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Crystal Growth and Characterization of II-VI Compound Light Emitting Diodes with Novel Superlattice Quasi-Quaternary Cladding Layers on InP Substrates

Wataru Shinozaki, Ichirou Nomura, Hiroyuki Shimbo, Hiroshi Hattori,
Takashi Sano, Song-Bek Che, Akihiko Kikuchi, Kazuhiko Shimomura, Katsumi Kishino
Department of Electrical and Electronics Engineering,
Sophia University,7-1 Kioi-cho, Chiyoda-ku, Tokyo 102-8554, Japan
Phone: +81-3-3238-3323, Fax: +81-3-3238-3321, E-mail: kishino@katsumi.ee.sophia.ac.jp

1. Introduction

MgZnCdSe II-VI compounds on InP substrates have wide band-gap energy from 2.1 to 4.2eV. Thus, the materials are expected for applications to wide-range visible optical devices. By now, crystal growth and characteristics of ZnCdSe and MgZnCdSe have been investigated[1,2] using molecular beam epitaxy (MBE) technologies, and recently n and p-type doping properties of ZnCdSe were reported[3]. However, a sufficient p carrier concentration for laser diodes (LD) has never been obtained. On the other hand, MgZnSeTe compounds which can be lattice-matched to InP substrates are expected to show capabilities for a high p-doping and wide bandgap, because which contains the high p-dopable ZnTe and the wide-gap MgSe and MgTe compounds[4,5]. However, it is very complex to satisfy both conditions of the lattice-matching of MgZnSeTe and the optimum II/VI source supply ratio during the MBE growth, and therefore difficult to fabricate a high-quality hetero-structure such as LDs.

In this study, we would like to present novel MgSe/ZnSeTe superlattice quasi-quaternaries (SL-QQs) which consist of short-period superlattices of lattice-matched ZnSeTe wells and MgSe barriers. The bandgap energy of the SL-QQs can be controlled by only changing layer thickness combinations (i.e., shutter opening and closing time), and a high hole concentration may be obtained due to the existence of high p-dopable ZnSeTe layers. Accordingly, the SL-QQs are expected to be used as p-side cladding layers of ZnCdSe/MgZnCdSe LDs and LEDs. In this study, MgSe/ZnSeTe SL-QQs were grown on InP substrates by MBE with p-type doping by RF-radical nitrogen. A high hole concentration of 9×10^{17} cm^{-3} was obtained for the crystal. ZnCdSe/MgZnCdSe quantum well (QW) LEDs were fabricated on InP substrates with introducing the SL-QQs into the p-side cladding layers. A yellow light emission at 577 nm was observed under a 77-K pulsed current injection.

2. MgSe/ZnSeTe SL-QQs

MgSe/ZnSeTe SL-QQs were grown by a solid-source MBE on semi-insulated (100) InP substrates with lattice-matched InGaAs buffer layers[6]. After thermally removing oxidation layers on the buffer layers at 520 °C, 300-pair MgSe/ZnSeTe superlattices were grown at 320 °C with doping RF-radical nitrogen into the ZnSeTe layers. RF power and N_2 flow rate were 400 W and 0.060 sccm, respectively. The Mg composition of the SL-QQ was measured to be 0.33 from an electron probe micro analysis (EPMA), and the MgSe and ZnSeTe layer thicknesses were estimated to be 0.85 and 1.7 nm, respectively, from the total thickness and the pair number. Reflectance and photoluminescence (PL) spectra at 15 K for the SL-QQs are shown in Fig. 1. The bandgap energy of the SL-QQ was evaluated around 2.4 eV because that the resonance oscillation in lower energy side of the reflectance spectrum rapidly disappeared over 2.4 eV. While, the PL peak was observed at 2.3 eV, which was lower than the bandgap energy by 0.1 eV. Hole concentrations of the SL-QQs were measured by Hall effect measurements using a van der Pauw method, and a high hole concentration of 9×10^{17} cm^{-3} was obtained.

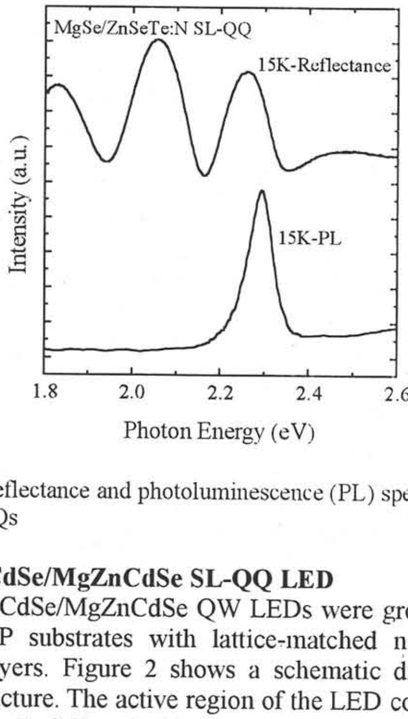

Fig.1 Reflectance and photoluminescence (PL) spectra at 15 K for the SL-QQs

3. ZnCdSe/MgZnCdSe SL-QQ LED

ZnCdSe/MgZnCdSe QW LEDs were grown on n-type (100) InP substrates with lattice-matched n-type InGaAs buffer layers. Figure 2 shows a schematic diagram of the LED structure. The active region of the LED consisted of 10-nm-thick ZnCdSe double QWs and MgSe/ZnCdSe SL-QQ[7] barrier layers. The p-side cladding layer was 0.7-μm-thick N-doped MgSe/ZnSeTe SL-QQs, and the n-clad was 0.8-μm-thick Cl-doped MgSe/ZnCdSe SL-QQs. After thermally removing oxidation layers of the substrates, a 0.1-μm-thick Cl-doped ZnCdSe buffer, the n-cladding layers, and the QW active region were sequentially grown at 280 °C. And then, the p-cladding and N-doped ZnSeTe and ZnTe cap layers were grown at 320 °C. The growth condition of the p-cladding layer was similar to that of MgSe/ZnSeTe SL-QQs described in Sec. 2. The Cl dopant was supplied from $ZnCl_2$.

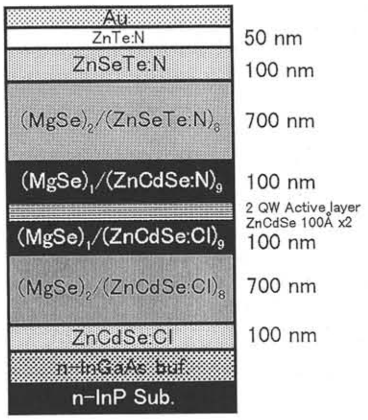

Fig.2 A schematic diagram of the LED structure

Carrier concentration profiles of the LED wafers were measured by using a Semiconductor Profile Plotter (PN4300: Bio-Rad Microscience Division) with chemically etching the each layer. A carrier concentration profile was shown in Fig. 3 as a function of the etching layer depth. From the measurements, it was made sure that a p-n junction was formed in the LED wafers. Hole concentrations around 10^{17} cm^{-3} were obtained for the p-cladding layers, and electron concentrations of the n-cladding layers were about $2x10^{18}$ cm^{-3}.

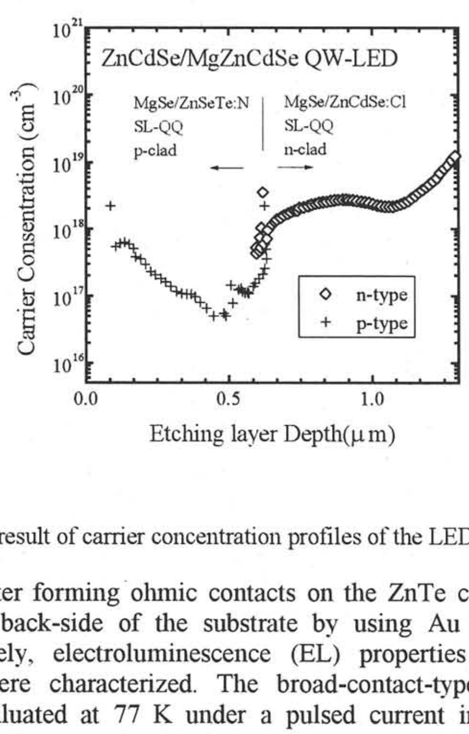

Fig.3 A result of carrier concentration profiles of the LED wafer

After forming ohmic contacts on the ZnTe cap layer and the back-side of the substrate by using Au and In, respectively, electroluminescence (EL) properties of the LEDs were characterized. The broad-contact-type LEDs were evaluated at 77 K under a pulsed current injection. Figure 4 shows an typical injection current versus applied voltage (I-V) characteristic. The current was injected from low applied voltage about 2 V. Figure 5 shows an EL spectrum at an injection current of 192 mA. A yellow light emission at 577nm (2.15eV) was observed, and full width of half maximum (FWHM) of the main peak was 30.8 meV.

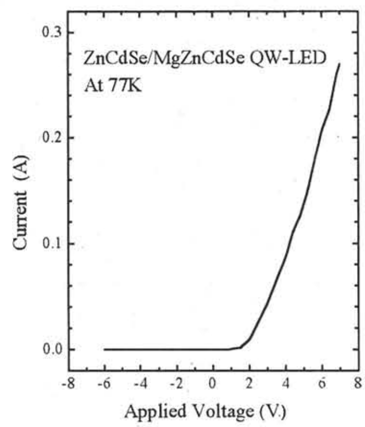

Fig.4 Injection current versus applied voltage (I-V) characteristic

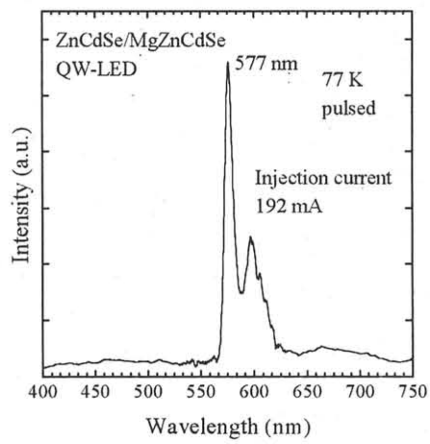

Fig.5 An EL spectrum at an injection current of 192 mA

4. Summary

MgSe/ZnSeTe SL-QQs were grown on InP substrates by MBE with p-type doping by RF-radical nitrogen. A high hole concentration of $9x10^{17}$ cm^{-3} was obtained for the crystal. By use of the SL-QQ as a p-side cladding layer, ZnCdSe/MgZnCdSe QW LEDs were fabricated on InP substrates. A yellow light emission at 577 nm was observed under a 77-K pulsed current injection.

Acknowledgments

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