Microdrilling Machinability of Organic Material for Semiconductor Packaging by 248 nm Excimer Laser

Yasufumi Kawasuji*, Akira Suwa, Masakazu Kobayashi, Junichi Fujimoto, and Kouji Kakizaki
Gigaphoton Inc., 400 Yokokurashinden, Oyama-shi, Tochigi 323-8558, Japan
*yasufumi_kawasuji@gigaphoton.com

An organic build-up film or a single crystal silicon wafer is used as the substrate material for a semiconductor multi-die package. However, the cost of a single crystal silicon wafer is very high and miniaturization of the processing of an organic build-up film by a commonly used 355 nm UV laser has almost reached the limit due to its long wavelength. In this paper, we report on the microdrilling processability of less than 10 μm diameter of a build-up film using a 248 nm excimer laser with high photon energy (5–6.4 eV). The dependence of the taper angle on the fluence was evaluated, in addition to the processing rate for various via hole diameters using major commercial build-up films (Ajinomoto GY50, GX-T31, GX92). The results of this study indicate the appropriate selection of build-up film material and excimer laser processing fluence to achieve the processing target diameter and taper angle. The micromachining of a build-up film by excimer lasers is thus expected to be widely used in future semiconductor packages due to their low cost and fine processing performance.

Keywords: Excimer laser, Organic material, Build-up film

1. Introduction
Semiconductor integration has continued to improve over the past 50 years in accordance with Moore's Law. However, it has almost reached the limit of resolution with respect to semiconductor die production. One of alternative solutions is multi-die packaging. The substrate material of multi-die packaging is organic build-up film or single crystal silicon wafer. However, single crystal silicon wafers have an issue of very high manufacturing cost, and the miniaturization of the organic build-up film process by the commonly used 355 nm UV laser has almost reached the limit due to its long wavelength. Therefore, to miniaturize the build-up film process, it is necessary to use an excimer laser with a shorter wavelength than the UV laser. In addition, the high photon energy due to the short wavelength of the excimer laser means the thermal effect of the material can be reduced by direct photon absorption [1-3].

In this paper, we report microdrilling processability of less than 10 μm diameter for a build-up film using a 248 nm excimer laser with high photon energy (5–6.4 eV). The dependence of the taper angle, processing rate on the fluence for various via hole diameters was evaluated for major commercial build-up films (Ajinomoto GY50, GX-T31, GX92).

2. Experimental
Figure 1 shows the test stand used for microdrilling of build-up film with the excimer laser. A Gigaphoton excimer laser was modified to a free-run laser as a laser drilling light source. The major laser light parameters are given in Table 1. Experiments were performed in the atmosphere, under the same conditions as for practical use. The irradiated fluence was adjusted by an optical attenuator. The beam shape was formed by a mask, an illuminator, and a projector lens system.

Ajinomoto build-up films (ABF) were used for this experiment with 10 μm thick ABF types of GX92, GX-T31, and GY50. The ABFs were formed on copper film.
3. Results and discussion

We have previously measured the drilling rate and taper angle with a constant hole diameter of 25 μm [4]. In the present work, we report the dependency of drilling rate and taper angle on the hole diameter for each ABF material.

Figure 2 shows the definition of the taper angle. The taper angle is an important parameter that represents the processing characteristics. The size of the bottom diameter of the hole is an important parameter that determines the reliability of the interlayer connection. A larger taper angle means a larger bottom diameter and thus higher reliability.

Figure 3 shows the drilling rate of each ABF material ((a) GY50, (b) GX92, and (c) GX-T31) as a function of the laser fluence for various hole diameters. This result indicates that a smaller hole diameter and a higher fluence result in a higher processing speed.

GY50 has the largest hole diameter dependency. The drilling rate of the ABF which has a large silica particle size (GX92 and GX-T31) was larger than the ABF which has a small silica particle size (GY50) for hole diameters ≥10 μm hole diameter. For a hole diameter of 5 μm, drilling rate of GY50 was almost the same as that for GX92.

Figure 4 shows the taper angle as a function of the fluence for various hole diameters with each ABF material. For each material, a smaller drilling size has a larger taper angle. The taper angle of GY50 (small silica particles) has a good correlation to the ablation fluence, whereas GX92...
and GX-T31 (large silica particles) have less correlation to the ablation fluence. The reason for the dependency of the taper angle on the fluence is under investigation. However, we consider the difference of the taper angle dependence on the fluence between the ABF materials is caused by the interaction between the laser ablation of the organic component of ABF material and the silica size that is appeared on the wall surface of the drilling hole.

This experiment result shows that the combination of the GY50 material and high fluence (>900 mJ/cm²) can produce a taper angle of over 85° before desmearing.

Fig. 3. Drilling rate as a function of the laser fluence for various hole diameters; (a) GY50, (b) GX92, and (c) GX-T31.

Fig. 4. Taper angle as a function of the laser fluence for various hole diameters; (a) GY50, (b) GX92, and (c) GX-T31 before desmearing.
Fig. 5. Top and cross-sectional views of 5 μm diameter holes of ABF (GY50, GX92, and GX-T31) microdrilled by a 248 nm excimer laser at fluences of 600, 800, and 1000 mJ/cm². The white part of the cross-sectional image is a protection coating for FIB cutting.
| 10 μm diameter; SEM top view | 600 mJ/cm² | 800 mJ/cm² | 1000 mJ/cm² |
|-----------------------------|------------|------------|-------------|
| GY50                        | ![Image](image1) | ![Image](image2) | ![Image](image3) |
| GX92                        | ![Image](image4) | ![Image](image5) | ![Image](image6) |
| GX-T31                      | ![Image](image7) | ![Image](image8) | ![Image](image9) |

| 10 μm diameter; SEM cross-section | 600 mJ/cm² | 800 mJ/cm² | 1000 mJ/cm² |
|----------------------------------|------------|------------|-------------|
| GY50                             | ![Image](image10) | ![Image](image11) | ![Image](image12) |
| GX92                             | ![Image](image13) | ![Image](image14) | ![Image](image15) |
| GX-T31                           | ![Image](image16) | ![Image](image17) | ![Image](image18) |

Fig. 6. Top view and cross-sectional view of 10 μm diameter holes of ABF (GY50, GX92, and GX-T31) microdrilled by a 248 nm excimer laser with fluences of 600, 800, and 1000 mJ/cm². The white part of cross-section image is a protection coating for FIB cutting.
Figures 5 and 6 show top views and cross-sectional views of 5 μm and 10 μm diameter holes, respectively. The size of the silica particles inside each ABF material is evident.

4. Conclusion

The dependence of the drilling rate and taper angle on the laser fluence for various via hole sizes was examined for ABF materials (GY50, GX92, and GX-T31). A high drilling rate can be achieved with small diameter via holes for each ABF material.

We also showed that the processing rate for each ABF material was higher as the hole diameter became smaller. The drilling rates for GX92 and GXT31 (large silica particle size) were larger than those for GY50 (small silica particle size). The taper angle did not increase with the fluence for GX92 and GXT31 due to their large silica particle sizes. On the other hand, the taper angle of GY50 (small silica particle size) increased with the fluence, and at a fluence of 1000 mJ/cm², a taper angle greater than 85° was achieved before desmearing. From the results presented here, appropriate materials and processing conditions can be selected for ABF microdrilling. We expect that ABF semiconductor package processing with 248 nm excimer lasers will be widely used in the near future.

References

1. J. Ihlemann and B. Wolff-Rottke, Appl. Surf. Sci., 106 (1996) 282.
2. R. Karstens, A. Gödecke, A. Prießner, and J. Ihlemann, Opt. Laser Technol., 83 (2016) 16.
3. J. Ihlemann, B. Wolff, and P. Simon, Appl. Phys., A54 (1992) 263.
4. A. Suwa, J. Fujimoto, Y. Kawasuji, M. Kobayashi, M. Shimbori, T. Onose, M. Arakawa, A. Mizutani, and H. Mizoguchi, Proc. SPIE, 10906 (2019) 1090609.