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Wafer Direct Bonding at Room Temperature by Means of the Surface Activated Bonding

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Si and Si as well as III-V compound semiconductor wafers and Si wafer were successfully bonded directly at room temperature by means of the surface activated bonding method. In the procedure of the method, the surfaces to be bonded are sputter-cleaned and activated by Ar fast atom beam irradiation in ultra-high vacuum, and brought into contact under slight pressure. Intermediate layers of the thickness less than 5 nm were found in the bonded interfaces of Si-Si and Si-GaAs by high resolution TEM investigations. The intermediate layers consist mainly of silicon.

1. INTRODUCTION

To fabricate III-VI optical devices on Si would facilitate new types of integrated devices, such as photonic integrated circuits and optoelectronic integrated circuits. The key technology to fabricate it has so far been heteroepitaxial growth. However, this technology to integrate different materials suffers from several significant disadvantage, such as a large lattice mismatch, which causes a high density of threading dislocation, and a large difference in thermal expansion coefficients, which leads to large residual thermal stress. Recently direct bonding techniques have reviewed a lot of attention, because highly lattice-mismatched heterostructures could be fabricated without any threading dislocation[1-3]. However their high process temperatures, usually higher than 400℃, may cause still serious problems in realizing a heterosturacure such as doping of impurity, thermal stress introduction, defect generation and metal wiring corruption. The purpose of the present paper is to report the first successful attempt of the room temperature bonding of the heterosemiconductors.

2. EXPERIMENTAL

A new method to bond silicon wafers as well as different kinds of simiconductor wafers directly at room temperature has been developed. In the bonding procedure, the surfaces of the wafers to be bonded are sputter-cleaned and activated by Ar fast atom beam bombardment, and brought into contact in an ultra-high vacuum. Strong and tight bonding can be achieved immediately after contact at room temperature. The method which has been developed by the authors for bonding metals and ceramics originally, and referred as the surface activated bonding (SAB) method[4-7], is now applied to wafer direct bonding at room temperature.

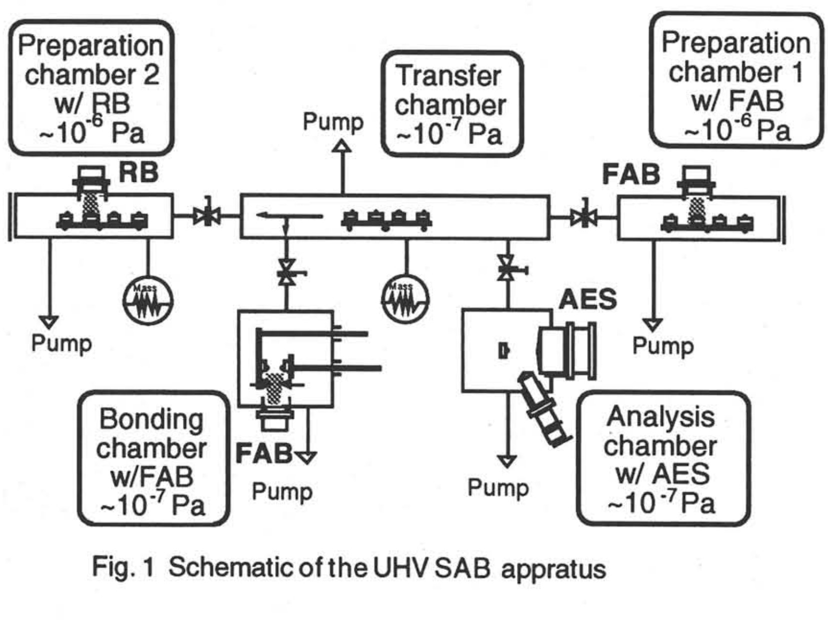


Fig. 1 Schematic of the UHV SAB appratus

Fig. 1 shows the bonding apparatus in which the SAB procedure is carried out. It consists of five UHV chambers: the preparation chambers in which the surfaces of the wafers are sputter-cleaned by means of Ar fast atom beam or irradiated by H radical, the transfer chamber, the AES chamber and the bonding chamber in which an Ar fast atom beam source is installed for removing contaminations from the surfaces before bonding operations.

Si (100), GaAs (100) and InP (100) as well as the thermal oxidized Si wafer are used for the bonding experiments. The wafers to be bonded are cut off into a plate form in a groove which is prepared by photo lithography and etching as shown in Fig. 2, intend to avoid any distortion of the wafer edge due to the cutting process. A pair of wafers are set in the preparation chamber of the background vacuum of 10^{-6}Pa and subjected to Ar FAB irradiation of applied voltage 1.5kV for 300 to 900 sec for removing the native oxides from the surfaces. The specimens are then transferred to the bonding chamber and brought into contact under a pressure between 0.1MPa and 20MPa in a vacuum 10^{-7}Pa.

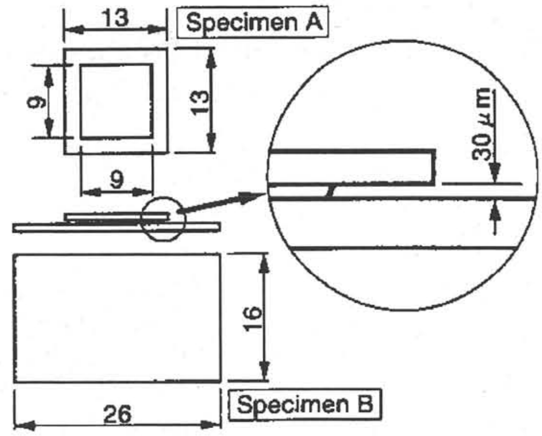


Fig. 2 Specimens used for the SAB experiments. Specimen A was patterned by etching to avoid any effect of distortion at cutting edge.

3. RESULTS AND DISCUSSION

The investigated combinations, Si-Si, Si-GaAs, Si-InP, GaAs-InP as well as SiO_2-SiO_2 , are bonded successfully at room temperature. No bonding was observed for the specimens which were not subjected to the surface activation process. Especially Si-Si bonding was very strong and could not be failed at the bonded interface, while interfacial failures was observed for the other combinations and their tensile strength takes values between 5MPa and 10MPa. Fig. 3 shows ultrasonic micrographs of bonded specimens of Si-GaAs. No apparent void is observed for the specimen which was bonded under a slight pressure (upper photo), while only the center is bonded for the specimen which was deformed due to too high pressure of about 20MPa (lower photo).

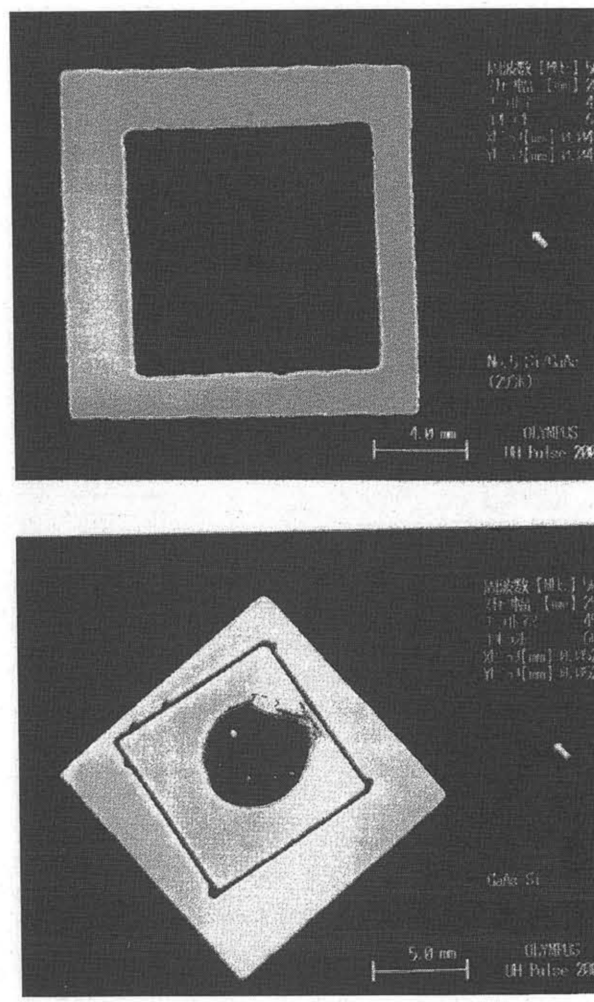


Fig. 3 Ultrasonic micrograph of Si-GaAs wafer bonding fabricated by SAB method at room temperature. Contact pressure Upper: 5MPa, Lower: 20MPa

The bonding conditions and the primary results of the experiments are compiled in Table 1. Although the bonding conditions are not optimized, all combinations investigated seem to have enough bond strength compared to the interfaces produced by the conventional methods. Especially Si and Si wafers could be bonded almost without pressure or less than 0.01MPa at room temperature, revealing no interfacial failure on tensile tests.

The microstructure of the bonded interfaces is currently under investigation by high resolution TEM. An intermediate layer is observed at the bonded interfaces, which might have been formed on the sputtered surfaces during the Ar irradiation process. A similar structure has been observed by the authors for the bonded interface between Si and Al.

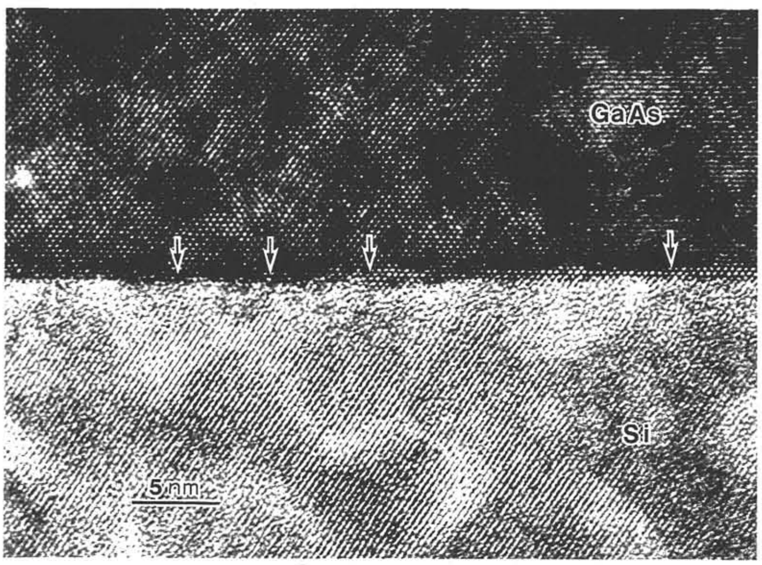
The thickness of the intermediate layer ia about 2 - 3 nm. Fig.4 shows a high resolution TEM image of the Si-GaAs bonded interface. In a certain area of the interface. According to the EDS analysis of the intermediate layer, it was found that it is composed mainly by silicon.

Although there remain many issues concerning with the mechanism of the bonding and characterization of the interfaces, the present method might be expected to provide new possibility of the wafer direct bonding technique for fabrication and integration of optoelectro devices due to its low process temperature, or eventually room temperature.

Table 1. Bonding conditions and results of the experiments

	Si - GaAs	Si - InP	GaAs - InP	SiO_2 - SiO_2	Si - Si
Vacuum in background	10^{-6} Pa				
Condition of surface activation	Acceleration voltage and current : 1.5kV,15mA Sputtering rate 0.9nm/min for Si Vacuum during Ar-FAB bombardment $1.6 \sim 1.8 \times 10^{-3}$ Pa				
Time for Ar-FAB	Si-300 sec GaAs-600sec	Si-300 sec InP-300sec	GaAs-900sec InP-900sec	SiO_2-300sec SiO_2-300sec	Si-300sec
Exposure before bonding	30 Pa·sec				
Bonding pressure	20 MPa				
Bonding time	600 sec				
Vacuum during bonding	10^{-7} Pa				
Bonding strength	~8 MPa(RT) ~10MPa(200℃)	-	-	<5 MPa(RT) <5 MPa(200℃)	10~16MPa (RT)

Fig. 4 High resolution TEM image of a Si-GaAs wafer bonded by the SAB method at room temperature.



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