strain induced lateral confinement*. It has been studied for the first time by Gershoni *et al.* [1] on III-V based heterostructures, and it is only recently that the first II-VI (CdTe/CdZnTe) structure has been grown [2]. The main advantage of this technique is that the dimensions of the QWR's can be controlled with the same precision as the width of a single quantum well (SQW). We report here on the first ZnSe/ZnCdSe QWR's achieved by this technique. The 2.7 eV emission energy of these QWR's is of particular interest for blue light emitter devices.

2. Experiments

The realisation of such QWR's involves two main steps: first a $Zn_{0.9}Cd_{0.1}Se$/ZnSe multiple quantum well (MQW) is grown by molecular beam epitaxy along the <001> direction, on a $Zn_{0.9}Cd_{0.1}Se$ buffer layer (see figure 1). The $Zn_{0.9}Cd_{0.1}Se$ buffer layer is thick enough (0.5 μm), to be completely relaxed, so that the ZnSe barriers are in tensile strain and the $Zn_{0.9}Cd_{0.1}Se$ QW's are strain free. Then, a $Zn_{0.935}Cd_{0.065}Se$ SQW is grown along the <110> direction, after the structure had been cleaved.

The micro-photoluminescence (μPL) experiments are performed at 7 Kelvin, and the 2 μm resolution allowed us to resolve the parts (a) and (b) shown on figure 1.

3. Discussion

The proportion of Cadmium, as well as the width of the ZnSe barriers (157 Å) and the width of the quantum well (36 Å) have been determined by simulating the X-ray diffraction spectra. All the material parameters are taken from reference [3]. The PL energy of the $Zn_{0.9}Cd_{0.1}Se$ alloy is in good agreement with the predicted one, taken from reference [3], and the calculated excitonic energy of the <001> QW is also in very good agreement with the experiment (see figure 2-a). Our calculation shows that this excitonic PL can be attributed to excitons formed with an electron and a heavy-hole. The light holes are not confined at all, as, due to the strain effects, the light-hole valence bands of the $Zn_{0.9}Cd_{0.1}Se$ alloy and of the ZnSe barriers have roughly the same energy. In order to calculate the band to band recombination energy, we have used the method describe in reference [4], which can be used in both <001> and <110> directions. To calculate the binding energy of the excitons the usual single variational parameter trial function is used [5].

Along the <110> direction, the proportion of Cadmium has been estimated by growing a thick layer of ZnCdSe on a <110> GaAs cleaved surface, and by fitting the PL energy. A 6.5 % composition is found. The ZnSe barrier width of the <110> QW is 120 Å, and the QW one is 24 Å. They are estimated as explained in the following.

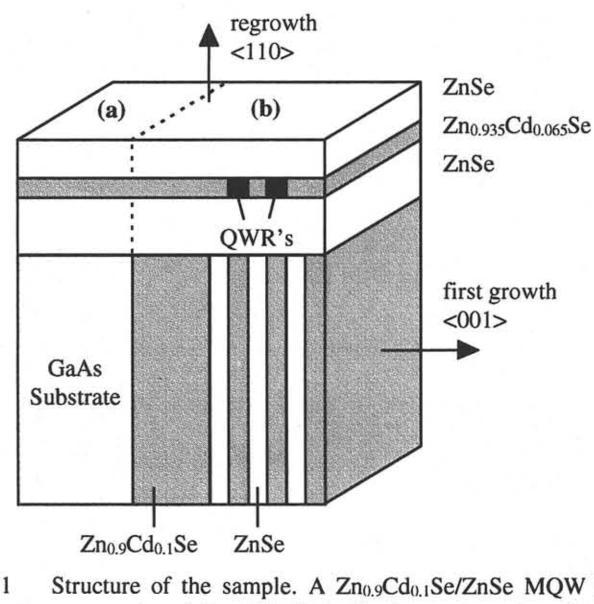

Fig. 1 Structure of the sample. A $Zn_{0.9}Cd_{0.1}Se$/ZnSe MQW is first grown on a relaxed $Zn_{0.9}Cd_{0.1}Se$ buffer layer along the <001> direction. The second step corresponds to the growth of a SQW on the <110> cleaved surface. The part (a) of this SQW is expected to be mainly strained to the GaAs substrate, while the part (b) is expected to be mainly strained to the $Zn_{0.9}Cd_{0.1}Se$ buffer layer.

Figure 2-b shows the μPL spectra of the sample when excited in the part (a) on figure 1. The full line corresponds to a polarisation along the <-110> direction, and the dashed line to a polarisation along <001>. This PL is polarised 2.2:1 along <-110> which is a strong indication of the

heavy-hole nature of the transition [1]. The calculation also shows that for this cadmium composition, only the heavy-holes are confined.

Figure 2-c shows the μPL spectra when the sample is excited in the part (b) on figure 1. As expected the MQW is

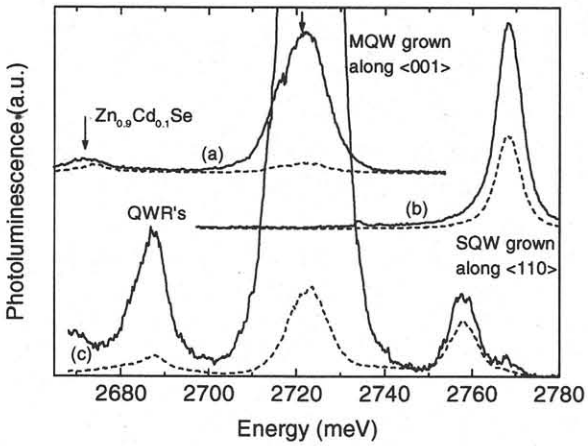

Fig. 2 (a) μPL spectra of the MQW alone, excited through the <110> plane. Arrows are theoretical calculations of the transition energy of the ZnSe(156 Å)/$Zn_{0.9}Cd_{0.1}Se$(36 Å) MQW and of the bulk $Zn_{0.9}Cd_{0.1}Se$. Full lines correspond to an PL polarisation along <-110>, and dashed line along <001>. (b) μPL spectra of the complete structure, excited through the <110> plane, in the part of the sample where the SQW is grown on the GaAs substrate. (c) same as (b), but in the part of the sample where the SQW is grown on the $Zn_{0.9}Cd_{0.1}Se$ buffer layer and the MQW.

strongly polarised (around 14:1) along the <-110> direction [6]. Compared to 2-b and to 2-a, two new peaks appear: one at 2758 meV, and the other one at 2687.5 meV. The first one can be unambiguously attributed to the SQW grown along the <110> direction, strained to the lattice parameter of the $Zn_{0.9}Cd_{0.1}Se$ buffer layer. In figure 2-b this SQW is strained to GaAs, and the calculation shows that for QW widths between 20 Å and 50 Å, the QW emission energy is red-shifted by about 25 meV, when strained to $Zn_{0.9}Cd_{0.1}Se$. The experimental red-shift is about 10 meV, and this difference may be due to the approximation we have made. Indeed, the parts (a) and (b) on figure 1 are considered to be two completely distinct QW's to perform the calculation, which is obviously not true. Nevertheless, due to the relaxation that occurs in the $Zn_{0.9}Cd_{0.1}Se$ buffer layer, any interaction between these two parts is very difficult to estimate, and this problem is still under investigation in our group. Finally, this PL is polarised roughly in the same way than in figure 2-b (1.6:1 instead of 2.2:1). In order to estimate the width of the <110> SQW, we have fitted the 2758 meV energy with the width as an adjustable parameter. With the assumption that the growth rates of ZnSe and $Zn_{0.935}Cd_{0.065}Se$ are roughly the same, the width of the barriers can also be estimated.

The second new peak on figure 2-c is red-shifted by 80.5 meV compared to figure 2-b, and is much more strongly polarised along the <-110> direction (7.5:1). We attribute it to excitonic transitions in the QWR's created by strain-induced lateral confinement (see figure 1).

The calculation of the strain effects using the method described in reference [2], let us expect the creation of the QWR's, and also that only the heavy holes are confined in the same layers as the electrons. The polarisation dependence of this 2687.5 meV peak confirms our assumption, as it has been previously reported for heavy-hole transitions in such QWR's [1].

4. Conclusion

ZnCdSe/ZnSe QWR's have been successfully achieved by strain-induced lateral confinement. The PL study shows a strong polarisation dependence along the <-110> direction for the heavy-holes (7.5:1), when it is only around 2:1 for the QW grown on the <110> cleaved surface. Calculations of the theoretical transition energy are in progress. Compared to the experimental energy, they will help us to check if a lateral piezoelectric field exists in these structures, as reported in CdTe based one [2], and to study more precisely the influence of the GaAs substrate on the strain configuration.

To improve the efficiency of the structure, the growth along the <110> direction must be fully controlled, in order to assure a lower transition energy of the SQW compared to the <001> MQW. In the sample studied here, the thin ZnSe barrier along <110> and the lowest transition energy of the MQW lead to a very strong PL of the MQW, even after the re-growth.

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