An investigation into the high strength bonding technology of wafer-to-wafer with large-scale au line

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Abstract. As well known, the sandwich-like construction is the classic unit construction of MEMS microthrusters, and these three layers should be bonded between the igniting circuit layer and the microchamber-array-layer, the microchamber-array-layer and the micronozzle-array-layer. It's bonded by BCB between the igniting circuit layer and the microchamber-array-layer, and their bonding strength is the key factor to determine the reliability of MEMS microthruster-array-chips. And the failure is mostly discovered on the bonding surface of the igniting circuit layer and the microchamber-array-layer in ignition experiments. For solving the bonding failure, the failure reason will be analysed and the improved bonding technique is designed. Here, the bonding strength is externalized, and the average shear strength increase to 11.63MPa from 2.80MPa, this is over 4times than before. The igniting experiments prove the Si3N4 layer can enhance the BCB bonding strength and this new bonding method does solve the bonding problem of MEMS microthruster-array-chips.

1. Introduction
Benzocyclobutene (BCB) has been gained comprehensive attention because of its unique properties such as low dielectric constant, low moisture absorption, low cure temperature, high degree of planarization, low level of ionic contaminants, high optical clarity, good thermal stability, excellent chemical resistance, and good compatibility with various metallization systems. Therefore, BCB is applied widely in bonding and packaging processes of 3D integrated circuits (IC) devices [1], optical devices [2], and micro electro mechanical system (MEMS) devices [3-8].

Bonding technology is one of the most important techniques in fabrications and packages of 3D IC devices and MEMS devices, and BCB is the key bonding materials in applications of wafer-to-wafer bonding, such as Silicon to Silicon and Silicon to glass. So, the BCB has been used as the bonding material between the micro igniters-array-chip and the micro chambers-array-chip in MEMS microthrusters-array-chips, which is the classic construction of like-sandwiches. As well known, the BCB could produce the great bonding strength with Si and compounds of silicon, but the bonding strength of BCB is not good enough with metal films. The bonding surface of igniters-array-chip is shown in Fig.1. However, there are a lot of Au lines on the bonding surface of micro igniters-array-chip. Therefore, the delamination [9] will be discovered on the bonding surface of igniters-array chips.
and microchambers-array-chips. Equally, the fail phenomena of bonding surfaces have been observed in the igniting experiments of MEMS microthruster-array-chips. The representative bonding failure could be seen in Fig.2.

Figure 1. The unit construction of MEMS microthrusters.

Figure 2. The classical failure in igniting experiment of MEMS microthruster-array-chips.

Above all, the bonding strength is one of the most important parameters which determines the working reliability of MMES microthrusters-array-chips.

In order to improve the bonding strength in fabrications and the reliability in applications of MEMS microthrusters, the dielectric layer has been applied in bonding process of MEMS microthruster-array-chips, and the bonding strength is enhanced, obviously.

2. Analysis into the reasons on bonding failure

2.1. The bonding mismatch on interfaces of BCB and igniting circuit layers

As well known, the module construction of BCB monomers is shown in fig.3 before its pre-hardening. The module construction of pre-hardening BCB shows that the BCB has great adhesion with materials of silicon, silica and silicon nitride, but BCB has not good adhesion with metallic materials, such as Au (the bonding surface of igniting circuit layer is shown in Fig.4). This is determined by the chemical properties of BCB and bonding materials, so some new method have to be developed.

Figure 3. The module construction of BCB monomers.
2.2. Bonding failures
As the classic construction, the unit of MEMS microthruster has three layers: the igniters-array-layer, the microchamber-array-layer, and the micronozzle-array-layer. The fabricating process references Fig.5. And the bonding surface is coated by BCB film applied bladecoating processes with patterned film, before bonding the igniting circuit layer and the microchambers layer (shown in Fig.6).

**Figure 5.** The fabricating process of MEMS microthruster-array-chips.

**Figure 6.** The bladecoating process of BCB in fabrications of MEMS microthruster-array-chips.

In another hand, there are large-scale Au lines on the bonding surface of igniting circuit layer. The thickness of Au lines is 3.2-3.5μm, and their minimum width is only 20μm. Therefore, it’s difficult to blade coat the BCB into the spaces between Au lines, because of the high viscosity of BCB and the small width between Au lines. The bonding surface of igniting circuit layers are shown in Fig.4.

From the Fig.2, we could get the serious consequence in igniting experiment of MEMS microthruster-array-chips, and this failure of bonding process is an important problem what has to be solved.

In order to analysis the failure reasons in bonding process of MEMS microthruster-array-chips, the bonding surfaces are investigated about the BCB bonding layer and the surfaces of igniting circuit chips. we apply the shovel blade to separate the microchamber layer and the igniting circuit layer for investigate the bonding surfaces. The fig.7 shows how to separate the bonding layers. The bonding surface of igniting circuit layers is shown in Fig.8, and the bonding surfaces of microchamber-array-layer are shown in Fig.9. There are some micro hollows are discovered on the bonding interfaces of BCB, and these micro hollows obviously decreased the bonding strength, which is one of the key factors to determine the reliability of MEMS microthruster-array-chips in their tests and their applications in future. These micro hollows are generated when the BCB is coated on the bonding surfaces with coating and scrapping method, and these BCB films are not uniform enough. Therefore, the coating process of BCB should be improved for better bonding strength.

In fig.8 and fig.9, the defect zones are highlighted by red circles. They indicate the reasons why reduces the low bonding strength. And it’s very hard to edulcorate these defect zones. Therefore, the new method is developed for decreasing these defect zones on the BCB layer and further for increasing the bonding strength between the igniting circuit layer and the microchamber-array-layer.

**Figure 7.** The illustration to separate the bonding layers.
3. Results and Discussion

3.1. Adding the dielectrometric layer of silicon nitride on the surface of the igniting circuit layer
From the module construction of BCB monomer, the bonding strength is better when the BCB with silicon and inorganic silica materials (such as silicon, silicon nitride, and silicon oxide) than metallic materials (i.e. Au).

Therefore, the silicon nitride layer is deposited on the surface of Au line to enhance the adhesion after bonding process of igniting circuit layers and microchamber-array-layers.

3.2. To improve the patterning technique of BCB
The original patterning process of BCB is scraped on the bonding surface of igniting circuit layer with patterned film in fig.6. However, its bonding strength is not good enough, and there are some micro defects on the bonding interfaces of microchamber layers and igniting circuit layers, such as folds and micro holes of BCB membranes (in fig.8 and fig.9). Additionally, the thickness of BCB layers is not consistent with the blade-coating process.

In order to improve the thickness consistency of BCB bonding membrane, the blade-coating process is replaced by the spin-coating process. The pre-hardening BCB bonding membrane is patterned by the ICP (Inductively Coupled Plasma) etching process, and the patterned resistance is applied as the masking layer. The improved patterning process of BCB is shown in fig.10.

After the process of fig. 10, the microchamber-array-chips are bonded on the surfaces of igniting circuit layers, what is shown in fig.11.
Figure 10. The improve patterning process of BCB.

Figure 11. The advanced bonding process of igniting circuit layers and microchamber-array-layers.

3.3. Tests of shear strength after bonding of igniting circuit layers and microchamber-array-layers

After bonding the igniting circuit layer and microchamber-array-layers, a MEMS microthruster-array-chip are cut into nine pieces at the same area, and the shear strength is tested to characterize the bonding strength for contrast the advances of two bonding processes. The test results certify that the shear strength is over 4 times than before. The experimental results are shown in fig.12.

Finally, the igniting experiment demonstrates the new bonding technique increases the bonding strength, and this improved bonding method can ensure the reliability of MEMS microthruster-array-chips. The igniting test is shown in fig.13 on the combustion of MEMS microthrusters unit what is recorded by the high-speed optical camera, and the combustion experiment is shown in fig.14 on the MEMS microthruster-array-chips ignited by the control circuit unit.

Figure 12. Contrasts of bonding strength between two bonding techniques.

Figure 13. The combustion process of a MEMS microthruster unit recorded by high-speed optical cameras.
4. Conclusion

For increasing the bonding strength, a new bonding technology is created by adding the patterned silicon nitride layer on the surface of metallic lines, and the knife coating technique is replaced by the patterning technology on the BCB adhesive layers.

Contrast the shearing tests, the experimental results indicated that the new bonding process could increase the bonding strength, obviously. The bonding strength of new bonding technique is over four times than the original knife coating process.

Above all, this investigation reveals a new bonding technology, and it can be applied in wafer-to-wafer bonding, single-chip bonding, multi-bonding and 3D bonding and packaging, comprehensively.

Acknowledgments
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