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Investigation of ZnO P-I-N light-emitting diodes

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1. Introduction

Zinc oxide (ZnO)-based semiconductors have been investigated as promising materials for advanced electronic and optoelectronic devices due to its wide direct band gap of 3.37 eV and large exciton binding energy of 60 meV. However, it is difficult to obtain p-type ZnO, because ZnO semiconductor is a natural n-type semiconductor. Therefore, n-type ZnO has, thus been deposited on various p-type semiconductors for fabricating related devices [1-2]. In this work, not only was the p-type ZnO deposited, but ZnO P-I-N structure was deposited on sapphire substrates. The performances of the resulted light-emitting diodes were measured and investigated**.**

2. Experimental

The radio frequency (RF) magnetron co-sputtering system equipped with a dual RF power supply was used to deposit AlN codoped ZnO films on sapphire substrates. Pure ZnO (99.99%) and pure AlN (99.99%) were used as the target materials and the corresponding RF powers were fixed at 100W and 25W, respectively. During the deposition process, the $N_2/(N_2+Ar)$ flow ratio was kept at 4%. To activate the doping impurities, the samples were post-annealed at 450^{o}C for 10 minutes in a N_2 ambient using a rapid thermal annealing (RTA) system to achieve p-type ZnO. The mobility and hole concentration of the resulted 400nm-thick p-type ZnO are 1.35 cm^2/Vs and 1.17×10^{18} cm^{-3}, respectively.

Vapor cooling condensation system was used to deposit the i-ZnO and n-ZnO:In films. Tungsten boats put on the ZnO powder (0.85g) and ZnO powder/In tablet (0.85 g / 0.12 g) were heated, respectively. The material vapor gases were driven directly and deposited on the p-type ZnO layer as the P-I-N structure using a pumping system. The sublimated materials were condensed on the p-type ZnO layer cooled by liquid nitrogen. Therefore, high quality and low defects of 500nm-thick i-ZnO and 400nm-thick n-type ZnO:In films can be deposited. The carrier concentration of the i-ZnO and n-type ZnO:In is 7.6×10^{15} cm^{-3} and 1.7×10^{20} cm^{-3}, respectively. The associated mobility of i-ZnO and n-type ZnO:In is 3.2 cm^2/Vs and 5.0 cm^2/Vs, respectively.

To fabricate the ZnO P-I-N light-emitting diodes from the deposited structure mentioned above, using an electron beam vapor deposition system and standard photolithographic technique, Ni/Au (30/100nm) was deposited on the p-type ZnO layer. The sample was then immediately loaded into RTA system and annealed at 400^{o}C for 1 min in N_2 ambient to perform ohmic contact [3]. To perform ohmic contact, Ti/Au (30/100nm) films were deposited on the n-ZnO:In layer and then thermally annealed at 300^{o}C for 1 minute under N_2 ambient by rapid thermal annealing system. Figure 1 shows the schematic diagram of the p-ZnO/i-ZnO/n-ZnO:In light-emitting diodes.

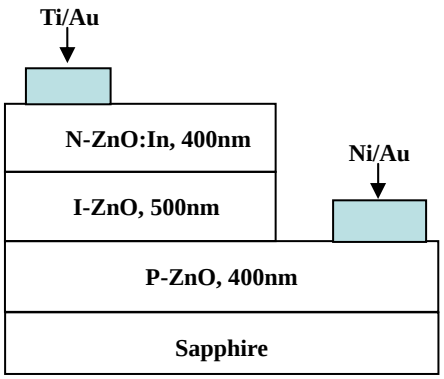

Fig. 1 The schematic diagram of *p*-ZnO/*i*-ZnO/*n*-ZnO:In light-emitting diodes.

3. Experimental results and discussion

Figure 2 shows the I–V characteristics of the ZnO P-I-N LEDs measured using an HP4156C semiconductor parameter analyzer. A rectifying behavior for the ZnO P-I-N light-emitting diodes was clearly observed. The forward turn-on voltage and reverse breakdown voltage are about 2V and -6V, respectively. Figure 3 shows the output optical intensity as a function of wavelength for the room temperature electroluminescence (EL) spectrum of the ZnO P-I-N LEDs operated at 15 μA. The emission band centered

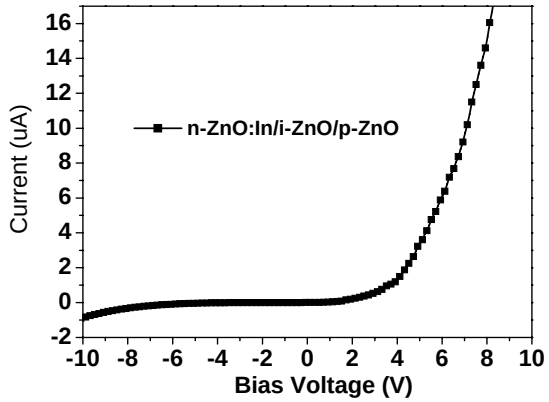

Fig. 2 The current–voltage characteristic of ZnO p-i-n light-emitting diodes.

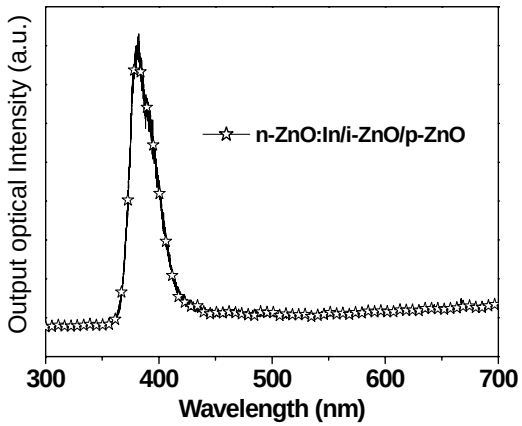

Fig. 3 The room-temperature electroluminescence (EL) spectrum of the ZnO p-i-n light-emitting diodes.

at 387 nm is attributed to the near-band edge (NBE) emission of the i-ZnO film. The radiative recombination occurred in the i-ZnO region when the electrons and holes injected, respectively, from the n-ZnO:In film and p-ZnO layer and flowed into the i-ZnO film. Therefore, ZnO P-I-N light-emitting diodes can be obtained by using the co-sputter system and vapor cooling condensation technique.

4. Conclusions

High quality p-type ZnO film can be obtained by co-sputtering of ZnO and AlN targets under adequate $N_2/(N_2+Ar)$ flow ratio of 4% and post-annealing at 450^oC. Furthermore, high quality of i-ZnO and n-type ZnO:In films can be deposited using vapor cooling condensation method. P-ZnO/i-ZnO/n-ZnO:In light-emitting diodes were fabricated successfully using a cosputtering technique and a vapor cooling condensation system. The UV EL peak of 387 nm was attributed to the radiative recombination occurred at the i-ZnO region. As our knowledge, the ZnO P-I-N LEDs are the first reported in the literature.

Acknowledgement

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