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Influence of atomic species of fast atom bombardment for surface activated bonding interface of germanium

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Abstract

In this research, Ge/Ge was bonded at room temperature by surface activated bonding (SAB) method using fast atom beam (FAB) in high vacuum condition. The bonded interface was observed by transmission electron microscopy (TEM), and it was compared by beam source of FAB was compared with the species; Ne, Ar, Kr, and Xe. As result, the interface consisted of defect layer and its thickness depended on the irradiated atoms' species.

1. Introduction

Surface activated bonding (SAB) is one of the wafer bonding technique at room temperature for the direct hetero junctions. Compared with other direct wafer bonding techniques, such as anodic bonding, hydrophilic bonding, and so on, SAB has the significance of bonding at room temperature to avoid the CTE mismatch of the hetero junctions. Typical SAB method for the semiconductor materials is as follows: Native oxide or contamination on the surface of the materials is removed by Ar fast atom beam (Ar-FAB) in high vacuum, then activated surfaces are contacted and bonded at room temperature.

Meanwhile, it has been reported that several nanometers thick damaged intermediate layer was formed by Ar-FAB irradiation[1]. This defect-rich layer was pointed out to be negative effect on the electrical characteristics at bonded interface[2], and it can be reduced by thermal process[3], but it is recommended to be optimized at room temperature, Therefore, in this study, the FAB process has been optimized for the damage control of intermediate layer of SAB.

2. Experimental Procedure

At first, we prepared Ge chips for □10 mm^2 and □6 mm^2 diced from Ga-doped (100) n-Ge with a carrier concentration of $1.6{\sim}3.0\times10^{-18}$ /cm^3 wafers. Diced chips were cleaned by acetone and ethanol and pure water with ultrasonic before installing to the apparatus. Then Ge chips were installed to the SAB apparatus. In the SAB apparatus, Ge chips were irradiated by FAB in vacuum around 10^{-6} Pa, then chips were bonded with an applied load of 10 MPa for 5 min at room temperature. The FAB process varied as in Table 1. The power of the FAB irradiation is defined by the applied voltage and the beam current, and the beam current is inversely proportional to the gas flow. Therefore, the energy of each noble gases was standardized by the beam current for controlling the gas flow rate and gas pressure. Incident angle of FAB irradiation was about 45°. Etching rate of Ge chip was 2.0 nm/min the Ne-FAB, 2.0 nm/min for Ar-FAB, 3.3 nm/min for Kr-FAB and 3.0 nm/min for Xe-FAB.

To investigate the interface structure of the bonded specimen, high-resolution transmission electron microscopy (HRTEM) was performed using JEOL JEM-2010F (200 kV). TEM specimens were prepared by cutting bonded specimens and microfabrication using JEOL EM-09100IS.

Table 1 Bonding parameters for surface activated bonding.

Background vacuum	$\sim 10^{-6}$ Pa
FAB atomic species	Ne, Ar, Kr, Xe
Radiation time for fast atom beam	3 min
Power for FAB	1.4 kV, 15 mA
FAB incident angle	45°
Bonding Load	10 MPa

3. Experimental Results

The HRTEM images of the Ge/Ge by SAB process with each FAB gases show in Figs.1(a)–(d). The interface layers have been observed in each TEM images, and these layers consist of defects of Ge surfaces damaged by irradiation of FAB. The interface thickness of Ne-FAB was c.a. 7.9 nm, that of Ar-FAB was c.a. 5.7 nm, that of Kr-FAB was c.a. 4.7 nm, and taht of the Xe-FAB was c.a. 4.4 nm, with uniformity of contrast. The large atom species' FAB (Kr-FAB and Xe-FAB) formed thiner interface layer than the small atom species' FAB (Ne-FAB and Ar-FAB).

EDS analysis of each interface layer has been performed and shown in Figs.2(a)–(d). These intermediate layers contain C, O, Si, and Fe as contaminant. C and O seem the contaminants during the TEM sampling, while Si and Fe seem the contaminant from the SAB apparatus chamber during FAB process. Ge chips were set on the Si-jig in order to prevent the Fe contaminant, but the Si contaminant was remarkable for Ne-FAB and Ar-FAB irradiation. Meanwhile, the Fe from the chamber material (SUS) was detected only Kr-FAB and Xe-FAB. It is considered that the sputtered contaminant has been selectively by the size of atomic species of FAB.

According to TEM and EDS results, damage and the contaminant by FAB irradiation can be controlled by the FAB species.

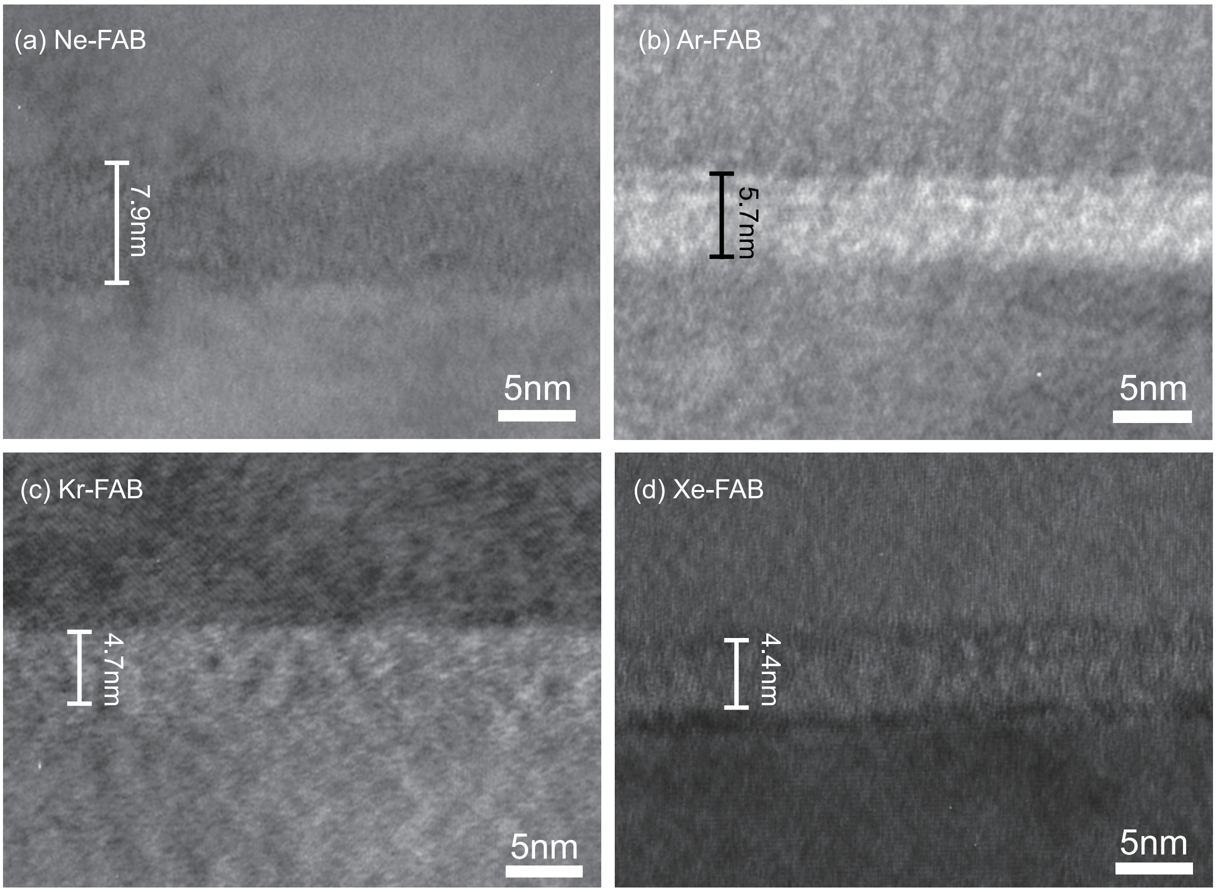

Figure 1 TEM images of Ge/Ge SAB interface activated by (a) Ne-FAB, (b) Ar-FAB, (c) Kr-FAB, and (d) Xe-FAB.

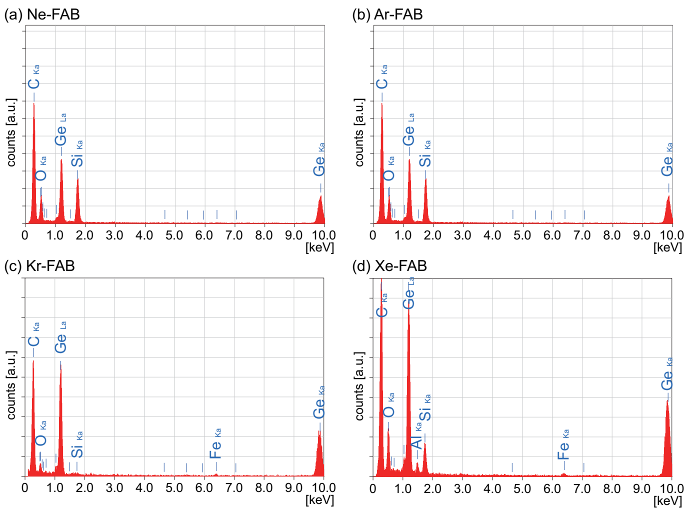

Figure 2 EDS analysis of Ge/Ge SAB interface activated by (a) Ne-FAB, (b) Ar-FAB, (c) Kr-FAB, and (d) Xe-FAB.

4. Conclusion

Bonded interface of Ge/Ge which was bonded by SAB using Ne-FAB, Ar-FAB, Kr-FAB, Xe-FAB was observed by TEM. The bonded interfaces consist of the damaged layer by the FAB irradiation, and the thickest interface layer was observed with Ne-FAB, and the thickness of the interface layer was placed in the order of atom size of FAB species. Therefore, to optimize the interface damage of SAB, the source of FAB should be chosen.

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