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Formation of Buried Isolation Layer by Implanting Focused B Ion Beam in GaAs Multilayer Using FIBI-MBE System

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Buried interlayer isolation has been successfully obtained by focused B ion beam implantation in a GaAs multilayer using the FIBI-MBE system. B ion implantation with a dose of more than $1x10^{14}$ions/cm^2 was found to be sufficient for maintaining the interlayer isolation. We confirmed that in spite of the high dose B implantation ($1x10^{14}$ions/cm^2), electrically and optically recovered epitaxial layers can be regrown on the B- implanted region.

1. Introduction

Maskless ion implantation has been studied as one of the most attractive applications of focused ion beam technology[1-3]. To utilize the advantages of this technology (submicron-size impurity doping, process simplicity and process cleanliness) we have constructed a novel crystal growth system (FIBI-MBE)[4] for fabricating optoelectronic integrated circuits (OEIC's) that consists of a 100kV focused ion beam implanter (FIBI) having a Au-Si-Be or Pd-Ni-Si-Be-B liquid metal (LM) ion source[5,6], a molecular beam epitaxy (MBE) chamber, and an UHV sample transfer tube. The Au-Si-Be and Pd-Ni-Si-Be-B LM ion sources provide us very stable ion beams with a long lifetime (100 to 700 hours). This system has actually enabled us to fabricate pattern-doped GaAs/AlGaAs multilayer structures by repeating the MBE crystal growth and the maskless Si, Be or B ion beam implantation without ever exposing the wafer to the atmosphere. We have successfully operated a new DH laser which contains the selectively Si-implanted cladding layer fabricated with this system [7].

To make fully planar devices possible, semi-insulating isolation of active regions by ion implantation is much more promising than conventional mesa-etching technology. Recently, there have been some reports on formation of isolation in GaAs by implanting focused Ga ion beams[8,9]. We have previously reported on submicron lateral-isolation in GaAs by implanting a focused B ion beam emitted from the Pd-Ni-Si-Be-B LM ion source[6]. The isolation achieved by B ion implantation has been found to be sufficient and thermally stable (800 °C). If vertical interlayer isolation is available in addition to the lateral isolation, this technique provides us with the capability of three dimensional structure device isolation.

In the present work, we have studied electrical properties of interlayer isolation formed in a B-implanted n-GaAs layer sandwiched by n-GaAs epitaxial layers and quality of the GaAs layer on the B-implanted isolation layer by Hall measurements and RT photoluminescence (PL) intensity measurements.

2. Experimental

The samples were fabricated with the FIBI-MBE system, being transferred back and forth between the MBE chamber and the FIB implanter through an UHV sample transfer tube.

Figure 1 shows the mass spectrum of the Pd-Ni-Si-Be-B LM ion source, using an ExB mass filter of the FIBI. Sufficient Be (p-type), B (isolation) and Si (n-type) ion species are obtained with the same amount of ion current. These ion beams for p- and n-type doping and for isolation are freely chosen by computer control

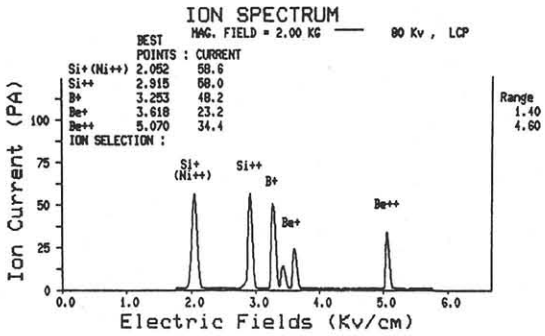

Fig. 1 Mass spectrum of Pd-Ni-Si-Be-B LM ion source measured by computer-controlled ExB mass filter of FIBI.

and implanted interchangeably in succession.

In this study, MBE epitaxial layers were grown on n^+GaAs (100) substrates at 600 °C. The As_4/Ga flux ratio was kept at ~5, and the growth rate at 1μm/h. A Si-doped n-type GaAs epitaxial layer ($1\text{-}2\times10^{17}/cm^3$) grown on the n^+GaAs substrate was implanted by raster-scanning a 80keV focused B ion beam of 0.2μm diameter with dose of 1×10^{13} to 1×10^{15}ions/cm^2 in 500μm squares. Implantations were carried out in a vacuum of 3×10^{-10}Torr and at room temperature. The incident angle for this ion beam was 7° off from the <100> axis. Prior to the regrowth on the B implanted surface, the samples were heat-treated at 630°C for 20 min to anneal implanted damages and thermally clean the crystal surface. An n-type GaAs epitaxial layer (3×10^{16} - $2\times10^{17}/cm^3$) was then regrown on the implanted layer. To measure the vertical electrical resistance of the B-implanted semi-insulating layer, part of the samples were mesa-etched in 80μm circles, and a Au/Au-Ge-Ni ohmic contacts were formed at both sides as shown in Fig. 2. The other samples were used to characterize the electrical and optical quality of regrown epitaxial layers by Hall measurements and PL intensity measurements. When a heat-treatment was needed, the samples were annealed at 800 °C in the forming gas environment for 20min with a 2000Å-SiO_2 encapsulant before forming the electrodes.

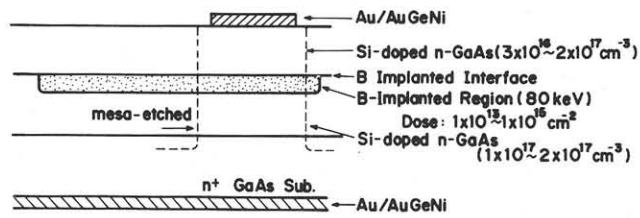

Fig. 2 Schematic structure of device for resistivity measurement.

3. Results and Discussion

Figure 3 shows the voltage-current characteristics of the B-implanted GaAs layer sandwiched by n-GaAs. Carrier concentration of the lower B-implanted layer is $1\times10^{17}/cm^3$ and that of the regrown upper layer is $3\times10^{16}/cm^3$. The results were obtained from as grown samples. We confirmed that interlayers were isolated completely by B implantation. We also observed that isolation properties have been maintained through a high temperature heat-treatment (800°C). More than 1×10^{14}ions/cm^2 dose is required for these interlayer isolation, because the isolation properties with 1×10^{13}ions/cm^2 dose B implantation disappeared with a 600 °C heat-treatment for the second MBE regrowth. Some carrier compensation mechanisms[10,11], such as Ga_{As} or B_{As} antisite defects created by B implantation and subsequent annealing which then act as compensating deep accepters, are responsible for the isolation region

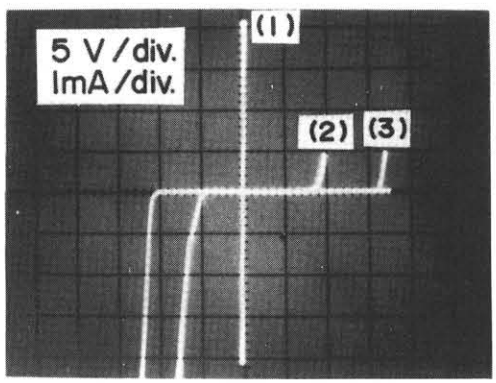

Fig. 3 Voltage-current characteristics of 80keV B-implanted samples with dose of (1) 1×10^{13} (2) 1×10^{14} (3) 1×10^{15} ions/cm^2.

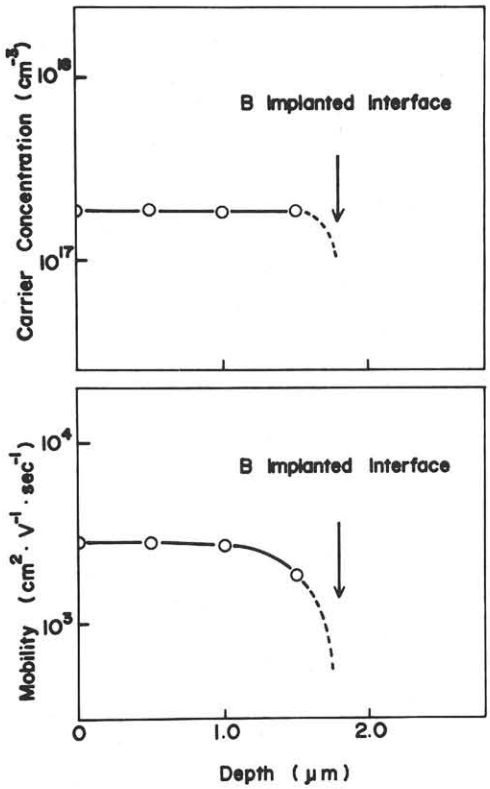

Fig. 4 Carrier concentration and electron mobility depth profiles of regrown epitaxial layer on B-implanted region.

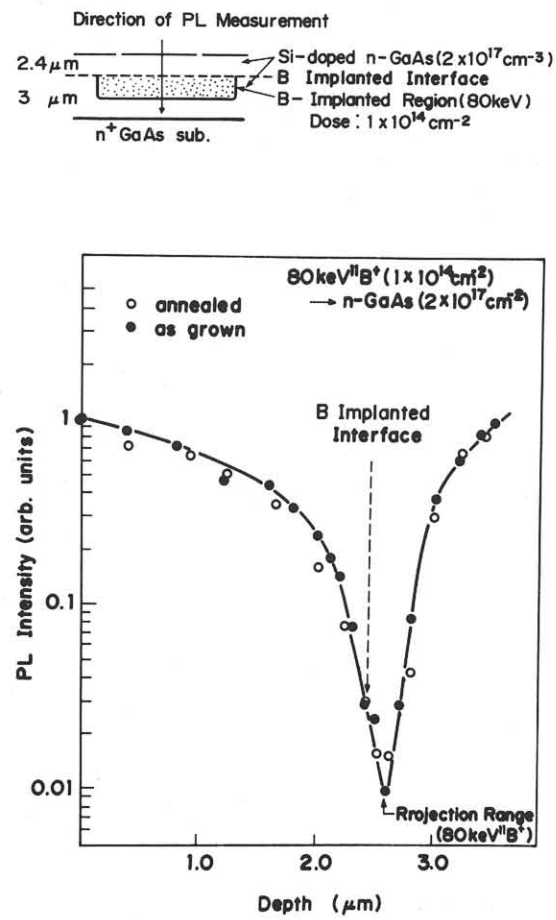

Fig. 5 PL intensity depth profiles of GaAs multilayer with B-implanted buried isolation region.

formation. The resistance is found to be $10^8\Omega$ and the breakdown voltage 7V to 15V. Forward characteristics are obtained when the upper layer is positively biased. The breakdown voltage is slightly higher than the reverse bias. These results seem to indicate that B-implanted regions which are sandwiched between n-GaAs layers of different carrier concentration are highly resistive p-type. This tendency agrees with the results of other reports that Ga-implanted regions also become highly resistive p-type[8,9].

We have investigated the electrical quality of the regrown GaAs epitaxial layer on B-implanted regions. Carrier concentration and electron mobility depth profiles were determined by Hall measurements in conjunction with sectioning the samples by repeated etching. Since forming semi-insulating highly resistive regions by B implantation requires more than a $1x10^{14}$ions/cm^2 dose, we were concerned that implantation damage would influence the quality of the regrown epitaxial layer on the B-implanted GaAs layer.

Figure 4 shows the carrier concentration and mobility depth profiles. The doping level of both layers sandwiching the B-implanted region is $2x10^{17}/cm^3$. We found that the degraded carrier concentration and mobility near the B-implanted interface in the regrown layer recovered with 0.3μm regrowth. These results indicate that the regrown epitaxial layer on the B-implanted semi-insulated region can be used satisfactorily as active regions with a 0.3μm buffer layer. This buried isolation layer, used with the previously reported submicron lateral-isolation technique, provides us with the capability to isolate devices.

When applying this isolation technique to optoelectronic integrated circuit (OEIC) fabricating technology, the optical quality of the regrown epitaxial layer and of the implantation region is also important.

Therefore, we also measured PL intensity depth profiles of a GaAs multilayer with a B-implanted burried isolation region at room temperature in conjunction with sectioning the samples by repeated etching. The excitation source was a 514.5nm line of an Ar ion laser. The results are shown in Fig. 5. The vertical axis represents the relative PL intensity normalized with that from the GaAs layer normally grown without B implantation. Solid circles represent values of the as-grown samples. Open circles represent the samples which are annealed at 800°C for 20min after the crystal growth process was finished. One report discusses selective polycrystalline growth on an ion implantation damaged layer[13]. The critical dose required for polycrystalline GaAs is about $5x10^{14}$ions/cm^2 for O^+ ion implantation. Therefore, the MBE regrowth on the B-implanted semi-insulated region was very severe. From the figure, it is clear that in spite of the high dose ($2x10^{14}$ions/cm^2) B implantation, the optical quality of the epitaxial layer regrown on the implanted region with irradiation induced damages recovered and was equal to that of an epitaxial layer normally grown with the 1.5μm regrowth. The bottom of the PL profiles agrees with the depth which represents the projection range of 80keV B ion in GaAs.

4. Conclusion

Buried interlayer isolation has been successfully obtained by focused B ion beam implantation in GaAs mutilayers, using the FIBI-MBE system. Implantation with a dose of more than $1x10^{14}$ions/cm^2 was found to be sufficient for maintaining the electrical property of interlayer isolation. We have investigated the quality of the epitaxial regrown layer on the B-implanted, semi-insulating region. In spite of the high dose B implantation ($1x10^{14}$ions/cm^2), electrically and optically recovered epitaxial layers can be regrown on the B-implanted region. Since active devices can be fabricated in this region over the isolation layer, using the previously reported submicron lateral-isolation technique and this buried isolation provides us with the capability of isolating devices.

Furthermore, this suggests that we can fabricate three-dimensional devices by forming the semi-insulating regions as well as p- and n-type doped regions in the GaAs/AlGaAs multilayer by the computer-controlled FIBI-MBE system with a Pd-Ni-Si-Be-B LM ion source.

5. Acknowledgments

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