Extended Abstracts of the 1997 International Conference on Solid State Devices and Materials, Hamamatsu, 1997, pp. 170–171 **C-3-2**

Structural and Electrical Characterization of InP Air/Semiconductor Gratings Formed by Mass-Transport Assisted Wafer Fusion Technique

Masahiro Imada and Susumu Noda
Department of Electronic Science and Engineering, Kyoto University, Kyoto 606-01, Japan
Phone: +81-75-753-5298, Fax:+81-75-751-1576,
E-mail: imada@kuee.kyoto-u.ac.jp, snoda@kuee.kyoto-u.ac.jp

1.Introduction

Recently, there is an increasing interest in the implementation of novel structures for realizing new devices and materials, such as two-dimensional (2D) circular grating surface emitting laser and three-dimensional (3D) photonic crystal. To develop such structures, it is necessary to form 2D or 3D submicron order periodical change in refractive index inside a semiconductor. When we consider using an epitaxial regrowth process for this purpose, following critical problems are present: 1)it is difficult to embed 2D gratings uniformly since the embedded grating shape is changed depending on wafer orientation, 2)it is difficult to fabricate 3D structure itself.

To overcome the above problems, we have recently proposed using a wafer fusion technique and demonstrated the feasibility[1][2]. However, the detailed characteristics of such fused gratings have not been disclosed. In the following, we describe the structural characteristics investigated by SEM and TEM, and also the electrical characteristics of the fused Air/Semiconductor gratings.

2.Fabrication

The InP system, which is widely utilized for optoelectronic devices, was chosen for the material to fabricate air/semiconductor gratings. The gratings with 0.4μm period, 0.1μm depth, and various stripe width were formed on the InP wafers by electron-beam lithography and reactive ion etching. The surface of each wafer was pretreated with buffered HF solution. Then, the wafers were stacked as shown in Fig.1 and fused by heating in H_2 atmosphere under the pressure greater than 1.7N/cm^2.

3.Structural Characteristics

Figure 2 shows the examples of SEM cross sectional view of air/semiconductor gratings with various stripe width before and after wafer fusion (wafer fused temperature/duration: 620℃/60min.). The grating shape changed to somewhat a circular shape after wafer fusion. We consider that this is due to mass-transport phenomenon. The gratings with the smallest stripe width were not fused with the upper substrate as shown in Fig.2 (right hand side), because the height of gratings decreased by mass-transport before the wafer fusion. We compared the fused grating shapes at various temperatures, and degree of mass-transport decreased with decreasing temperature. The grating shapes, which were parallel to [110] and [1$\bar{1}$0] direction, had almost no dependence on the wafer orientation. This may be because mass-transport occurs, so that the surface-energy becomes minimal.

Figure 3 shows the TEM cross sectional view of fused interface. In this figure, there are many patterns around the fused interface, which probably expresses the influence of strain caused by small misorientation around [001] (normal to the substrate surface) or caused by pressure during heating. However, no threading dislocation was observed. The dark line, which seems to show the fused interface, was not flat but curved. It was observed in higher resolution TEM that the fused interface at the edge of grating has deviated from (001) plane toward (115) plane. Note the fused interface was flat when plane wafers were fused. We consider this curved interface shows exactly that mass-transport occurs so that the strain and surface energy become minimal during heating.

4.Electrical Characteristics

We also investigated the electrical characteristics of air/semiconductor gratings. First, we measured the I-V characteristics of fused interface without gratings. It was found that voltage barrier existed at the interface when both wafers were p-type, but voltage barrier did not exist when both wafers were n-type. Then, even if both wafers were p-type, the voltage barrier tended to decrease for the wafers with fused gratings which had a larger mass-transport effect. From this result, we may say that mass-transport has a good influence on the electrical characteristics of fused interface.

Based on these results, we have developed the distributed feedback (DFB) laser with air/semiconductor gratings embedded by wafer fusion technique. Figure 4 shows the SEM cross sectional view of DFB laser (wafer fused temperature/duration:620°C/30min.). The air/semiconductor gratings with 0.4μm period and about 0.2μm depth was formed uniformly. Figure 5 shows the I-V characteristics of the DFB laser. The turn-on voltage was as low as 1.0 V, which is comparable to the conventional epitaxial p-n junction, and no leak current was observed for backward bias. Then, we have measured the lasing characteristics. The lasing oscillation has been successfully achieved, as shown in Fig.6. The threshold current density was estimated to be as low as 1.3kA/cm^2.

5.Conclusion

We have investigated the structural and electrical characteristics of air/semiconductor gratings formed in a semiconductor by wafer fusion technique. The grating shape has changed depending on grating width and/or fused temperature. The TEM observation found that fused interface is not flat but curved due to mass-transport, which occurs so that strain and surface energy become minimal. We have found that there is no threading dislocation. Furthermore, the electrical characteristics tend to improve by mass-transport. Based on these results, we have developed a DFB laser with air/semiconductor gratings embedded by wafer fusion technique and achieved the lasing oscillation successfully. The threshold current density has been estimated to be as low as 1.3kA/cm^2. These results encourage us to implement a new 2D or 3D structure by using wafer fusion technique.

Acknowledgments

The authors would like to thank Prof. A. Sasaki and Dr. A. Wakahara for valuable discussions and to thank Dr. S. Rouvimov at Lawrence Berkeley National Lab. for TEM observation and valuable discussions. They also would like to thank Drs. H. Kobayashi and G. Sasaki at Sumitomo Electric Industries, Ltd. for providing us epitaxial wafers. This work was supported in part by a Grant-in-Aid for Scientific Research from Ministry of Education, Science, Sports and Culture of Japan, in part by the Matsuo Foundation, and in part by the Venture Business Laboratory of Kyoto University.

References

1) S. Noda, N. Yamamoto, and A. Sasaki: Jpn. J. Appl. Phys. **35** (1996) p.L909.

2) M. Imada, S. Noda, A. Sasaki, H. Kobayashi, and G. Sasaki: IEEE Photon. Technol. Lett. **9** (1997) p.419.

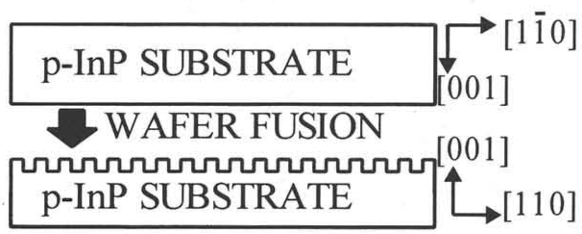

Fig.1 The schematic diagram showing the configuration of the wafer fusion.

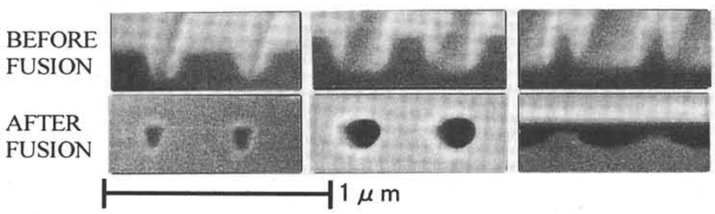

Fig.2 SEM cross sectional view of gratings before and after wafer fusion.

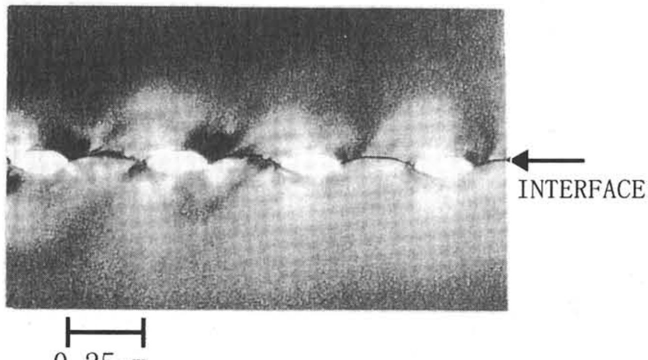

Fig.3 TEM cross sectional view of wafer fused interface.

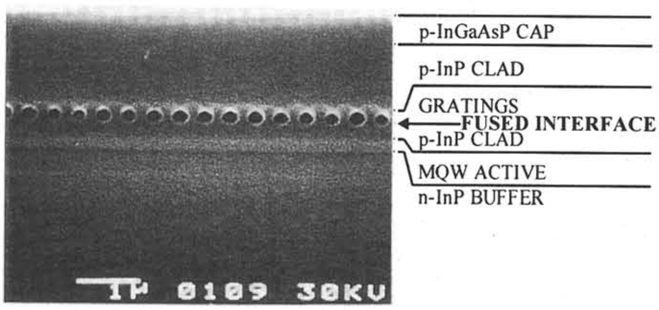

Fig.4 SEM cross sectional view of the DFB laser with air/semiconductor gratings embedded by wafer fusion technique.

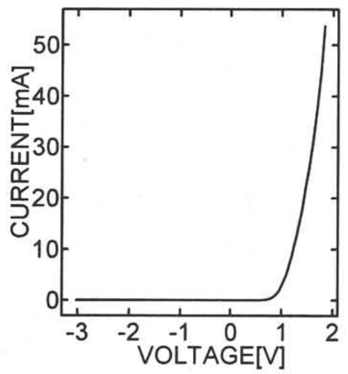

Fig.5 I-V characteristics of DFB laser with air/semiconductor gratings embedded by wafer fusion technique.

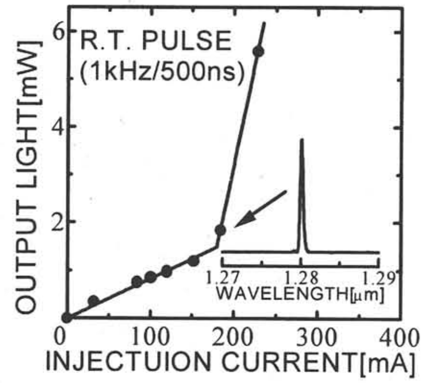

Fig.6 Lasing characteristics of the DFB laser under pulsed operation. The cavity length is 242μm.