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# Highly Conductive p-type ZnSe Formation Using $Li_3N$ Diffusion

S. W. Lim, T. Honda, K. Yanashima[1], K. Inoue[1], H. Munekata[1], H. Kukimoto[1], F. Koyama and K. Iga

Precision and Intelligence Lab., Tokyo Institute of Technology
[1]Imaging Science and Engineering Lab., Tokyo Institute of Technology
4259 Nagatsuta, Midori-ku, Yokohama 227, Japan

(Phone + 81-45-924- 5064, Fax + 81-45-924-5014)

We have achieved a highly doped p-type ZnSe layer using $Li_3N$ diffusion. The hole concentrations of the ZnSe:(Li, N) layers, grown on a GaAs substrate by metalorganic vapor phase epitaxy, are in the order of high $10^{17}$ $cm^{-3}$. The averaged hole concentration $\bar{p}$ of the p-type layer formed at the diffusion temperature of 470°C is as high as $1x10^{18}cm^{-3}$, with resistivity $\rho$=0.3 $\Omega$·cm and hole mobility $\mu_p$=18 $cm^2/V{\cdot}s$. We made an ohmic contact to p-type ZnSe layer using the $Li_3N$-diffused ZnSe as a contact layer for the first time.

Recently, room temperature cw operation in ZnSe based laser diodes (LDs) have been demonstrated with the help of a high p-type conductivity control by molecular beam epitaxy (MBE).[1)] However, a difficulty in p-type doping still remains as a long standing problem in the fabrication of ZnSe based LDs by metalorganic vapor phase epitaxy (MOVPE).[2)] A current issue in successful development of II-VI laser devices is to make a low resistance ohmic contact to p-type Zn(S)Se. Some techniques to achieve an ohmic contact to p-type ZnSe were reported.[3)] However, most of them employed rather complicated multi-layer structures.

In this letter, we report a new approach for making a highly doped p-type ZnSe layer and solving the ohmic contact problem to p-type ZnSe. We employed $Li_3N$ diffusion to an ZnSe layer, which is expected to act as shallow acceptors by forming $Li_{Zn}$ and $N_{Se}$, respectively.

Two different layers, an undoped ZnSe and a nitrogen-doped ZnSe layer, were grown at the substrate temperature of 470°C on a (001) GaAs substrate by metalorganic vapor phase epitaxy (MOVPE). The diffusion of $Li_3N$ was carried out in the vacuum sealed tube at 350 - 570°C for 30min. We studied the effect of the diffusion temperature on the optical and electrical properties of the samples using photoluminesence (PL), Hall effect and current-voltage (I-V) measurements.

Figure 1 shows PL spectra at 35K for an undoped ZnSe and $Li_3N$-diffused epilayers at 470 and 570°C. The PL spectrum of the undoped ZnSe layer exhibits a neutral donor bound exiton line ($I_2$) with a free exiton line ($E_x$). After $Li_3N$ diffusion at 470°C, a neutral acceptor bound line ($I_1$) is clearly observed while $I_2$ line disappeares. The PL spectrum is dominated by the donor-acceptor pair (DAP) emission with phonon replica. This result indicates that high concentration of Li and N efficiently substitute for Zn and Se site as shallow acceptors in ZnSe. At diffusion temperature higher than 470°C, only a broad DAP emission peak is observed. We conclude from these results that the doping efficiency depends on the $Li_3N$ diffusion temperature.

The electrical properties of $Li_3N$-diffused ZnSe epilayers were investigated at room temperature by means of I-V characteristics and Hall effect measurements. The I-V characteristic, measured between Au contacts on a $Li_3N$-diffused ZnSe, appears to be perfectly ohmic. Figure 2 shows the dependence of the averaged free-hole concentration $\bar{p}$ on the diffusion temperature. At diffusion temperature higher than 430°C, the hole concentrations and the hole mobilities of the p-type layers are in the order of $10^{17}$ $cm^{-3}$ and 10 $cm^2/V\cdot cm$, respectively. The hole concentration increases as the diffusion temperature is increased. At 470°C, the diffusion of $Li_3N$ on a nitrogen-doped ZnSe layer produces a highly conductive p-type ZnSe with the averaged hole concentration $\bar{p}$ of $1x10^{18}$ $cm^{-3}$, as shown in fig. 2 (b). This result is higher than the highest value reported for p-type ZnSe obtained by MBE. However, when the diffusion temperature is increased over 470°C, the hole concentration decreases to $6x10^{17}$ $cm^{-3}$. The decrease of hole concentration at the high temperature is due to the self-compensation caused by extremely high doping of Li and N.

In conclusion, we demonstrate, for the first time, that $Li_3N$ diffsion process can make a good ohmic contact to MOVPE-grown ZnSe. Hall measurement at room temperature reveals that a hole concentration and a resistivity of the ZnSe layer with $Li_3N$ diffusion at 470°C are $1x10^{18}$ $cm^{-3}$ and 0.3 $\Omega\cdot cm$. These values are comparable to those for the best quality nitrogen doped ZnSe layer obtained by MBE. Our experiments indicate that the $Li_3N$ diffusion is effective to solve the ohmic contact problem for MOVPE-grown p-type ZnSe without any complicated material processing.

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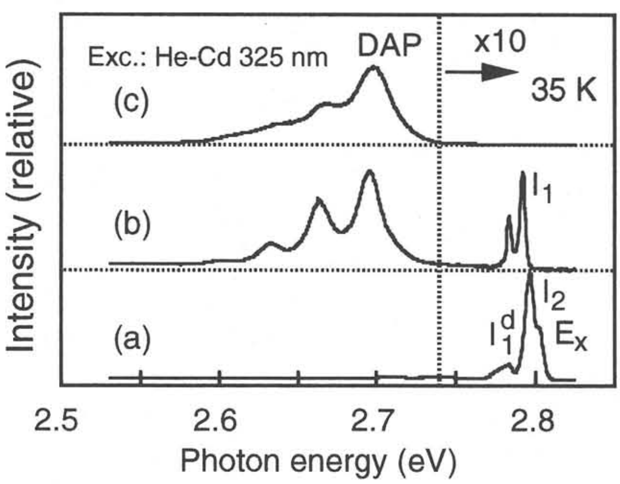


Fig. 1. PL spectra at 35K for
a) undoped ZnSe,
b) ZnSe diffused at 470°C and
c) ZnSe diffused at 570°C.

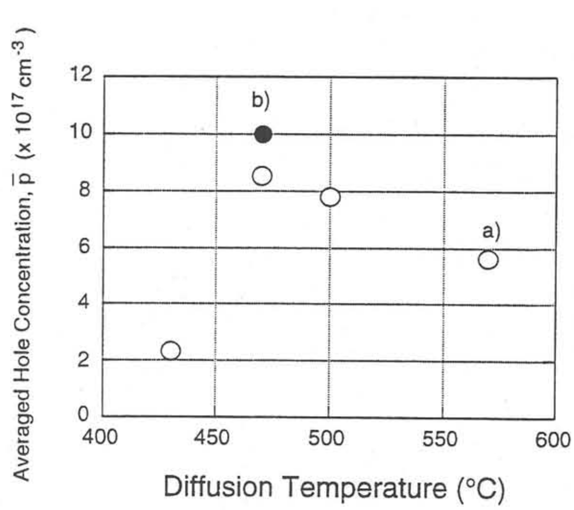


Fig. 2. Averaged hole concentration at room temperature vs diffusion temperature. The wafers used are a) as-grown undoped ZnSe and b) as-grown nitrogen-doped ZnSe.