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Growth of high quality ZnMgO films on diamond substrates

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Abstract

ZnMgO films were prepared at room temperature on freestanding diamond (FSD) substrates by co-sputtering. The Mg content was controlled by varying RF sputtering power of MgO and the effects of Mg contents on the properties of ZnMgO films were investigated. The results showed that the (0002) peak of ZnMgO shifted from 34.5° to 35.6° with the increasing sputtering power of MgO target. The UV-visible and PL spetra of ZnMgO films revealed that the bandgap of ZnMgO was approximately linear related to the sputtering power of MgO target.

1. Introduction

The large exciton binding energy of 60 meV, wide bandgap energy of 3.37 eV at room temperature, good optical quality, high radiation hardness and relatively low deposition temperatures make ZnO a promising candidate for optoelectronic applications in the ultraviolet (UV) region, e.g. for UV detectors, light emitting diodes [1-3]. An important step in order to design ZnO-based opto-electronic devices is the realization of bad gap engineering in device. It has been reported that the increase in the band gap can be achieved by the incorporation of Mg in ZnO layers [4-6]. In most studies, glass, sapphire, silicon and ZnO have been widely used as substrates for ZnMgO growth. Due to the highest thermal conductivity, wide band gap, high radiation resistance, good chemical and temperature stability, diamond can be an ideal substrate for application of optoelectronic devices used in severe environments (e.g., high temperature, high radiation flux) and surface acoustic wave (SAW) devices[7].

Radio-frequency (RF) magnetron sputtering technique has been widely used to deposit thin films because of its advantageous features such as high deposition rates and low deposition temperature. Especially, if RF co-sputtering is used, it is possible to control the concentrations of dopant element Mg in the ZnMgO film relatively easily. Up to now, few studies involved in the fabrication of ZnMgO films using co-sputtering method have been reported. In this work, we ZnMgO films were grown on freestanding diamond (FSD) substrates using RF co-sputtering method. The

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nucleation surface of FSD film was very smooth which could be used as substrates directly without polishing process which was a time-consuming and expensive technological step for diamond [8]. The effects of sputtering power of MgO on the properties of ZnMgO films are investigated in detail.

2. Experimental

ZnMgO films were prepared on the nucleation side of FSD substrates by RF co-sputtering method with a ZnO ceramic target (purity 99.99%) and a MgO ceramic target (purity 99.99%). The FSD substrates were first disposed in mixed solution of H_2O_2 and H_2SO_4 to eliminate non-diamond surface layer of the diamond films, and cleaned by ultrasonic vibration in deionized water. Cleaned substrates were loaded in the central region of the substrate holder located about 90 mm away from the targets. The sputtering chamber was evacuated to 7×10^{-4}Pa before sputtering. The sputtering gas was the mixture of pure argon (Ar) and pure oxygen (O_2) adjusted by two mass flow controller. During the ZnMgO films deposition, the working pressure was maintained at about 0.6 Pa with Ar/ O_2 ratio of 19:1, the substrate temperature was 400°C, the sputtering time was 60min, the sputtering power of ZnO target was 150W and the sputtering power of MgO target varying from 40 to 100W. Prior to the film deposition, pre-sputtering was performed for 10 min to remove any contamination on the target. The films were annealed in oxygen atmosphere at 550 °C for an hour.

The properties of the films were analyzed by UV-visible spectrophotometer (JASCO V-570), X-ray diffraction (XRD D/MAX-3C, Cu Kα1, λ=0.154056nm) and Raman spectroscopy (Horiba Jobin Yvon HR800UV, Cd-He laser, 325 nm).

3. Results and Discussions

Figure 1 shows the Raman spectrum of nucleation side of the FSD film. The sharp Raman scattering peak at 1332cm^{-1}, is the characteristic of diamond and a weaker Raman scattering band, existed in range of 1400-1600cm^{-1}, is the characteristic of non-diamond carbon [9]. It is well known that the Raman signal for non-diamond carbon phase is about 75 times of that for diamond [10]. Therefore, the Fig.1 indicates a high quality diamond of FSD films with low content of non-diamond carbon.
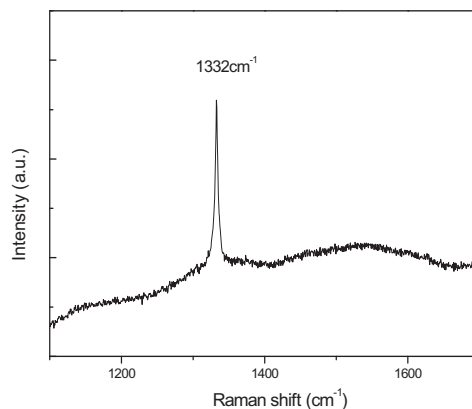

Fig. 1 Raman spectrum of nucleation side of the FSD film

The XRD patterns of the ZnMgO films with sputtering power of MgO target varying from 40W to 100W are shown in Fig. 2. Only a peak indexed to hexagonal (0002) ZnMgO is observed in these patterns. No peak from other compounds appeared indicating that the ZnMgO films possess a single phase hexagonal wurtzite structure with a preferential *c*-axis orientation. With the increasing sputtering power of MgO target from 40W to 100W, the (0002) peak shifts from 34.5° to 35.6°, indicating larger strain of ZnMgO films with increasing sputtering power which is due to substitution of the larger Zn^{2+} ions (0.60 Å) by the smaller Mg^{2+} ions (0.57 Å). Moreover, the intensity of

ZnMgO (0002) peak decreases with the increasing sputtering power of MgO target, which suggest that the excess of Mg will lead to a poor crystal quality. The Fig.2 also shows a diamond (1 1 1) peak at about 44°.
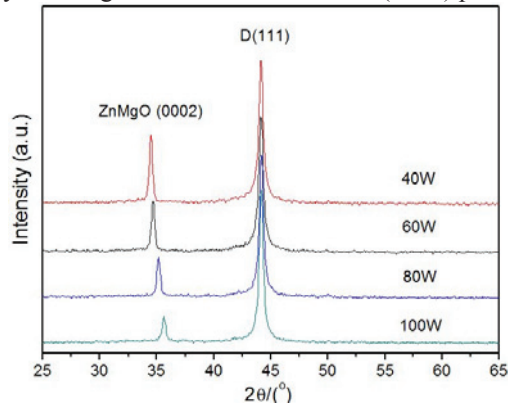

Fig. 2 XRD patterns of ZnMgO films with different sputtering power of MgO target

In order to calculate the bandgap, the ZnMgO films were prepared with the same deposition conditions above but deposit on glass substrate. The optical properties were characterized by UV-visible spectrophotometer. The bandgap is estimated using the relationship of Tauc *et al.* [11] between the absorption coefficient α and the photon energy hv using $(\alpha hv)^2 = A(hv - E_g)^{1/2}$. Fig.3(a) shows that the bandgap of ZnMgO is modulated from 3.39 to 3.56 eV continuously as the sputtering power of MgO target increases. Fig.3(b) exhibits the bandgap of ZnMgO as a function of sputtering power of MgO target, from which it can been seen that the bandgap of ZnMgO is approximately linear related to the sputtering power of MgO target. Hence, the bandgap could be conveniently modulated to a designed value by adjusting sputtering power of MgO target.
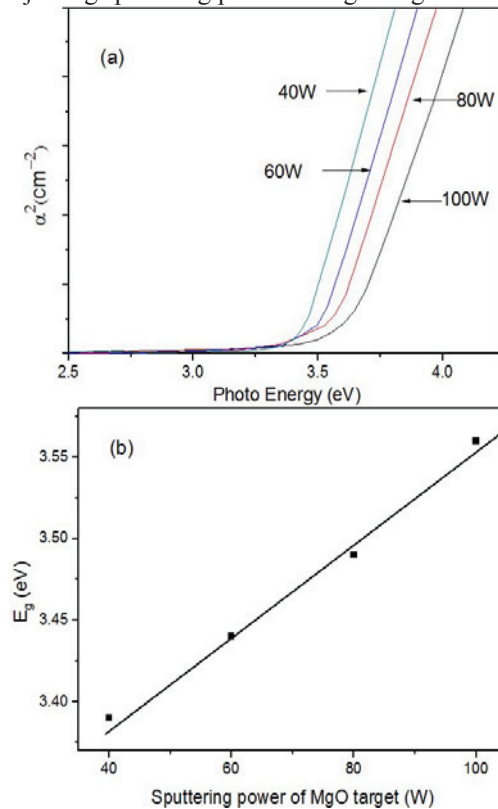

FIG. 3(a) Energy bandgaps of ZnMgO films with different sputtering power of MgO target, (b) Energy bandgap of ZnMgO as a function of sputtering power of MgO target.

Figure 4 presents the PL characteristics of ZnMgO films on FSD substrates with different sputtering power of MgO target at room temperature. PL measurements are performed using the 325 nm line from a He-Cd laser as the excitation source. An obvious blue shift in the near-band edge emission from 3.38 eV (40W) to 3.55eV (100W) was observed, which is consistent with the results obtained from Fig.3.
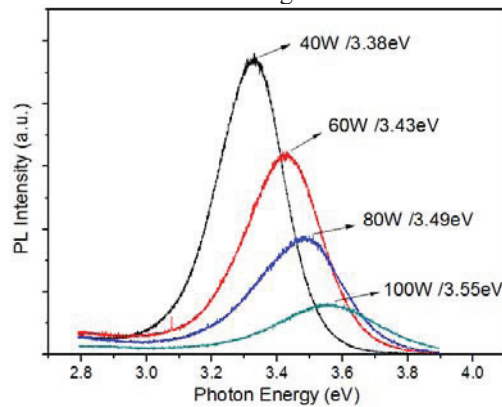

Fig.4 Room-temperature PL spectra of ZnMgO films on FSD substrates with different sputtering power of MgO target

4. Conclusion

In this work, ZnMgO films were prepared at room temperature on freestanding diamond (FSD) substrates by RF co-sputtering. The Mg content was controlled by varying RF sputtering power of MgO. Only a peak indexed to hexagonal (0002) ZnMgO was observed in XRD patterns and the (0002) peak of ZnMgO shifted from 34.5° to 35.6° with the increasing sputtering power of MgO target. With the sputtering power of MgO target varying from 40W to 100W, the bandgap of ZnMgO was modulated from 3.39 to 3.56 eV and approximately linear related to the sputtering power of MgO target.

Acknowledgements

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