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ZnO/MgO distributed Bragg reflectors

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ZnO/MgO distributed Bragg reflectors (DBRs) are grown by pulsed laser deposition. DBR samples grown at the same temperature and the same pressure show obvious reflections in transmission spectra. If there is a standing wave in the ZnO layers, it is evident that the full width at half maximum of the ZnO peak in photoluminescence spectra could be decreased when the sample reflects more photons whose wavelength is about 380 nm.

Keywords: zinc compounds, semiconducting II-VI materials.

1. Introduction

ZnO has attracted considerable research attention for many years because it is a suitable candidate for a blue or ultraviolet light-emitting device or photodetectors [1–7]. ZnO is a direct wide band gap semiconductor with a high exciton binding energy of 60 meV. Such a large binding energy permits excitonic recombination well above room temperature.

Distributed Bragg reflector (DBR) typically has low efficiency gratings constructed from two different materials, *e.g.*, air and AlGaN [8], GaN and AlN [9], InP and SiO_2 [10], with a refractive index difference. DBR is one of the key elements in the fabrication of a laser for a wider variety of emission wavelengths and a higher quality pulse.

However, less attention has been devoted to the DBRs used in ZnO-based ultraviolet laser diodes. The reliability of the DBRs is still a question. Therefore we believe that researching a suitable DBR for the ZnO device is significant. In this paper, we investigate the transmission and photoluminescence spectra of ZnO/MgO multilayers grown by pulsed laser deposition (PLD).

2. Experiment

Three ZnO/MgO multilayers samples with different layer thicknesses were directly grown on sapphire (0001) substrate by the pulsed laser deposition method. The growth

T a b l e. Growth times of the ZnO layers and MgO layers of the three samples.

Sample	Growth time of ZnO layer [min]	Growth time of MgO layer [min]	Thickness of the film [nm]	Estimated thickness of ZnO layer [nm]	Estimated thickness of MgO layer [nm]
1	50	70	2100 (±50)	198	277
2	70	98	3100 (±50)	292	409
3	30	42	1300 (±50)	123	172

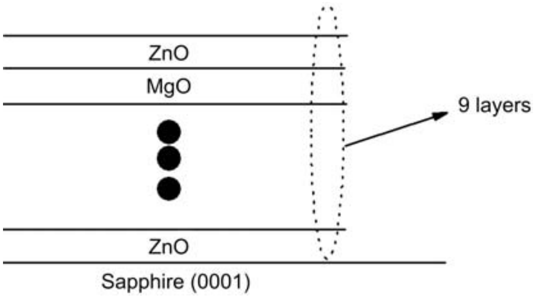

Fig. 1. The schematic diagram of the three samples.

temperature and partial pressure of oxygen were 500 °C and 60 Pa, respectively. The details of the samples are shown in the Table. Figure 1 shows the schematic diagram of the samples. By assuming that the growth rate of ZnO layer and the growth rate of MgO layer are almost the same, the estimated layer thickness could be calculated. KrF excimer laser pulses were impinged on ZnO ceramic targets (99.999%) and MgO ceramic targets (99.999%) located about 5 cm away from the substrate surface with 3.2 J/cm^2. The repetition rate was 5 Hz. The photoluminescence (PL) was excited by a continuous wave He-Cd laser (325 nm). The structural properties of films were determined by X-ray diffraction (XRD) with a CuKα radiation (0.15418 nm).

3. Results and discussions

Figure 2 shows the XRD pattern of sample 1. The ZnO (002) peak at 34.5° and MgO (200) peak at 42.9° can be observed in the pattern. The full width at half maximum (FWHM) of the ZnO peak and MgO peak are 0.21° and 0.20°, respectively.

Figure 3 is the transmission spectra of the three samples. The valley at about 560 nm in transmission spectra of sample 2 should be due to the reflections of ZnO and MgO layers. For the layer thicknesses in sample 2 multiplied by the refractive index of the layer do not perfectly match, the width of the valley is larger than the calculated one, which is about 55 nm. Because the ratios of growth time of each layer in the three samples are the same, there should also be reflections in sample 1 and 3.

Considering that the ratios of growth time of each layer to the thickness of the film in the three samples are almost the same, the maximum reflections in sample 1 and 3

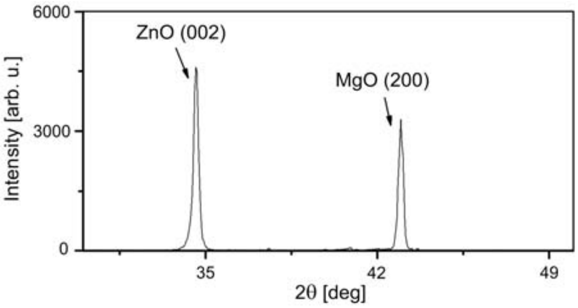

Fig. 2. XRD pattern of the sample 1.

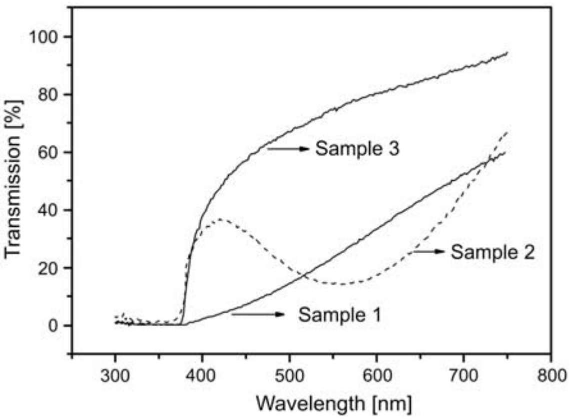

Fig. 3. The transmission spectra of the three samples.

could be calculated by using the 560 nm multiplied by the ratio of the film thickness in sample 1 or 3 to the sample 2. Then 400 nm in sample 1 and 240 nm in sample 3 could be obtained. For there is a large absorption in ZnO layers when the wavelength is smaller than 350 nm, if the intensities of incident rays are not the same, the maximum reflection in sample 3 should vary from 240 nm to 350 nm.

The estimated layer thickness and the valley in sample 2 indicate that the reflection is due to the fact that the optical path in each layer is equal to the valley position multiplied by 5/4. This is because if it were equal to the valley position multiplied by 7/4 or 3/4, the refractive index of each layer would be too large or too small. Then the refractive indexes of ZnO layer and MgO layer, which are about 2.39 or 1.71, respectively, could be calculated.

Figure 4 shows the PL spectra of the three samples. For comparison, the transmission and PL spectra of the ZnO thin film grown at 500 °C and an oxygen pressure of 60 Pa are shown in Fig. 5. The three samples show different FWHM of the peaks at about 380 nm, which is due to the free exciton recombination. The FWHM of the peak of sample 2 or 3 is almost the same as that of the ZnO thin film. It is indicated that this phenomenon is due to the reflections at about 380 nm. Because the refractive index of air or the substrate is smaller than that of the ZnO, when the ZnO layers shine as laser

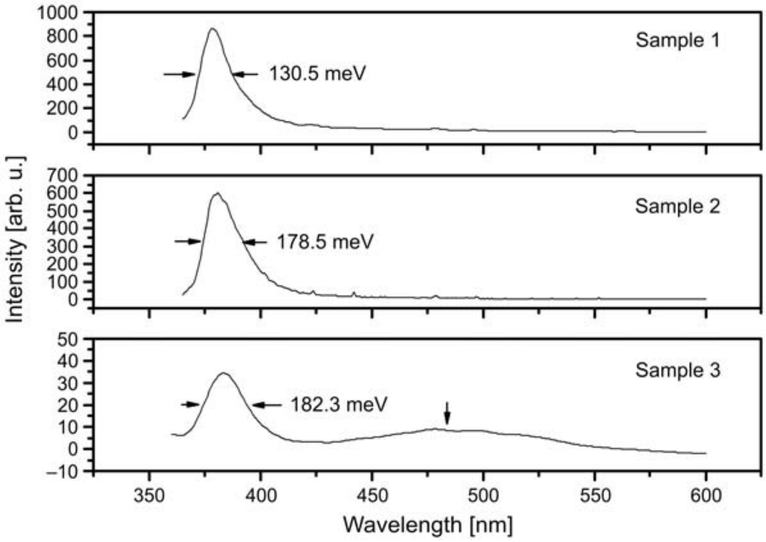

Fig. 4. The PL spectra of the three samples. The deep level emission of sample 3 is shown by arrow.

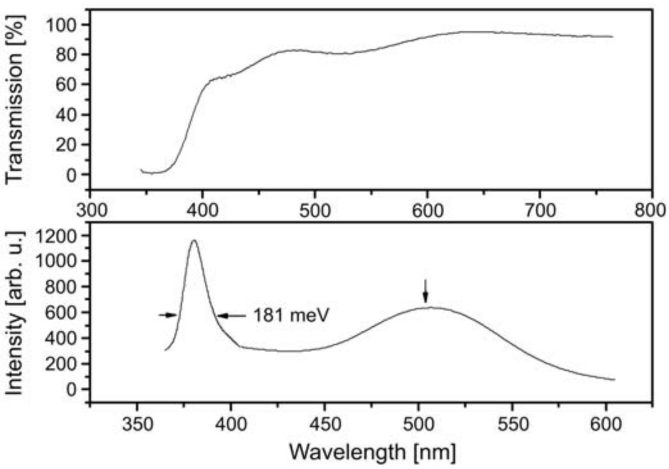

Fig. 5. The transmission and PL spectra of the ZnO thin film grown at 500 °C and at oxygen pressure of 60 Pa.

source, the interfaces in samples 1–3 could reflect more photons whose wavelengths are about 400, 560 and 240 nm, respectively. In the ZnO layer there could be a standing wave whose wavelength is the optical path in ZnO layer multiplied by 2/3. So the luminous intensities at about 333, 466.5, 200 nm in the samples 1–3 may be amplified, respectively. By suggesting the standing wave and reflection, the luminous intensities in sample 1 at about 333–375 nm would become stronger, and at 375–429 nm would become weaker. Therefore the FWHM of the peak of sample 1 is smaller than that of sample 2 or 3. The peak at about 500 nm, which is due to the defect in ZnO, could only be observed in sample 3. Similarly, it could also happen because of the reflection at about 500 nm. The FWHM of the peak at about 500 nm is so large that some parts of the luminous intensities would be amplified, but the other part would be weakened. Therefore it is hard to differentiate between the peak and the noise. As seen in Fig. 3, the reflection at 500 nm in sample 3 is very small, but in sample 1 or 2 is not. That is why the peak could only be observed in sample 3.

The relationships between the intensities of the peaks and the reflections could not be quantitatively described because the thickness is different. But as it seen in the PL spectra of sample 1 and 3, it is evident that if there is a standing wave at about 380 nm in the ZnO layers, the reflection at about 380 nm could amplify the intensity.

4. Conclusions

In summary, we grow ZnO/MgO multilayers samples on sapphire (0001) substrate by the pulsed laser deposition method. The transmission and photoluminescence spectra show that the samples exhibit some DBR phenomenon. It is evident that the DBR used in ZnO-based ultraviolet laser diodes could be grown with ZnO and MgO. Considering that the ZnO layers would absorb the photon whose wavelength is smaller than 380 nm, the ZnMgO could be better. Such DBRs are to be researched in the near future.

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