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Temperature dependent photoluminescence from ZnO/MgZnO multiple quantum wells grown by pulsed laser deposition

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Abstract

We have studied temperature dependent photoluminescence (PL) from ZnO Multiple Quantum Wells (MQWs) of different well layer thicknesses in the range ∼1–4 nm grown on (0001) sapphire by a novel in-house developed buffer assisted pulsed laser deposition. At 10 K the PL peak shifted toward blue with decreasing well layer thickness and at constant well layer thickness the PL peak shifted towards red with increasing temperature. To the best of our knowledge we have observed for the first time an efficient room temperature (RT) PL emanating from such MQWs. The red shift of the PL peak with increasing temperature has been found to be due to the band gap shrinkage in accordance with the Varshni's empirical relation. The spectral linewidth was found to increase with increasing temperature due to the scattering of excitons with acoustic and optical phonons in different temperature regimes. Both at RT and at 10 K the PL peak shifted with respect to the well layer thickness in the range of ∼3.35–∼3.68 eV with decreasing thickness in agreement with the calculated values.

Keywords: Multiple quantum wells; II–VI oxide semiconductors; ZnO; Photoluminescence

1. Introduction

Recently, ZnO based quantum wells have received a great deal of attention due to their potential applications in optoelectronic devices operating in the blue–ultraviolet region of the

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spectrum and transparent electronics [1–3]. The size dependent quantum confinement effects in these quantum structures result in large oscillator strength, enhanced excitonic binding energy, tunability of operating wavelength and very low threshold of lasing. Motivated by these advantages a number of researchers have grown ZnO/MgZnO Multiple Quantum Wells (MQWs) on commonly used sapphire substrates in recent years [4–8], where size dependent quantum confinement effects have been demonstrated through low temperature photoluminescence measurements. The large in-plane lattice mismatch between ZnO and sapphire ($\sim$18%) resulted in inadequate quality of ZnO MQWs due to strain and physically rough surfaces and interfaces, and hence prevented efficient photoemission at room temperature [4,5]. An efficient emission in the UV spectral region at room temperature from ZnO/MgZnO MQWs was only observed when MQWs where grown on lattice matched $ScAlMgO_4$ (SCAM) substrates [1,9,10]. However the SCAM substrates are scarce and very expensive compared to abundantly available sapphire substrates and therefore one of the challenges is to achieve high quality ZnO MQWs with room temperature PL on sapphire substrates, making them versatile for practical applications. Recently we have observed size dependent efficient PL at room temperature emanating from ZnO MQWs of different active layer thicknesses grown on (0001) sapphire substrates by pulsed laser deposition using a novel in-house developed buffer assisted growth scheme [11].

In this paper we report our studies on the temperature dependent PL from ZnO/MgZnO MQWs of well layer thickness in the range of 4–1 nm on (0001) sapphire substrates grown by buffer assisted PLD. We have observed efficient excitonic PL from these MQWs up to room temperature, which to the best of our knowledge has been accomplished for the first time. We have investigated the temperature dependence of PL peak position and linewidth at different thicknesses of the well layers in a broad temperature range of 10 K to RT. The existing theoretical models have been deployed to explain the observations. From this study a relationship between the band gap of an MQW and the thickness of its active layer was also established.

2. Experimental

The ZnO/MgZnO MQWs were grown by Pulsed laser Deposition (PLD) on epi-polished sapphire substrates with rms surface roughness <0.5 nm. The third harmonic of a Q-switched Nd:YAG laser (Quantel, France) operating at 355 nm, 10 Hz repetition rate and 6 ns pulse width was used at a fluence of $\sim 0.6\ \mathrm{J/cm^2}$ to ablate alternately and sequentially the ZnO and MgZnO targets which were mounted on a multi-target carousel in the PLD chamber. The MgZnO targets were prepared by sintering the pellet of calcined mixture of 15 mol% of high purity MgO in ZnO. The growth chamber was initially evacuated to a base pressure of $\sim 1 \times 10^{-7}$ Torr using a turbomolecular pump and depositions were carried in high purity oxygen ambient at a partial pressure of $\sim 1 \times 10^{-5}$ Torr. The typical growth rate at this fluence, which was measured in separate experiments, was found to be ~ 0.1 nm/s for ZnO and ~ 0.08 nm/s for MgZnO targets respectively. The Mg concentration in the PLD grown MgZnO film was found to be $\sim$34% using energy dispersive x-ray Analysis (EDAX). Prior to the growth of every ZnO/MgZnO MQW a 50 nm thick ZnO buffer layer was grown on the sapphire substrate at 750 °C. This high temperature grown ZnO buffer layer provided a highly crystalline, relaxed and smooth surface of the ZnO template layer on sapphire for the growth of ZnO MQWs at low temperatures [12]. Ten periods of ZnO/MgZnO MQW structures were grown at 600 °C over the ZnO tamplet layer. The barrier layer thickness was kept constant at $\sim$8 nm while the ZnO well layer thickness was varied from 4 to 1 nm to grow MQWs of different well layer thicknesses. Photoluminescence spectra of MQW