Extended Abstracts of the 1997 International Conference on Solid State Devices and Materials, Hamamatsu, 1997, pp. 196-197 **C-5-5**

Electrical Properties of ZnSe/ZnSe Homointerfaces Formed by MBE Regrowth Process

Yuji Yamagata, Koji Fujiwara, Takayuki Sawada, Kazuaki Imai, Kazuhiko Suzuki and Isao Tsubono
Department of Applied Electronics, Hokkaido Institute of Technology, 7-15 Maeda, Teine, Sapporo 006, Japan
Phone: +81-11-681-2161, Fax: +81-11-681-3622, E-mail: sawada@hit.ac.jp

1. Introduction

After the first demonstration of a ZnSe-based blue/green laser diode (LD),[1] considerable efforts have been devoted to clarifying the degradation mechanism and to improving the lifetime of the LDs.[2] If the problem is fully overcome, the epitaxial regrowth on active conducting layers exposed to various processings would be employed to fabricate more sophisticated LDs or other optoelectronic devices involving low dimensional structures such as quantum wires and quantum dots. However, as concerns ZnSe-based semiconductors, electrical properties of the regrowth interface have not yet been studied.

In the present work, we have investigated the electrical properties of MBE-regrown ZnSe/ZnSe homointerfaces formed on GaAs substrates by measuring I-V, C-V and DLTS characteristics of the Schottky diodes and analyzed their behavior by considering the interface states.

2. Experimental

Two kinds of ZnSe epilayers, with and without regrowth interface were used in this study. The n-ZnSe:Cl was grown on a chemically-etched n^+-GaAs (100) substrate at 330℃ under Se rich condition by conventional MBE. The doping density was set to 2×10^{17} cm^{-3}. For the regrowth sample, the first grown epilayer was exposed to the atmosphere for a few hours, then the surface was slightly etched in a saturated $K_2Cr_2O_7$ solution immediately before introducing the sample into the growth chamber. The second epilayer was grown under the same conditions. The regrowth interface was located at mid epilayer whose total thickness was 1.0 μm. The sample without regrowth interface was also prepared as the standard sample. Au electrodes with radius of about 500 μm were deposited onto the surface to form Au/n-ZnSe/n^+-GaAs Schottky diodes.

3. Results and Discussion

Figure 1 compares forward I-V characteristics obtained from the Schottky diodes with and without the regrowth interface. As compared with the standard sample, a considerable lowering of the current level, being more than four orders of magnitude, was observed for the regrown sample. The result indicates that a relatively high potential barrier arising from interface states is formed at the regrowth homointerface and it limits the current flowing.

On the basis of the thermionic emission theory, the potential barrier height at the regrowth interface, ψ_p, can be calculated from the observed ledge current by using the following equation:

$$\psi_p = \frac{k_B T}{q}\ln\frac{A^{**}T^2}{J_n},$$

where J_n is the current density across the regrowth interface and A^{**} is the effective Richardson constant. A^{**} is given by $120(m^*/m_0)$ $A/cm^2/K^2$ for semiconductors with isotropic effective mass. Using m^*/m_0 = 0.17 for n-ZnSe, ψ_p was estimated to be about 0.72eV under the application of the forward bias voltage; the interface Fermi level is almost pinned at corresponding energy owing to a high density of interface states. Note that the potential barrier height under the null bias condition is larger than that value.

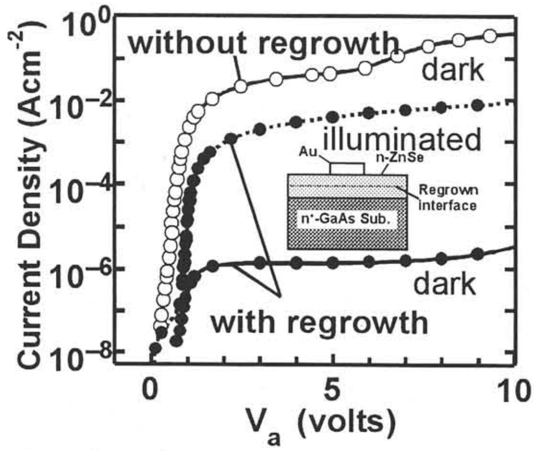

Fig.1 Comparison of I-V curves between samples with and without regrown interface.

In order to confirm the potential barrier height deduced from I-V characteristics, DLTS measurements were performed using the same samples. A repetitive population bias pulse with its height of ΔV=0.1 V and its width of 10ms was used for the regrown sample, while ΔV was chosen to be 1.0 V for the standard sample because of much smaller signal. Figure 2 compares DLTS spectra obtained from these two samples. Considerably large signals are observed in the regrown sample as compared with the standard sample even when ΔV is one tenth of that for the standard sample. These spectra from the regrown sample are much broader and can be explained by the existence of continuum states. Furthermore, the peak shift of the spectra toward lower temperature with increase of the population bias is another notable feature for the regrown sample. The above described observations confirm that those signals arises from interface states at the regrowth homointerface. From the Arrhenius plots, the activation energy can be determined to be 0.79 eV, which corresponds to ψ_p=0.73 eV, under the condition of V_p = 1.5 V. The ψ_p value is reasonably in agreement with that determined from the I-V measurement and is different from the discreet level of 0.51 eV observed in the standard sample.[3] It is known that the interface Fermi level is gradually pinned around this energy owing to a high density of interface states, as schematically shown in Fig.3.

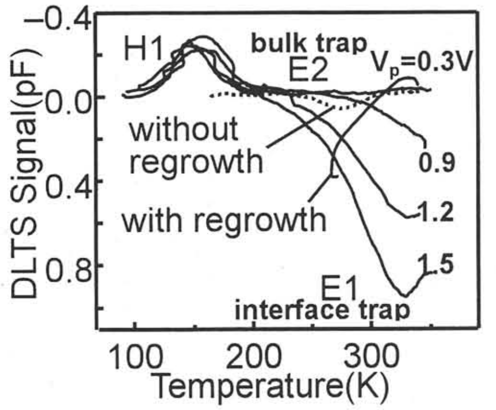

Fig.2 DLTS spectra obtained from the regrown sample.

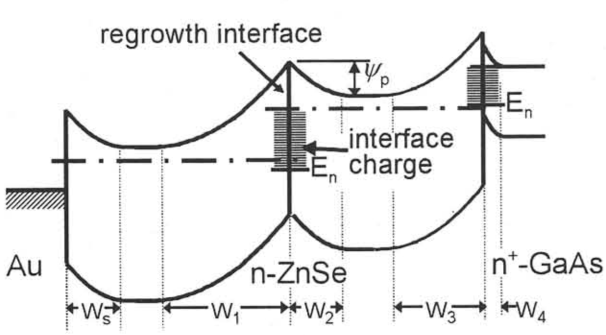

Fig.3 Schematic band diagram of Au/n-ZnSe/n^+-GaAs Schottky diode with regrowth interface

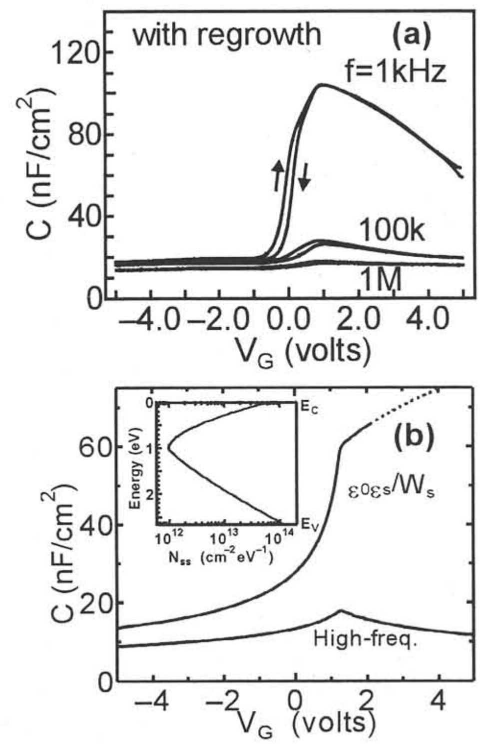

Fig. 4 (a) Experimental C-V curves of the regrown sample and (b) calculated high-frequency C-V characteristics.

Formation of such a high potential barrier at the regrowth interface also affects the Schottky C-V characteristics. Figure 4(a) shows measured C-V curves of Au/n-ZnSe/n^+-GaAs diode with regrowth interface. C-V curves are characterized by a large frequency dispersion of capacitance in the forward bias region and by a decrease of capacitance with increase of the applied forward bias more than 1V.

The behavior for the regrown sample can be qualitatively explained as follows. Under a high-frequency limit condition, the total capacitance of the Au/n-ZnSe/n^+-GaAs diode can be given by a series connection of each depletion layer capacitance formed at Schottky surface, regrowth homointerface and substrate heterointerface, as shown in Fig.3. Then, the applied bias voltage will be distributed to these depletion layers so as to satisfy current continuity, charge balance and energy balance requirements.[4] Based on this, when the Schottky barrier is highest among those potential barriers, under the null bias condition, as is the present case, the applied forward bias would be effectively used to decrease the Schottky barrier down to the potential barrier height at the regrowth interface. The increase of capacitance within the forward bias region up to 1V can be understood by such an explanation. Further increase of the forward bias would lead to expansion of the depletion layer W_1 located on the left side of the regrowth interface because of the existence of interface states. Therefore, the total capacitance decreases with increasing the forward bias, though the current slowly increases owing to the shrinkage of the depletion layer W_2. The large capacitance dispersion can be interpreted in terms of the time-lag of carrier flow across the potential barriers and charging/discharging of electrons in interface states.

Figure 4(b) shows the theoretical high-frequency C-V characteristics. For comparison, the true Schottky capacitance, $\varepsilon_0\varepsilon_s/W_s$, which corresponds a low-frequency C-V curve under some condition, are also indicated. In the calculation, only bias dependent potential barriers at Schottky surface and the regrowth interface are taken into account for simplicity. Also, the Schottky barrier height and the donor concentration measured from the standard sample, which are Φ_B=1.6eV and $N_D=2\times10^{17}$ cm^{-3}, are used. The U-shape distribution of interface states deduced from the I-V measurement was used, which is shown in the inset. It is seen that well reproduced C-V curves can be obtained based on the present model. A cure for the formation of potential barrier at the regrowth interface is now under searching.

4. Summary

Electrical properties of MBE-regrown ZnSe/ZnSe homointerfaces have been measured for the first time. It is found that the potential barrier being about 0.7eV is formed at the air-exposed and chemically-etched homointerface. The observed peculiar C-V behavior, showing a large capacitance dispersion and the capacitance decrease within a forward bias region, can be theoretically fitted by using the interface state distribution deduced from I-V characteristics.

Reference

1) M. A. Haase *et al.*, Appl. Phys. Lett. **59**(1991)1272.
2) K. Nakano *et al.* Electron. Mater. **25**(1996)213.
3) G. Karczewski *et al.*, J. Appl. Phys. **75**(1994)7382.
4) Y. Yamagata *et al.*, J. J. Appl. Phys. **36**(1997)56.