A Novel Method to Maintain Alignment Accuracy in Bonding Process Utilizing Resin as an Adhesive Material

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ABSTRACT

In this paper, we have firstly reported that a novel method to maintain alignment accuracy in wafer bonding process utilizing resin as an adhesive material. In order to maintain alignment accuracy after aligning of two wafers, we have proposed tentatively localized bonding method with 1100 nm near infrared (NIR) radiation that is transparent to Si wafers. With the aid of NIR radiation spots onto the wafer after aligning, wafers are bonded locally and tentatively. The tentatively localized bonding areas act as anchors, which hold wafers during bonding process. In the experiment of wafer bonding process utilizing resin, we have achieved about 4 to 5 times more accurate alignment in micrometer order between wafers for typical case than without tantatively localized bonding.

Keywords: wafer bonding, tentatively localized bonding, near infrared, wafer level package, MEMS

1 INTRODUCTION

Wafer bonding technique utilizing resin as an adhesive material has many advantages in terms of low temperature processing (maximum temperatures lower than 400°C), surface planarization and tolerance to particles contamination (the intermediate resin layer can incorporate particles with the diameter in the layer thickness range). Moreover, the physical properties of resin bonding layers such as isotropic dielectric constants, good thermal stability, low Young’s modulus and good adhesion to different substrates are also desirable to various application fields. Especially, advantages mentioned above are much valuable Micro-Electro-Mechanical Systems (MEMS) devices fabrication utilizing various wafer bonding processes, since various types of substrates are using in MEMS devices fabrication. Bonding technique utilizing resin is also applicable to wafer-level packaging in MEMS devices, which causes low manufacturing cost [1,2].

On the other hand, due to liquid-like soft state of resin before applying temperature and pressure, it is hard to keep good alignment accuracy between wafers in bonding process. In other words, when pressing the wafers together with the bond chucks during bonding process using commercially available bonding equipment, it is practically inevitable that shear forces occur and the coated resin cannot counteract the shear forces. As the result of shear forces during bonding process, the wafers move relatively each other and alignment dismatching between wafers is produced. For a commercially available bonding equipment, the achievable alignment accuracy deteriorate to 15 μm although its typically attainable alignment accuracy is 2-5 μm [3].

In order to improve alignment precision during bonding process with resin, several methods have been proposed. One of them, a method utilizing structure at the wafer surfaces to provide areas with solid-state material contact between the two wafers during the bonding process is remarkable [3]. It uses metal pattern on a wafer prepared for bonding process. Metal pattern increases the friction forces between wafers, which prevent the wafers from shifting relative to each other during the time the intermediate adhesive resin is in a liquid-like soft state. With the aid of solid-state material contact, they have improved relatively poor alignment accuracy in wafer bonding process with resin. However, in order to prepare metal contact on a wafer, it is needed to additional fabrication process and device area on a wafer is decreased.

In this paper, we propose a novel method in order to prevent the wafers from shifting relative to each other when applying temperature and pressure after alignment. After alignment we apply 1100 nm NIR radiation spots that is transparent to silicon. The NIR radiation spotted areas are locally heated and tentatively bonded, which play a role of anchors. By doing that without additional any fabrication process, we have achieved the maintenance of alignment accuracy even when applying temperature and pressure using commercially available bonding equipment.

2 EXPERIMENT

In wafer bonding process with resin as an adhesive material, in order to prevent the wafers from shifting relative to each other when applying temperature and pressure after alignment between wafers, we apply NIR radiation spots after alignment. The NIR with wavelength around 1100 nm is used, which is transparent to Si wafers. After alignment, we apply NIR radiation on the pre-bonded wafer, which is attached but not really bonded. Typically NIR radiation is spotted three places on the pre-bonded

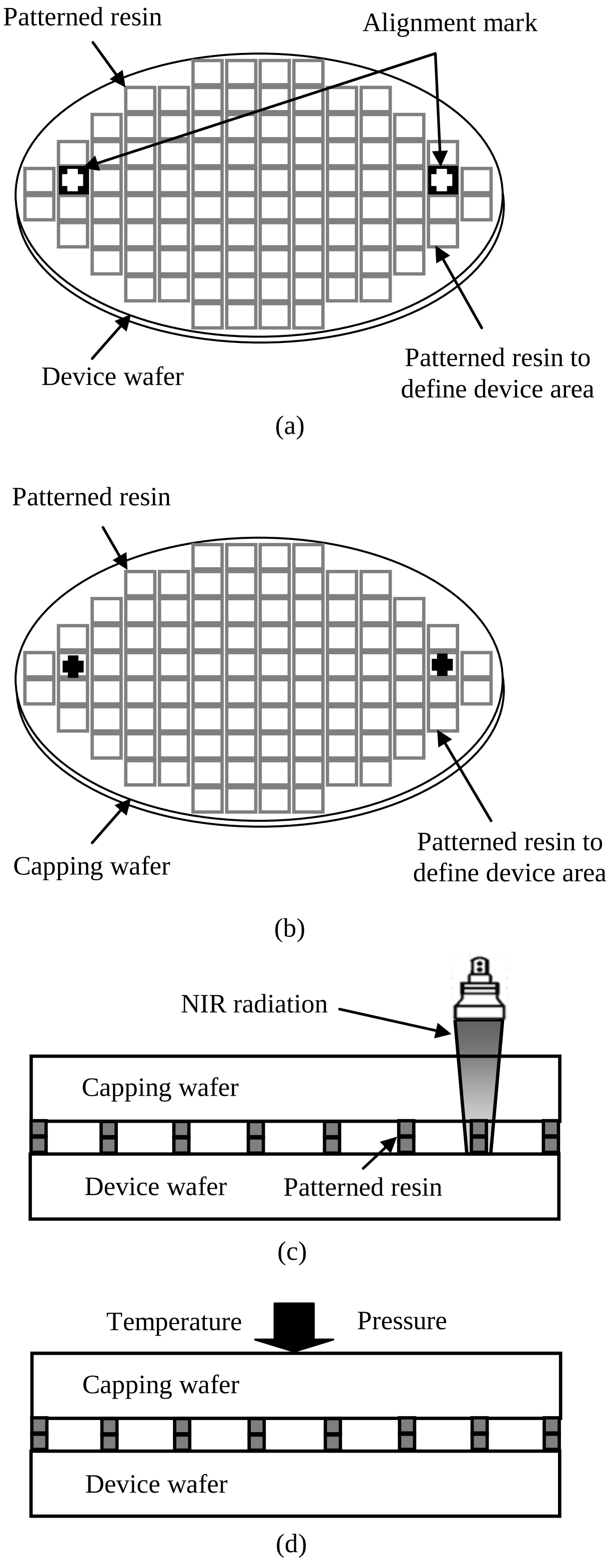

Figure 1: Experimental process; Resin is coated and/or patterned on a device wafer (a) and a capping wafer (b), respectively. NIR radiation is spotted on the aligned wafers (c) to tentatively localized bonding. Temperature and pressure are applied for wafer bonding (d).

wafer surface. The NIR radiation irradiated from NIR halogen heater generates thermal energy in three spotted resin areas, and then there is locally heated and tentatively bonded. These localized tentatively bonded areas play a role of anchors. By doing that without additional any fabrication process, we have achieved the maintenance of alignment accuracy even when applying temperature and pressure in bonding process using commercially available usual bonding equipment.

Detailed experimental process is illustrated in Fig. 1. First, resin for an adhesive material is coated on a device wafer after dehydration bake on a hotplate (Fig. 1 (a)). Resin layer may be patterned to define device area. As a resin, photosensitive polymers such as polyimide and benzocyclobutene (BCB) or thermosetting polymers can be applicable in our experiment if there are adhesive property and hardening property by NIR radiation. Next, resin layer as an adhesive material is also coated on a capping wafer after dehydration bake on a hotplate (Fig. 1 (b)). It also may be patterned to define device area corresponding to device wafer. In this experiment, we irradiated with NIR to patterned resin area directly or resin layer in case of there is no patterning of resin layer. However, dummy patterns at blank space near the wafer boundary can be prepared and used as anchors as well to prevent any damage of patterned resin area defining devices. After alignment between a capping wafer and a MEMS device wafer using conventional bonding equipment, we irradiate with NIR using NIR halogen heater onto three resin areas (Fig. 1 (c)). The spot diameter of NIR raditaion is about 2 mm. Finally, we apply adequate temperature and pressure to bond wafers (Fig. 1 (d)).

Our experimental setup is shown in Fig. 2. It consists of infrared halogen heater, heat controller, pump for cooling water and wafer holder. NIR radiation time and temperature of NIR halogen heater is controlled by controller

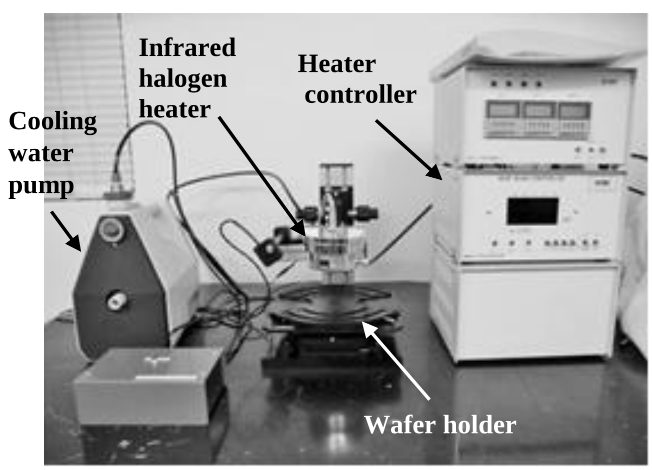

Figure 2: Photograph of our experimental setup; It consists of infrared halogen heater, heater controller, cooling water pump and wafer holder.

automatically. Radiation time and temperature are optimized according to wafer thickness, resin type and its thickness, and pattern dimension of resin. Pump for water cooling is ready to cool halogen heater because the temperature of halogen heater increases extremely high, especially when the radiation time becomes long. Wafer holder can be moved up and down and the distance between wafer on the holder and halogen heater is fixed to 30 mm in our experiment.

3 RESULTS AND DISCUSSION

In the experiment, we used photosensitive polyimide as adhesive resin. The 5 μm thick polyimide was coated on a Si capping wafer before alignment. Then, it was patterned and cured at 250°C. On a counterpart wafer acting as the device wafer, the same 5 μm thick polyimide was coated, patterned and cured at 250°C. Consequently, the total polyimide thickness as adhesive layer becomes 10 μm.

In NIR radiation process for the tentatively localized bonding, we investigated temperature profile to decide optimal process condition for NIR halogen heater and adhesion of resin. The typical temperature profile used in the experiment is shown in Fig. 3. The temperature was measured with thermocouple mounted to the frontside surface of capping wafer under the NIR spot. The temperature is high enough to harden the resin. Actual radiation time showing high temperature was around 15 seconds.

In order to confirm the effect of tentatively localized bonding, we also prepared a bonded wafer without NIR radiation treatment. As a result of comparison, alignment shift after wafer bonding was improved from about 20 μm to about 4-5μm owing to tentative bonding by the NIR radiation. Even though the alignment shift depends on various process conditions, we could have achieved about 4 to 5 more accurate alignment in the experiment. It means that tentatively localized bonding by the NIR radiation is an effective method to maintain the alignment accuracy when the liquid-like resin is used as an adhesive material in wafer bonding.

As an example of our experiment results, infrared camera observation results of alignment mark are presented in Fig. 4. Fig. 4 (a) shows alignment result of two wafers after aligning by the aligner. After alignment, NIR is radiated to aligned wafers for tentatively localized bonding according to the temperature profile shown in Fig. 3. We irradiated to three spots near the wafer boundary. Even after NIR treatment, alignment accuracy is still maintained that could be confirmed by an infrared image shown in Fig. 4 (b). Then, tentatively bonded wafers were bonded with commercially available bonder. In bonding process, we applied temperature of 350 °C, which is necessary temperature to harden resin. After bonding process, we also observed the alignment mark and could confirm thers is no shift between wafers. The infrared image of the mark after bonding process is shown in Fig. 4 (c). Although, alignment

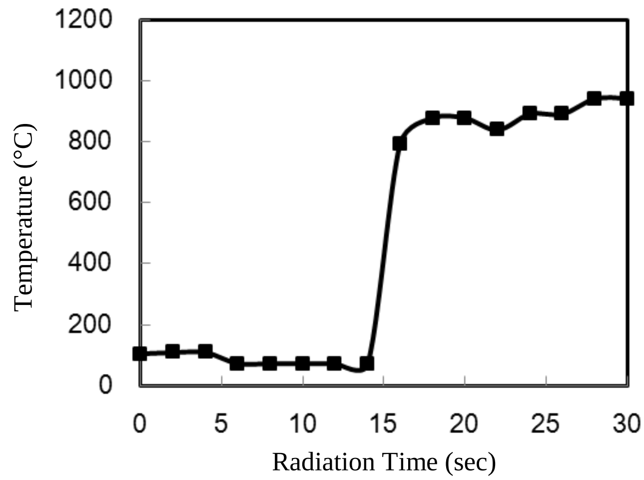

Figure 3: Temperature profile we used in the experiment, which was measured with thermocouple on the frontside surface of capping wafer.

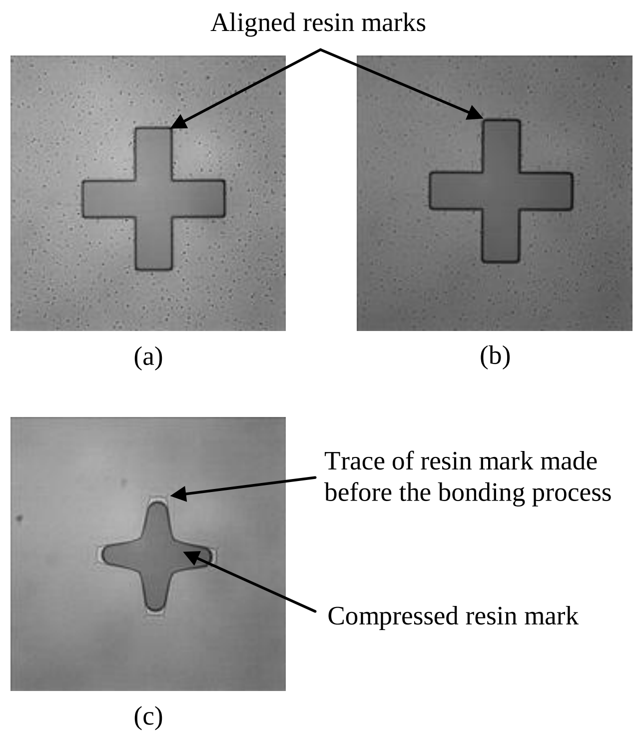

Figure 4: Infrared camera images showing alignment results of two wafers; (a) after aligning by the aligner, (b) after NIR treatment for tentatively localized bonding, and (c) after bonding process.

mark made of resin is compressed by high temperature and pressure, we could not observe alignment mark shift. In order to confirm more clearly the effect of tentatively localized bonding, we need to prepare alignment mark that is not made of resin.

4 CONCLUSIONS

We have proposed a novel method to maintain alignment accuracy during wafer bonding process with resin as an adhesive material, which utilize tentatively localized bonding after aligning wafers by aligner. Localized bonding is achieved by 1100 nm NIR radiation that is transparent to Si.

We performed experiment to confirm our method with our experiment setup. In the experiment, we used photosensitive polyimide as a resin and halogen heater as an NIR radiation source. The NIR spots were radiated from NIR halogen heater whose diameter is about 2 mm and distance between wafer and heater is 30 mm. We optimized temperature profile of NIR radiation.

As a result of experiment, alignment shift after wafer bonding was improved to about 4-5 μm from about 20 μm that is conventional alignment result. Owing to our tentative localized bonding by the NIR radiation, even though the alignment shift depends on various process conditions, we could have generally achieved about 4 to 5 more accurate alignment in the experiment. It means that tentatively localized bonding by the NIR radiation is an effective method to maintain the alignment accuracy when the liquid-like resin is used as an adhesive material in wafer bonding.

As a future work, we need another experiment with alignment marks which is not made of resin to confirm effectiveness of our method more clearly.

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