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Photoluminescence of ZnTe/ZnMgTe multiple quantum well structures grown on ZnTe substrates by molecular beam epitaxy

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Photoluminescence (PL) properties of ZnTe/ZnMgTe quantum well (QW) structures grown by molecular beam epitaxy (MBE) were investigated systematically with respect to well widths and Mg contents. Observed PL peak energies were consistent well with the calculated emission energies of the QWs considering a lattice distortion in the ZnTe well. From the temperature dependence of PL intensity, it was found that a suppression of a carrier escape from QW is crucial to obtain a PL at higher temperature in the ZnTe/ZnMgTe QW. Based on the results, multiple quantum well structures were designed and fabricated, which exhibited a green PL at room temperature.

1. Introduction

II-VI compound semiconductor ZnTe has been expected as a promising material for various optoelectronic applications such as light emitting diodes (LEDs), solar cells, waveguides, modulators, and THz devices, which has generated a great deal of effort toward the growth and characterization of this and the related alloy materials [1–11]. Using ZnTe, it is possible to obtain pure green light emission at the wavelength of around 550 nm because of its direct transition band gap of 2.26 eV at room temperature where the so-called "green gap" problem exists in current LED technologies [12,13]. However, it was very difficult to realize a green LED using ZnTe because of the difficulties in controlling *n*-type conductivity of ZnTe.

Recently, a thermal diffusion technique using Al as a donor impurity was studied extensively in ZnTe [2,14–18] and *n*-type ZnTe was successfully obtained. Then, a homo-junction LED was fabricated by the thermal diffusion of Al into p-type ZnTe crystal, and revealed a wall-plug efficiency of more than 0.15% [19], which is comparable to the efficiency of the commercially available GaP LED.

In order to improve the efficiency of LED, the investigation on the hetero structures including quantum wells (QWs) which can confine carriers is inevitable. For ZnTe, $Zn_{1-x}Mg_xTe$ (ZnMgTe) is considered to be a suitable material for the barrier layer because ZnMgTe has a larger band gap than ZnTe and can form a type-I hetero structure with ZnTe. In contrast to the extensively studied $CdTe/Cd_{1-x}Zn_xTe$ QWs [20–23], only a few papers have been published on the ZnTe/ZnMgTe QW structures [24,25] so far. However, the promising optical properties of the QW structures with sharp photoluminescence (PL) and cathode luminescence peaks were demonstrated at 2 K, indicating the possibility of the ZnTe/ZnMgTe QWs as emitter [24,25]. By understanding the nature of the QWs and optimizing the structure using high-quality epitaxial layers on ZnTe substrates, it

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is expected to realize PL at room temperature, which is an important first step for the LED application. Here, we report the results of a systematic investigation of photoluminescence (PL) properties for ZnTe/ZnMgTe QW structures grown on ZnTe substrates by molecular beam epitaxy (MBE).

2. Experiments

ZnTe/ZnMgTe QW structures were grown on ZnTe(001) substrates by a conventional solid-source MBE system. The background pressure of growth chamber is less than 3×10^{-8} Pa. Zn (7N), Te (6N), and Mg (6N) were used as source materials. ZnTe(001) substrates were ultrasonically cleaned in organic solvents prior to wet-etching using a Br-methanol solution. After introducing the substrates into the growth chamber, a low-temperature ZnTe buffer layer was grown at 250 °C for 5 min, followed by the growth of a few nm-thick ZnTe control layer at 350 °C to check the growth rate of ZnTe. Then, a ZnMgTe buffer layer with a thickness of 230 nm was grown at 350 °C, and ZnTe/ZnMgTe QW structures were grown at the same temperature on the ZnMgTe buffer layer. The ZnTe well widths and the Mg contents in the ZnMgTe barrier layer were changed between 1 and 3 nm and between 0.14 and 0.32, respectively, while the thickness of ZnMgTe barrier layers was kept constant at 40 nm in all samples. The Mg content in the ZnMgTe buffer layer was set to the same value for the ZnMgTe barrier layers.

During the growth, a reflection high-energy electron diffraction (RHEED) pattern was monitored. The RHEED intensity oscillation was recorded to check the growth rate of ZnTe control layer, and the growth times for ZnTe wells were determined based on the growth rate. High-resolution X-ray diffraction (HR-XRD) analysis was performed using a Philips X'pert XRD system equipped with a beam monochromator consisting of a four-bounce Ge (220) crystal and X-ray mirror in the primary optics and a secondary optics with a three-bounce Ge analyzer crystal between the sample and the detector. The in-plane and out-of-plane lattice parameters, $a_{||}$, and $a_{\perp}$, were determined by the 2θ-ω scans of symmetrical (004) and asymmetrical (224) reflections in order to obtain a relaxed lattice constant a_{relax} of ZnMgTe. Here, the elastic coefficients ratios of $C_{12}/C_{11} = 0.57$ for ZnTe [26] and 0.53 for MgTe [27] are used for the calculation. The Mg content in a ZnMgTe layer after the growth was determined using a relaxed lattice constant a_{relax} of ZnMgTe assuming Vegard's law [28].

Photoluminescence (PL) measurement was performed in a temperature variable cryostat using a blue-violet laser diode at 405 nm as an excitation source. The PL signal was dispersed by a conventional 1 m type grating spectrometer and detected by a photomultiplier using a phase sensitive lock-in amplification system.

2.1. Calculation of emission energy from ZnTe/ZnMgTe QWs

The schematic band diagram of a ZnTe/ZnMgTe QW structure is shown in Fig. 1. The emission energy $h\nu$ from QW can be determined by eq. (1):

$$h\nu = E_{g'ZnTe} + E_{C1} + E_{V1} \tag{1}$$

where $E_{g'ZnTe}$ is a modified band gap of ZnTe due to a lattice distortion resulting from lattice mismatch between ZnTe and ZnMgTe and E_{C1} and E_{V1} are quantum energy levels in the conduction and the valence bands of ZnTe, respectively. The $E_{g'ZnTe}$ is

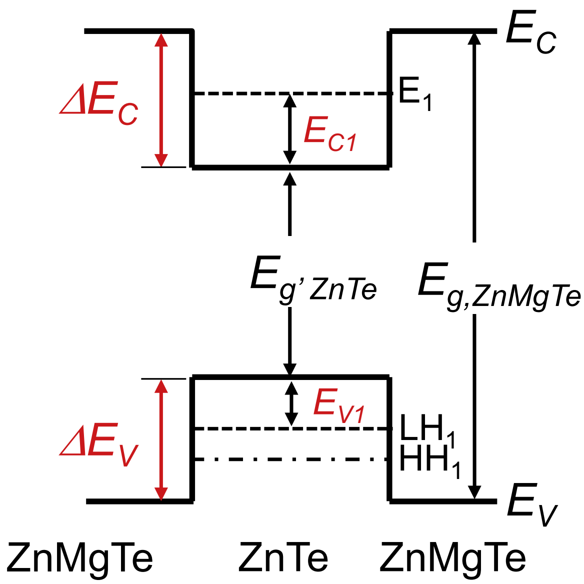

Fig. 1. Schematic band diagram of a ZnTe/ZnMgTe QW structure.

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