Extended Abstracts of the 1997 International Conference on Solid State Devices and Materials, Hamamatsu, 1997, pp. 210-211 **C-6-4**

High-Reflectivity ZnSe/ZnS Distributed Bragg Reflectors in Blue Region Grown on (311)B GaAs Substrates

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1. Introduction

Semiconductor microcavities are attractive both from the basic physics and from practical applications such as vertical cavity surface emitting lasers (VCSELs) and high-efficiency light emitting diodes with highly collimated output beams.[1] In II-VI semiconductor VCSELs, dielectric substance multilayers or metals have been used for the cavity mirrors.[2-3] But if distributed bragg reflectors (DBRs) consisting of II-VI semiconductors are realized, which have large difference of refractive index and high reflectivity with small periods, monolithic fabrication of VCSELs will be possible. On the other hand, in the crystal orientation close to (111) planes, optical anisotropy and high optical gain are obtained by the modulation of the valence band structure[4] and VCSELs with polarization control and low threshold will be possible. Therefore the examination of growing widegap semiconductors on non-(100) orientation substrates is very important.

In this paper, we examined the growth of DBRs consisting of II-VI semiconductors on (311)B GaAs substrates for the first time by metalorganic vapor phase epitaxy. The high reflectivity up to 94.5% was observed in a ZnSe/ZnS with only 10 periods DBR.

2. Results

To obtain the high reflectivity mirrors, it is necessary to realize optically flat heterointerfaces. The initial growth processes of II-VI semiconductors on GaAs surfaces are crucially dependent on the surface stoichiometry of GaAs substrates and the growth conditions.[5] Therefore, we examined the conditions of thermal cleaning on (311)B GaAs surfaces. Figure 1 shows the AFM images of (311)B GaAs surfaces cleaned with the TDMAAs [$As(N(CH_3)_2)_3$] flow. The cleaning temperature is 700°C and the TDMAAs flow rates are (a) 10μmol/min and (b) 20μmol/min. These results prove that supply of sufficient TDMAAs during the thermal cleaning leads to extremely-flat (311)B GaAs surface and are attributed to the suppression of As desorption on (311)B surfaces.

Growth of ZnSe and ZnS on the (311)B GaAs substrates was examined. For the purpose of studying the dependence on the initial growth condition, the VI/II ratio was varied. Figure 2(a) shows FWHM of the X-ray rocking curve measured on (311)B ZnSe and root-mean-square (rms) of ZnSe surface roughness observed by AFM grown with the different VI/II ratio. The higher crystal qualities with the lower FWHM values were observed for the lower VI/II ratio, but the FWHM value increased abruptly below the VI/II ratio of 0.5. This figure clearly shows that the rms values of the surface roughness is in direct correspondence with the crystal quality for the different VI/II ratio.

ZnS was deposited on the (311)B GaAs surface with an additional ZnSe Buffer layer. Figure 2(b) shows the FWHM of the ZnS (311) X-ray rocking curve and the rms of the surface roughness observed by AFM for the different VI/II ratio. In this growth of ZnS, misfit dislocations will be generated since the lattice mismatch between ZnSe and ZnS is 4.6% and is large. Due to this problem, both the FWHM of the X-ray rocking curve and the rms of the surface roughness were increased compared with those of ZnSe. Nevertheless the optimum VI/II ratio was clearly observed to be 10-12 both for the FWHM of the X-ray

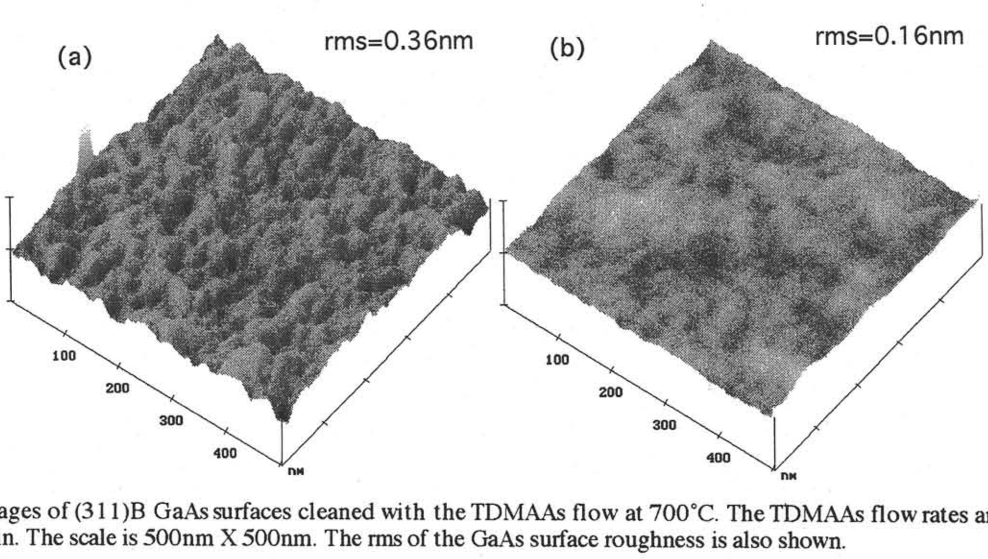

Fig.1 AFM images of (311)B GaAs surfaces cleaned with the TDMAAs flow at 700°C. The TDMAAs flow rates are (a) 10μmol/nim and (b) 20μmol/min. The scale is 500nm X 500nm. The rms of the GaAs surface roughness is also shown.

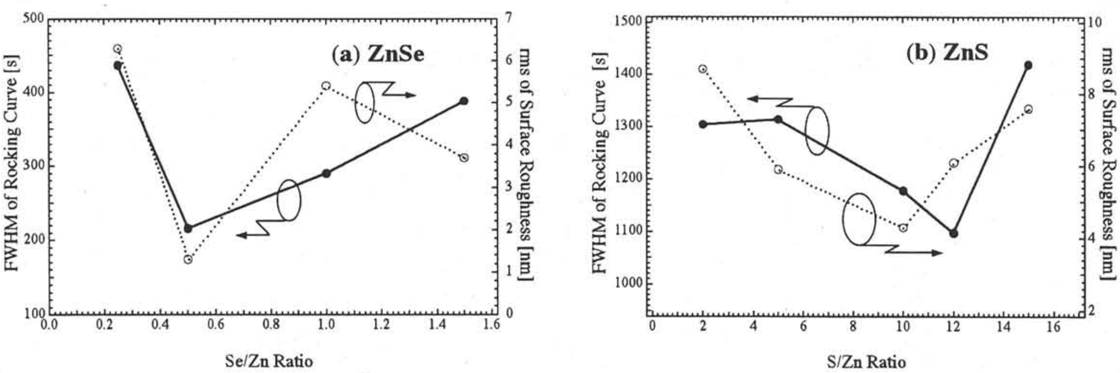

Fig.2 FWHM of (311) X-ray rocking curve and rms of surface roughness for different VI/II ratio. Each figures show (a) about ZnSe and (b) about ZnS. The solid lines and dashed lines show the FWHM and the rms, respectively.

rocking curve and the rms of the surface roughness.

10 periods of ZnSe/ZnS DBR layers were grown on the (311)B GaAs substrates. The DBR used in our experiments was designed so that the center of the reflection spectrum was in the blue region at room temperature. The solid line in Fig.4 shows the reflection spectrum measured at room temperature on the DBR grown on the (311)B GaAs substrate. The maximum reflectivity measured was 94.5% at 468nm. The measured reflectivity at the center wavelength is close to the theoretically calculated reflectivity of 94.8%. Both the calculation and the measurement indicate that only 10 periods of DBRs show the high reflectivity. The reflectivity of the DBRs in blue region reported up to now with II-VI semiconductors was 70% with 10 periods and 86% with 20 periods of MgZnSSe/ZnSSe DBR[6] and 81% with 25 periods of ZnSSe/MnZnSSe DBR[7] on (100) GaAs substrate grown by MBE. Compared with these reports, the present DBR has much higher reflectivity with only 10 periods.

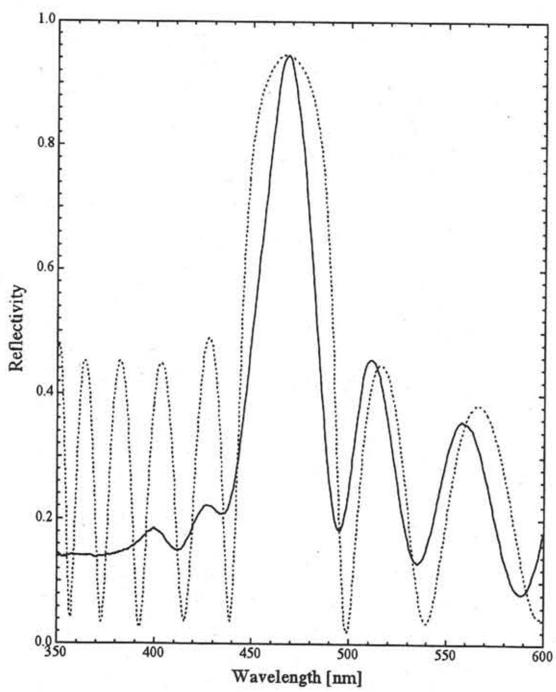

Fig.3 Reflectivity of ZnSe/ZnS DBR with 10 periods grown on (311)B GaAs surface measured at room temperature (solid line). Dashed line shows the theoretical spectrum. The measured maximum reflectivity is 94.5% at the wavelength of 468nm.

3. Conclusions

In conclusion, we demonstrated high-reflectivity ZnSe/ZnS DBRs grown on (311)B GaAs substrates by MOVPE. The conditions of the thermal cleaning with the TDMAAs flow and the growth of ZnSe and ZnS on (311)B GaAs surfaces were investigated for realizing the atomically flat surfaces. The maximum reflectivity measured on the ZnSe/ZnS DBRs grown on (311)B GaAs substrate under these conditions was 94.5% at the wavelength of 468nm with only 10 periods. High performance microcavities and VCSELs monolithically grown with II-VI semiconductors in blue region will be possible by extending the present results.

Acknowledgments

The authors wish to thank Dr.Yoshikatsu Ichimura of Hewlett-Packard Laboratories Japan for his support and useful suggestions and Trichemical Laboratory Co. for supplying metalorganic precursors. They also wish to thank Mitsuo Hoshiyama for his technical support. This work was supported in part by Grant-in-Aid for Exploratory Research No.08875061 from the Ministry of Education, Science, Sports and Culture.

References

1) Y.Yamamoto, S.Machida and G.Björk : Phys. Rev. **A44** (1991) 657

2) P.Kelkar, V.Kozlov, H.Joen, A.V.Nurmikko, C.-C.Chu, D.C.Grillo, J.Han, C.G.Hua and R.L.Gunshor : Phys. Rev. **B52** (1995) R5491

3) T.Aherne, A.L.Bradley, J.P.Doran, J.O'Gorman, J.F.Hefferman, J.Hegarty, H.De Nove, C.Brys, G.Geens, P.Van Daele, R.Baets, P.Demeester, K.Rakennus, A.Salokatve, P.Uusimaa and M.Pessa : J.Cryst.Growth **159** (1996) 636

4) T.Ohtoshi, T.Kuroda, A.Niwa and S.Tsuji : Appl. Phys. Lett. **65** (1994) 1886

5) K.Uesugi, H.Suzuki, H.Nashiki, T.Obinata, H.Kumano and I.Suemune : Jpn. J. Appl. Phys. **35** (1996) L1006

6) P.Uusimaa, K.Rakennus, A.Salokatve, M.Pessa, T.Aherne, J.P.Doran, J.O'Gorman and J.Hegarty : Appl. Phys. Lett. **67** (1995) 2197

7) A.Salokatve, K.Rakennus, P.Uusimaa, M.Pessa, T.Aherne, J.P.Doran, J.O'Gorman and J.Hegarty : Appl. Phys. Lett. **67** (1995) 407