Atomic Diffusion Bonding Using AlN and Al_2O_3 Films

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Abstract

We demonstrated atomic diffusion bonding (ADB) of wafers at room temperature using AlN and Al_2O_3 films. High surface free energy at the bonded interface was obtained even for as-bonded wafers using these films having negligibly small electrical conductivity. These properties of bonded wafers using nitride and oxide films are useful for new devices of compound semiconductors.

INTRODUCTION

Atomic diffusion bonding (ADB) of two flat wafers with thin metal films is a promising process to achieve room temperature wafer bonding [1]. In typical ADB process, thin metal films are formed on wafer surfaces using sputter deposition, followed by bonding of the two films on the wafers in vacuum. Any mirror polished different wafers can be bonded at room temperature, which is very effective for bonding wafers with different coefficients of thermal expansion such as compound semiconductors. Another advantage of ADB process is to achieve conductive bonding using thin metal films. However, in some devices, the electrical conductivity of bonded interface is undesirable. In order to improve this electrical conductivity, recently we demonstrated ADB of wafers at room temperature using nitride and oxide films [2, 3]. This paper presents the bonding performance and current status of ADB using AlN and Al_2O_3 films, respectively.

EXPERIMENTAL PROCEDURE

1) ADB using AlN films: AlN films were deposited on two flat wafers using reactive sputtering of Al target. Then, the two flat wafers were brought into contact with each other and bonded in the same vacuum. No heating and no high loading force were applied during bonding. Bonding performance using AlN films, described herein, was obtained using ADB bonding equipment for mass production ("BC7000", Canon ANELVA Corp.).

2) ADB using Al_2O_3 films: Al_2O_3 films were deposited on two flat wafers using sputtering of Al_2O_3 target. The subsequent bonding processes was identical to that for AlN. In some of studies, the bonded wafers were annealed in air using hot plate.

RESULTS

1) ADB using AlN films

AlN films are representative nitride material films used for ADB to show a large bonding strength. Figure 1 portrays values of the surface free energy at bonded interface γ for Si wafers bonded using AlN film as a function of AlN film thickness on each side. We fixed the N_2/Ar pressure ratio at 55%. The γ values are evaluated for as-bonded wafers using blade method. Large γ values greater than 2 J/m^2 were obtained in the thickness range from 0.5 nm to 3 nm.

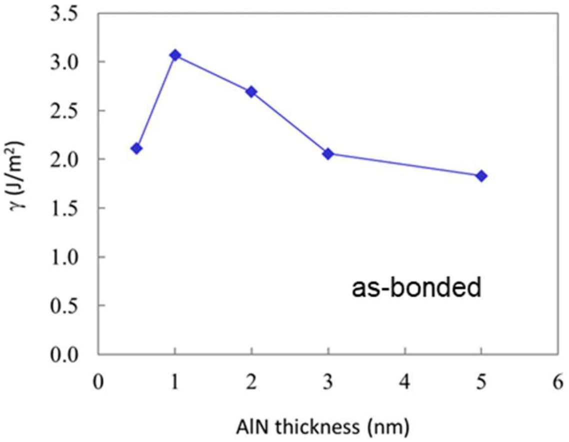
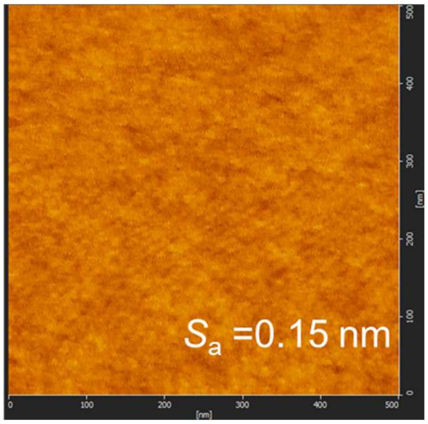
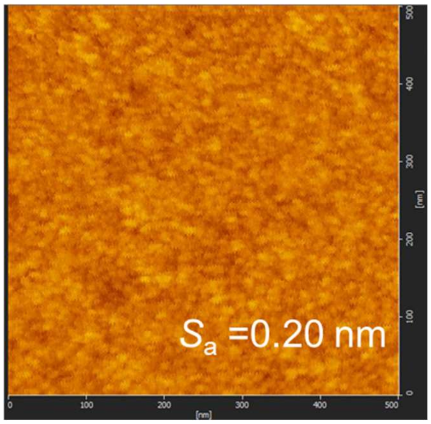


Fig. 1. Values of γ for Si wafers bonded using AlN films as a function of film thickness.

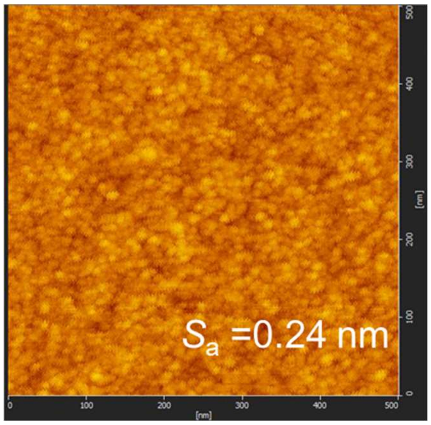
Figure 2 (A) presents a surface image observed using atomic force microscopy (AFM) for 1-nm-thick AlN film deposited on a Si wafer. Figure 2 (B) and (C) present AFM images for 5-nm-thick and 30-nm-thick films. Surface roughness S_a increased from 0.15 nm to 0.24 nm as film thickness increased from 1 nm to 30 nm. The γ value in Figure 1 decreased gradually as film thickness increased from 1 nm to 5 nm, which was caused by the increase of S_a.



(A) 1 nm thick AlN film



(B) 5 nm thick AlN film



(C) 30 nm thick AlN film

Fig. 2. AFM images of AlN films with film thicknesses of (A) 1 nm, (B) 5 nm, and (C) 30 nm.

Figure 3 portrays the values of γ and the resistivity ρ of AlN films as a function of the N_2/Ar pressure ratio in deposition. The γ values were obtained for bonded Si wafers using 1-nm-thick AlN film on each side. The ρ values were measured by the mercury probe method for 30- nm-thick AlN film deposited on Si wafers. Values of γ and ρ were high in the wide range of N_2/Ar pressure ratio from 55% to 80%. Particularly a great ρ value of 2.6×10^{12} $\Omega\cdot$cm was achieved at N_2/Ar pressure ratio of 55% while maintaining a large γ value of 3.1 J/m^2.

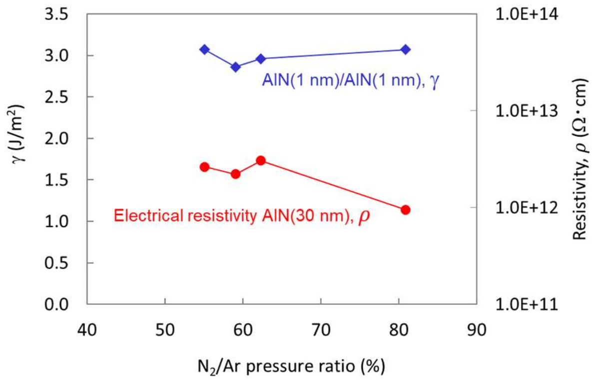


Fig. 3. Values of γ and ρ as a function of N_2/Ar pressure ratio in sputter deposition.

Figure 4 presents a cross-section image of Si wafers bonded using AlN (1 nm) film on each side observed by transmission electron microscopy (TEM). The image is for as-bonded wafers, with no post-bonded annealing. No vacancy was observed at the bonded interface although the original interface was partially observed.

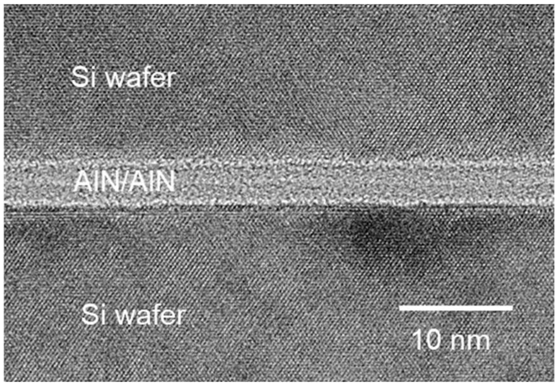


Fig. 4. TEM cross-section image of Si wafers bonded using AlN (1 nm) film on each side (as-bonded).

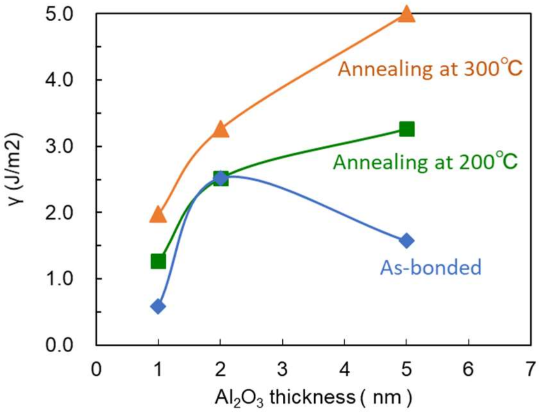
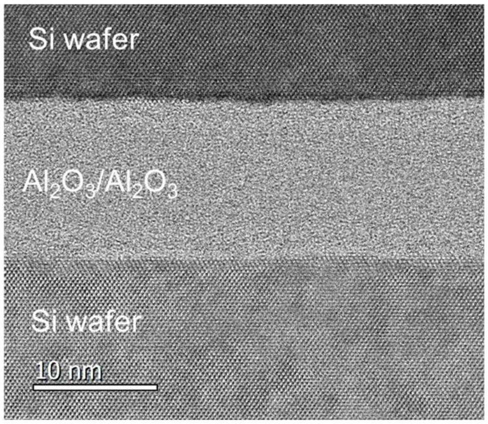
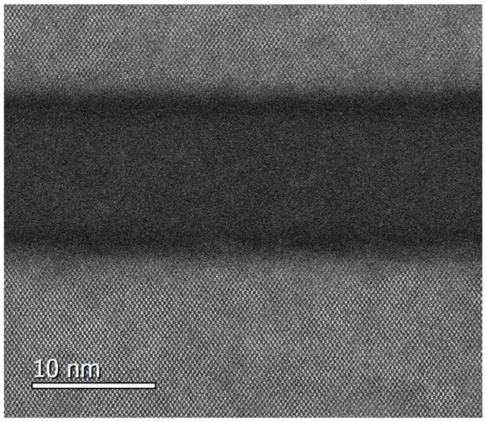


Fig. 5. Values of γ for quartz glass wafers bonded using Al_2O_3 films as a function of film thickness on each side.



(A) BF-STEM image



(B) HAADF-STEM image

Fig. 6. (A) BF-STEM cross-section image of Si wafers bonded using Al_2O_3 (5nm) film on each side (as-bonded), and (B) HAADF image corresponding to (A).

2) ADB using Al_2O_3 films

Al_2O_3 films are representative oxide material films used for ADB with high bonding strength. Figure 5 portrays values of γ for quartz glass wafers bonded using Al_2O_3 films as a function of Al_2O_3 film thickness on each side. A great γ value of 2.5 J/m^2 was achieved for as-bonded wafer at 2 nm thickness. Post-bonded annealing enhanced γ values further. After the annealing at 300 ºC, γ values were 3.2 J/m^2 using 2-nm-thick films and 5 J/m^2 using 5-nm-thick films.

Figure 6 (A) presents a cross-section image of Si wafers bonded using Al_2O_3 (5 nm) film on each side observed by scanning transmission electron microscope (STEM), and (B) a corresponding high angle annular dark field (HAADF) image. These images are for as-bonded wafers, with no post-bonded annealing. No interface corresponding to the original film surface was observed, indicating high performance of bonding.

CONCLUSIONS

We demonstrated ADB of wafers at room temperature using AlN and Al_2O_3 films. ADB using AlN films was performed by using the bonding equipment for mass production (“BC7000”, Canon ANELVA Corp.). Results indicated high bonding performance with great electrical resistivities of AlN films. Since AlN films show high thermal conductivity with no electrical conductivity and a low thermal expansion coefficient, ADB using AlN films is effective for enhancing heat dissipation efficiency for devices fabricated on wafers while maintaining electrical insulation.

Results of ADB using Al_2O_3 showed that bonded interface disappeared perfectly at room temperature, indicating high bonding potential. Al_2O_3 has a large bandgap property, and bonded interface consisting of Al_2O_3 should be useful for high optical density applications.

We expect that ADB using nitride and oxide films opens a new way to fabricate new devices of compound semiconductors.

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ACRONYMS

ADB: Atomic Diffusion Bonding
AFM: Atomic Force Microscopy
TEM: Transmission Electron Microscope
STEM: Scanning Transmission Electron Microscope
HAADF: High Angle Annular Dark Field