

Room temperature Bonding using Thin Metal Films: Technical Potential and Current Status

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Abstract

This report reviews the technical potential and current status of room temperature bonding using thin metal films (atomic diffusion bonding). This technique, which enables bonding of any mirror-polished wafer, is gaining wider use for fabricating optical and electrical devices. Moreover, bonding of mirror polished metals and polymer sheets can be achieved, which further extends the application of this bonding technique.

1. Introduction

Atomic diffusion bonding of two flat wafers with thin metal films is a promising process to achieve wafer bonding at room temperature [1–3] along with surface-activated bonding [4–6]. Thin nanocrystalline metal films are deposited on two flat surfaces, thereby bonding the two metal films on the wafers. Any mirror-polished wafer can be bonded using thin metal films. High surface energies of metal films and a large atomic diffusion coefficient at the grain boundaries and film surfaces enable bonding at room temperature without unusually high loading pressure.

We have two processes for atomic diffusion bonding. One is bonding in vacuum: after metal films are fabricated on two flat wafer surfaces using sputter deposition, the two films are bonded on the wafers in vacuum (Fig. 1(A)). Another bonding process is bonding in air. Bonding of the two films on the wafers can be done in air after sputter film deposition in vacuum [2] (Fig. 1(B)). As described herein, we review the technical potential and current status of atomic diffusion bonding in vacuum and in air.

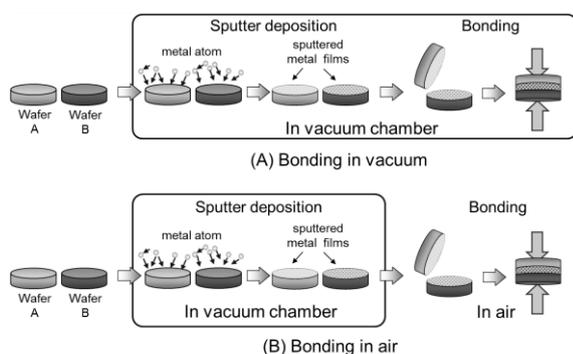


Fig. 1. Atomic diffusion bonding processes: (A) bonding in vacuum and (B) bonding in air.

2. Bonding in Vacuum

An important benefit of bonding in vacuum is that wafers can be bonded using almost any metal film. Figure 2 portrays TEM cross-section images of bonded Al–Al and W–W films on Si wafers. The film thickness on each side is about 20 nm. The Ta (5 nm) underlayers are used for Al–Al films. The Al–Al bonded films show no interface corresponding to the original film surfaces, as is true also for other material films having large self-diffusion coefficients D with a closest-packed crystal structure such as Ti, Ag, Au, and Cu [1,2]. Dynamic recrystallization occurs at the bonded interface at room temperature. A much clearer interface corresponding to the original film surfaces was observed for W–W bonded films, but no vacancy was observed. The value of D of W is the smallest value among normally used metals, implying that bonding using films in UHV vacuum can be performed using almost any metal film, including one composed of alloys.

Another important benefit of bonding in vacuum is that wafers can be bonded even with film thickness of a few angstroms on each side [2,3]. Figure 3 shows TEM cross section images of synthetic quartz crystal wafers bonded using Ti(0.4 nm)–Ti(0.4 nm) films. No vacancies were observed at the bonded interface. The Ti–Ti film was nearly twice as thick as the original thickness because of the formation of the reactive layer of Ti with the wafer material (SiO_2) [3]. Figure 4 portrays images of two synthetic quartz

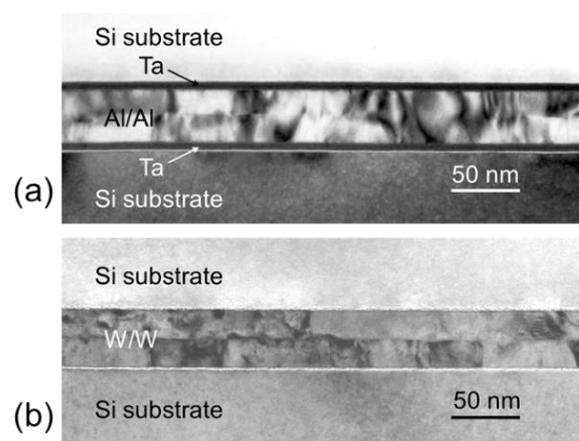


Fig. 2. TEM cross-section images of bonded Al–Al and W–W films on Si wafers.

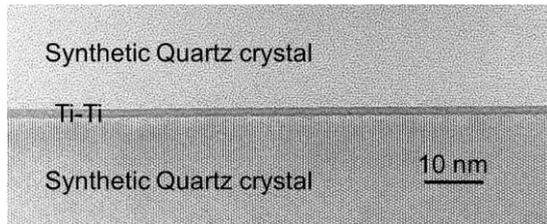


Fig. 3. TEM cross section images of synthetic quartz crystal wafers bonded using Ti(0.4 nm)-Ti(0.4 nm) films.

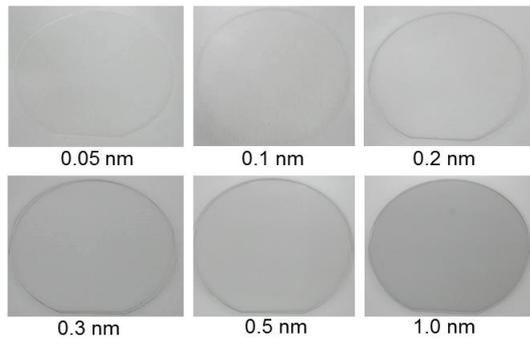


Fig. 4. Images of two synthetic quartz crystal wafers (2 inch, 0.5 mm thickness) bonded using Ti films of various thicknesses on each side from 0.05 nm to 1.0 nm.

crystal wafers (2 inch, 0.5 mm thickness) bonded using Ti films of various thickness on each side from 0.05 nm to 1.0 nm. Wafers were bonded over the entire area. Incident light can pass through transparent wafers bonded with film thickness of a few angstroms on each side, without marked reduction in intensity. Moreover, the electrical resistance of the bonded films with film thickness of a few angstroms is high [2]. These properties are useful to produce optical or electrical devices such as optical devices of synthetic quartz crystal wafers [7] and high-output deep ultraviolet light-emitting diodes [8]. They have been used for some fundamental studies of devices [9]. Moreover, bonding in vacuum is used increasingly to mass-produce new thin film devices.

3. Bonding in air

Another bonding process is bonding in air. This process is limited to use with Au and Au alloy films, but it is convenient. For instance, bonding of patterned Au films can be done with sputter film deposition using metal masks. It is actually used for the production of new etalon filters for optical fiber communication [10], as shown in Figure 5.

We also demonstrated bonding of wafers with mirror-polished metals in air [11] (Fig. 6), which is effective for enhancing the heat dissipation efficiency of devices fabricated on the wafers. Bonding of mirror-polished Al with other mirror-polished metals such as Cu and stainless steels was also achieved with bonding strength greater than the creep strength of Al. Moreover, the bonding process has been applied to bonding of polymer sheets with polymer sheets, ceramics wafers, and mirror-polished metals [12].

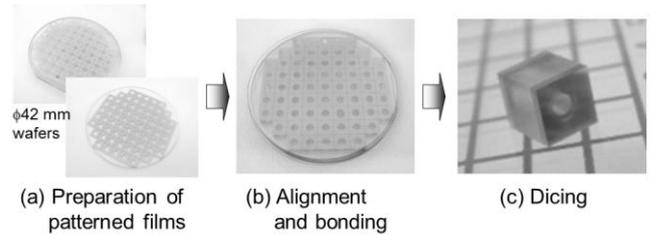


Fig. 5. Fabrication process of air-gap type etalon filters for optical communication.

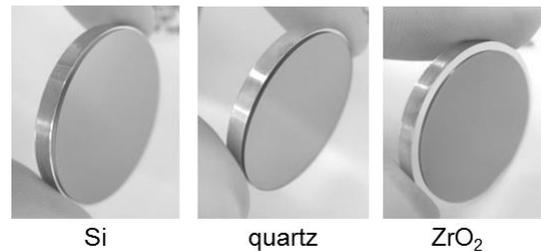


Fig. 6. Si, quartz and ZrO₂ wafers (1 inch-diameter) bonded with Al plate (3 mm thick).

Additional discussion can be made of the bonding energy of wafers related to the surface energy of the metal films used for bonding and the bonded interface microstructure. This process holds great potential for new device fabrication.

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