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Improvements in the Electrical Activity of Nitrogen Doped P-Type ZnSe Due to InGaP Buffer Layer

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We have applied an InGaP buffer layer to improve the electrical activity of nitrogen doped p-type ZnSe, the net acceptor concentration of a p-type ZnSe layer on a GaAs buffer layer being low near the intermediate interface. The net acceptor concentration near the interface of p-type ZnSe on a InGaP buffer was one order of magnitude higher than that on a GaAs buffer, and was enhanced by a factor of 2 near the upper p-type ZnSe surface. This improvement in the electrical activity due to the InGaP buffer layer was also found to be effective in reducing the operation voltage of ZnSe-based LEDs.

1. Introduction

ZnSe-based II-VI semiconductors are promising materials for blue-green light emitting devices. Since the first report of laser diode operation by Haase et al. [1], much work has been done to improve its device characteristics. [2-5] However, the operation voltage of these devices is still higher than that expected from the bandgap energies of the active layers. A reduction of this operation voltage is necessary for practical devices. We have proposed a novel structure to reduce the band offset between p-type ZnSe and p-type GaAs by the introduction of a p-type In(Ga,Al)P layer, which has a valence band depth between those of ZnSe and GaAs [6]. As reported before the thermal or P_2S_5 surface preparation of the InGaP buffer layer is effective in growing high quality ZnSe epilayers [7]. Although, the growth of ZnSe on InGaP ternary buffer layers on GaAs substrates has already been reported, to reduce the lattice-mismatch between ZnSe and GaAs [8], there is no report about the electrical properties of nitrogen doped ZnSe on an InGaP buffer layer.

In this letter, we report on the electrical activity of nitrogen doped p-type ZnSe on a InGaP buffer layer. Also, a mesa type structure LED was constructed and current-voltage (I-V) characteristics were measured to confirm that the high electrical activity for reduced the operating voltage.

2. Experimental

P-type GaAs (500nm) and InGaP buffer layers (200 nm), lattice matched to GaAs, were successively grown by metalorganic chemical vapor deposition (MOCVD) on p-type (100) GaAs substrates.

After the buffer layers were grown by MOCVD, the ZnSe layers were grown by molecular beam epitaxy (MBE). The source materials for ZnSe MBE growth were elemental zinc and selenium. The p-type dopant was nitrogen. The detailed condition for the nitrogen doping and characterization is described elsewhere [9]. The growth temperature was 270 ℃ and the growth rate was about 700 nm/h. A p-type ZnSe cladding layer (2 μ m), 6 CdZnSe quantum well layers (7.5 nm) with ZnSe barrier layers (5.0 nm), an n-type ZnSe cladding layer (1.5 μ m), and an n-type ZnSe contact layer (700 nm) were grown on the buffer layers.

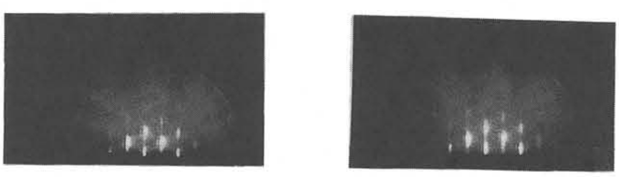
The surfaces were monitored by reflection high energy electron diffraction (RHEED) before and during the MBE growth. The net acceptor concentration ([Na-Nd]) was determined by an electrochemical capacitance-voltage (C-V) measurement. To obtain the [Na-Nd] depth profile, the p-type ZnSe was chemically etched in stages with C-V measurements taken after each etching step. The depth from the surface was determined from the etching rate.

3.Results and discussion

3.1 Surface preparation and RHEED observation

Two samples, one with a InGaP buffer and the other with a GaAs buffer, were exposed to the same growth run. Surface treatments were performed by dipping in a P_2S_5:$(NH_4)_2S$ solution (2 g P_2S_5 in 100 ml $(NH_4)_2S$) for 30 s, and rinsing in water for 60 s. No thermal treatment was carried out prior to growth. The wafer was transferred into the MBE chamber, and heated directly to the growth temperature.

Just after loading into the MBE chamber, a streaked RHEED pattern was observed for both GaAs and InGaP surfaces. This result indicates that the P_2S_5 surface preparation was suitable for both buffer layers. At the growth temperature before growth, the RHEED patterns of both GaAs and InGaP surfaces were sharply streaked. A spot pattern was observed for about 1 min after the initiation of the ZnSe layer growth and then recovered to a streak pattern, as shown in Fig. 1. After the MBE growth, the RHEED pattern was sharply streaked for both buffers. No difference, due to the buffer layers, was observed in the RHEED pattern.



(a) (b)

Fig. 1 RHEED patterns of ZnSe surfaces 1 min after growth initiation (a) on the InGaP buffer layer, (b) on the GaAs buffer layer

3.2 Electrical activity in N-doped ZnSe

Figure 2 shows the net acceptor concentration profiles for p-type ZnSe layers grown on the GaAs and on the InGaP buffer layers. The net acceptor concentration on InGaP buffer was constant throughout the ZnSe layer, while the net acceptor concentration on the GaAs buffer decreased near the interface between ZnSe and GaAs. The net acceptor concentration on InGaP was found to be one order of magnitude higher than that on GaAs near the ZnSe-GaAs interface, and was enhanced by a factor of 2 near the p-type ZnSe layer surface. The nitrogen concentration profiles, determined by secondary ion mass spectrometry (SIMS) were uniform throughout the layers for both samples. The width of the low acceptor region was wider than the expected depletion width of the heterojunctions. Thus, this result indicates that the electrical activity of p-type ZnSe was improved by growing on an InGaP buffer layer.

The changes observed in the RHEED pattern were the same. The FWHM of X-ray diffraction for p-type ZnSe on the InGaP buffer layer was equal to that on the GaAs buffer layer. It could be that the electrical activity is affected by small alterations of microscopic growth mechanism which be not able to observe by these technique.

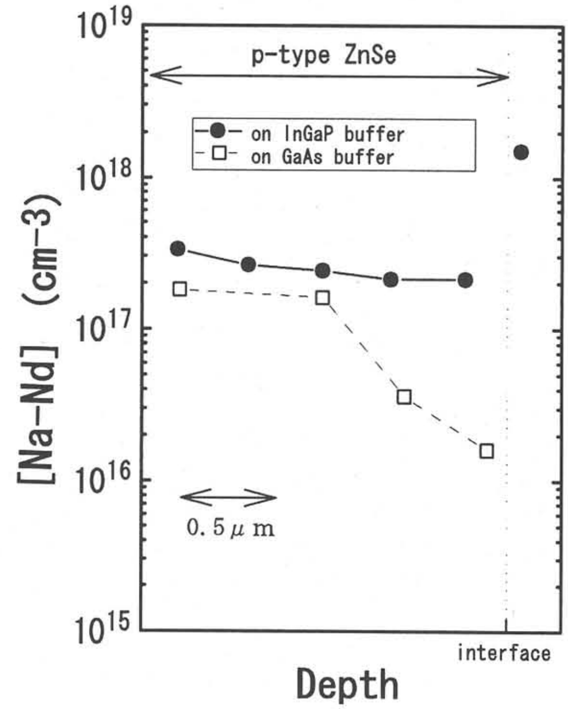


Fig. 2. The net acceptor concentration ([Na-Nd]) profiles obtained by electrochemical C-V measurements using step etching for p-type ZnSe layers on InGaP and GaAs layers.

3.3 Fabrication of a surface contact LED

We constructed a mesa type structure LED to confirm the effect of the buffer layers, as is shown in Fig. 3. The prepared wafers were etched to lower p-type cladding layer, so as to form a device having a mesa type structure [10]. The p-type contact was made to a relatively high p-type doped region near the upper surface. Typical current / voltage graphs for both GaAs and InGaP buffer layer samples are shown in Fig. 4. The applied voltage at 20 mA for the LED with the InGaP buffer layer was found to be 4 V, which was lower than that with a GaAs by 3.5 V. The reason for this was that the acceptor concentration of the p-type ZnSe layer on the InGaP buffer layer was two times higher than that on the GaAs layer in the p-type contact region. Thus, the improvement in the electrical activity was found to be effective in reducing the operation voltage of ZnSe-based LEDs.

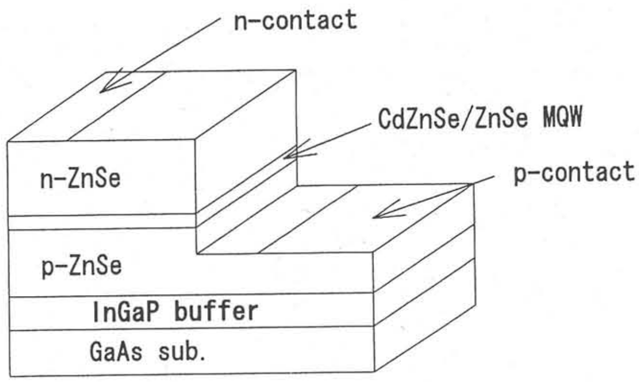


Fig. 3. The structure of a mesa type LED with an InGaP buffer layer.

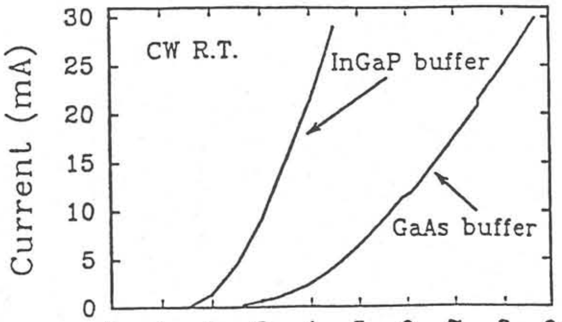


Fig. 4 The typical current / voltage graph for both GaAs and InGaP buffer layer samples

4. Conclusion

We have investigated that the use of an InGaP buffer layer to improve the electrical activity of nitrogen doped p-type ZnSe. The net acceptor concentration of p-type ZnSe on the InGaP buffer was found to be higher than that on the GaAs buffer. The use of InGaP buffer was seen to produce a substantial improvement in the electrical activity of p-type ZnSe. This improvement affected the operation voltage of a surface contact type LED. The applied voltage of LED being reduced.

Acknowledgments

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