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# Feasibility Investigation of Amorphous Silicon as Release Layer in Temporary Bonding for 3-D Integration and FOWLP Scheme

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**ABSTRACT** A reliable temporary bonding scheme with both inorganic amorphous silicon release layer and HD-3007 polyimide based on high 355-nm-wavelength laser absorption coefficient in release layer is proposed and investigated. Effects of laser absorption coefficient and laser ablation path are also studied to develop a high throughput laser ablation process. The bonding scheme can be achieved within the optimized temperature of 210 °C under 1 MPa bonding force. In addition, chemical resistance, mechanical strength with reliability assessment, and thermal stability test for bonded structure are inspected. There is no obvious degradation in electrical characterization after laser ablation, indicating that the temporary bonding scheme has high potential to be used for 3-D integration applications.

**INDEX TERMS** Three-dimensional integration, temporary bonding, laser release.

## I. INTRODUCTION

The desire to pursue smaller, thinner, and multifunctional integration scheme is the motivation for the consumer electronics in the market such as smartphone, tablets, wearable device, and Internet of Things (IoT) [1]. Therefore, three-dimensional integration and advanced packaging scheme have been proposed as promising solutions for the aforementioned pursue due to their advantages of small form factor, low power consumption, and heterogeneous integration in next generation semiconductor fabrication era [2], [3]. The platforms that utilized this technology include fan-out wafer-level package (FOWLP), 2.5D interposers with through silicon via (TSV), and 3D-IC high-density integration with TSV interconnects [4]. The above-mentioned platforms involve a key technology of mechanically supported thin wafer handling through temporary bonding process [5].

The temporary bonded structure must meet the requirements of chemical resistance ability for subsequent back-end-of-line (BEOL) process, thermal stability during post fabrication process with a temperature of 300°C or even

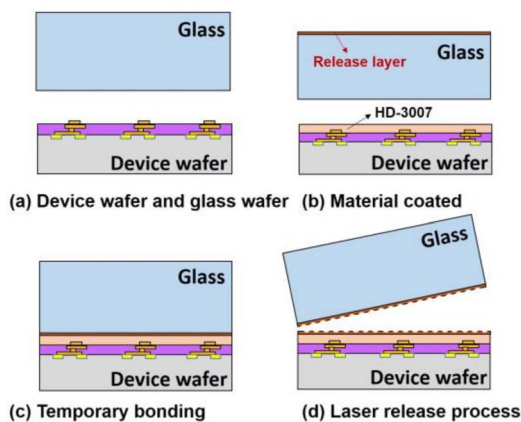
higher, and reliable mechanically bonding strength between a carrier wafer and an ultra-thinned device wafer with thickness below 100 μm [6], [7]. Moreover, release process temperature and high throughput are both significant factors that have to be taken into consideration in the de-bonding technology. The prior arts have shown several useful temporary bonding scheme and release methods to achieve the demand of manufacturing process [6]–[8].

In this paper, a new bonding structure constituted with both high UV absorption inorganic amorphous silicon as release layer and the HD-3007 polyimide as adhesive layer is demonstrated. The bonding structure is used for temporary bonding platform that utilizes carrier glass wafer and amorphous indium gallium zinc oxide (a-IGZO) thin-film transistors (TFTs) device wafer with room temperature high throughput laser ablation procedure. Although amorphous silicon as release layer has been successfully implemented with the adhesive layer of spin on glass (SOG) in Tohoku University [9], the distinct structure with more detailed inspection for laser release technology is carried out in

this paper. Hence, using the proposed promising bonding structure with high throughput laser release scheme can be an attractive option for 3D integration and advanced packaging applications.

## II. TEMPORARY BONDING AND LASER RELEASE PROCEDURE

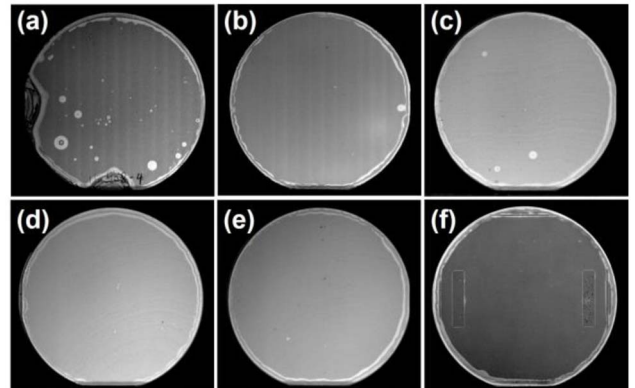
Fig. 1 shows the schematic process flow of temporary bonding with fabricated device integration scheme. The key technologies used are temporary bonding and laser release process. Amorphous IGZO TFT is fabricated through the process of photolithography, IGZO/TaN active/contact layer sputtering, and oxide layer deposition. HD-3007 polyimide adhesive layer is spin-coated and fully imidized at 300 °C for 30 min on the device wafer before bonding. The photolysis polymer has been utilized as a release layer with great bonding result as well as good laser ablation quality [10], [11]. In addition, the promising candidate material of 250-nm-thick amorphous silicon with higher absorption coefficient than photolysis polymer is deposited by HDP-CVD on the carrier glass wafer (Corning Inc. Eagle XG glass wafer) with the presence of boro-aluminosilicate. The device wafer is bonded face-to-face with the carrier glass wafer for 10 min under 1 MPa bonding force in the  $1.33 \times 10^{-7}$  hPa vacuum chamber. Subsequently, laser release process is applied for the bonded structure between the polyimide adhesive layer and amorphous silicon release layer at room temperature. Finally, separation of the carrier wafer and device wafer can be obtained without any extra force in a high throughput scheme. In addition, the residue amorphous silicon on both device wafer and glass wafer can be cleaned by  $C_4F_8/SF_6$  chemistry dry-etching process with inductively coupled plasma (ICP) [12]. Then the HD-3007 can be removed with 60°C EKC-865 solvent in 5 min with a 40 kHz ultrasonic treatment.



**FIGURE 1.** Process flow of temporary bonding before and after laser ablation process.

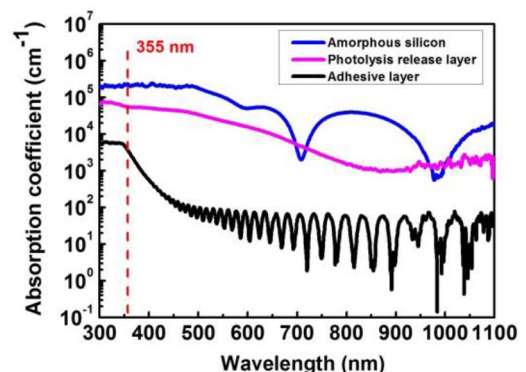
The wafer-level temporary bonding with amorphous silicon and HD-3007 polyimide as release layer and adhesive layer is successfully developed under 220°C low bonding

temperature and 1 MPa bonding force. Figures 2(a)-(e) show the Scanning Acoustic Tomography (SAT) images from 180°C to 220°C for the inspection of the bonding quality [13]. Although some voids can be seen when bonding temperature is below 210°C, an entire well-bonded blanket wafer can be achieved when bonding temperature is at 210°C. In addition, the amorphous IGZO TFT device with optimized bonding temperature of 210°C in Fig. 2(f) shows the void-free bonding quality, which demonstrates a promising alternative for temporary bonding procedure.



**FIGURE 2.** SAT images of wafer-level bonding with different conditions as: (a) 180°C; (b) 190°C; (c) 200°C; (d) 210°C; (e) 220°C; and device wafer with (f) 210°C, 1 MPa.

The laser ablation mechanism is mainly focused on the dry-etching process. The photon-energy from laser pulse shot is projected onto the high absorption coefficient release layer, then the molecular bonds are broken through the transition of the material from solid phase to gas phase and some are ejected as powder plume in the process [14]. To investigate the optical characteristics of amorphous silicon, photolysis polymer, and polyimide adhesive layer, these three materials are coated on one glass wafer respectively, and then scanned from 300 nm to 1100 nm wavelength through a spectrometer to obtain their transmittances. The absorption coefficient of three materials can then be calculated.



**FIGURE 3.** The absorption coefficient of adhesive, amorphous silicon, and photolysis release layer under different wavelengths.

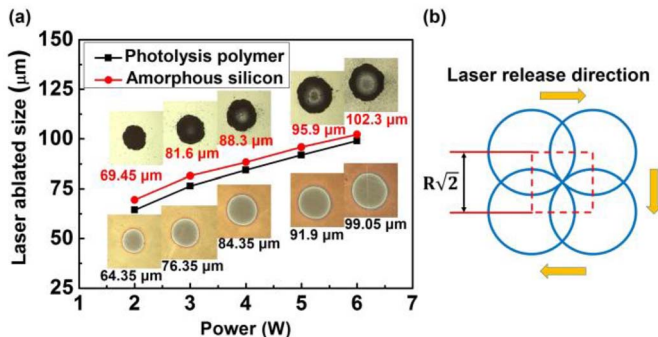
Fig. 3 shows that the obvious difference of the absorption coefficient among the adhesive layer, amorphous silicon, and photolysis release layer at 355 nm wavelength. This indicates that the UV wavelength can be absorbed into the amorphous silicon and the photolysis release layer but not the adhesion layer. In addition, the amorphous silicon has a higher absorption coefficient than the photolysis polymer. Hence, unlike the photolysis polymer used in prior art [10], [11], 250-nm-thick amorphous silicon, which does not require aging process before bonding, is recommended as a great release layer for temporary bonding.

The laser power density is about 196 mJ/cm<sup>2</sup> when the laser emission power is 2.5 W. To realize the throughput ability of laser release process between amorphous silicon and photolysis polymer, the ablated size with corresponding laser emission power is investigated. The laser-ablated radius in the amorphous silicon is slightly larger than in the photolysis polymer, as shown in Fig. 4(a). Fig. 4(b) shows the well laser release direction in meander shape with every pulse laser shot overlapped by using a low-cost 355-nm diode-pumped solid-state (DPSS) laser from KYO Laser Debonder. The throughput of laser ablation can be calculated using formula (1)-(2):

$$\text{Scan speed} = f \times \text{Line pitch} = f \times R\sqrt{2} \quad (1)$$

$$\text{Release time} = \frac{A}{\text{Line pitch} \times \text{Scan speed}} = \frac{A}{2R^2f} \quad (2)$$

where R is the laser-ablated radius of the release area, A is the laser-released area, and f is the frequency of laser auto-mechanical scanning system. Scanning line pitch is designed as the distance between two centers of the ablation area. In addition, the laser release time for a 100-mm wafer in diameter in this study is less than 15 s when amorphous silicon is used as release layer. Therefore, larger ablated size in the amorphous silicon release layer lead to shorter laser release time and higher throughput, which is suitable for 3D integration and advanced packaging.



**FIGURE 4.** (a) OM images of laser ablated on photolysis polymer and amorphous silicon at different laser power. (b) Laser release direction with overlapped ablation area in meander shape.

### III. RELIABILITY ASSESSMENT OF BONDING SCHEME

In order to validate the bonding strength and the impact of the subsequent manufacturing processes on both release

layer and adhesive layer, a chemical resistance assessment is examined with five types of acid and alkaline solutions. Table 1 shows the results of the bonded structure of amorphous silicon and HD-3007 polyimide [13]. The bonded structure remains the same without de-lamination even after being assessed for 30 minutes, indicating the feasibility of a reliable bonded structure between device wafer and carrier wafer.

**TABLE 1.** Results of bonded structure for chemical resistance assessment.

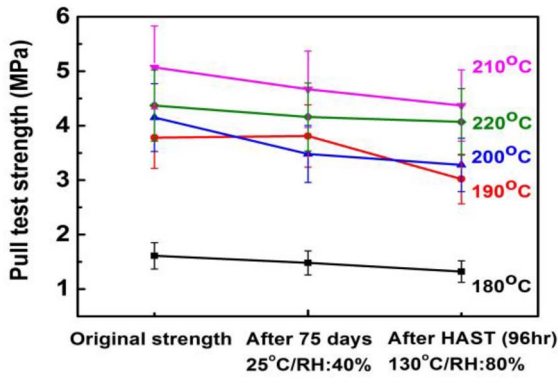
Solution	Time (min)	Remark
20% H <sub>2</sub> SO <sub>4</sub>	30	Pass, no significant debonded
SPM (H <sub>2</sub> SO <sub>4</sub> :H <sub>2</sub> O <sub>2</sub> =3:1)	30	Pass, no significant debonded
BOE (NH <sub>4</sub> F:HF=6:1)	30	Pass, no significant debonded
SC-1 (NH <sub>4</sub> OH:H <sub>2</sub> O <sub>2</sub> :H <sub>2</sub> O=1:4:20)	30	Pass, no significant debonded
SC-2 (HCl:H <sub>2</sub> O <sub>2</sub> :H <sub>2</sub> O=1:1:6)	30	Pass, no significant debonded

For the purpose of assessing the bonding strength of the bonded structure between amorphous silicon and HD-3007 polyimide, pull test is carried out to evaluate mechanical characteristics on the diced bonded chip with size of 2 cm x 2 cm. The optimized bonding temperature at 210°C has the highest bonding strength of 5.07 MPa with estimated error of 15% as shown in Table 2, which has the similar result as SAT images in Fig. 2(d). Moreover, the environmental conditions of BEOL fabrication procedure and reliability assessment are also considered. Therefore, a humidity test with the conditions of a 40% humidity at 25°C in 75 days and un-bias standard highly accelerated stress test (un-bias HAST) based on JESD22A-118 with the conditions of 85% humidity at 130°C are utilized to realize the degree of decline in the mechanical strength of the bonded structure. The results of the mentioned reliability assessment conditions in Fig. 5 indicate that the optimized bonding temperature at 210°C has the highest bonding strength as compared to the others.

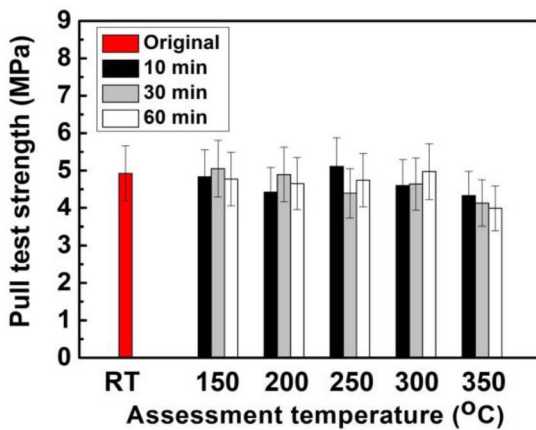
**TABLE 2.** Pull-test results at different bonding temperature and reliability assessment.

Bonding Temperature (°C)	Original strength (MPa)	After 75 days 25°C/RH:40% (MPa)	After HAST (96hr) 130°C/RH:80% (MPa)
180°C	1.61±0.24	1.48±0.22	1.32±0.20
190°C	3.78±0.57	3.81±0.57	3.02±0.45
200°C	4.15±0.62	3.48±0.52	3.28±0.49
210°C	5.07±0.76	4.67±0.70	4.37±0.66
220°C	4.37±0.66	4.16±0.62	4.07±0.61

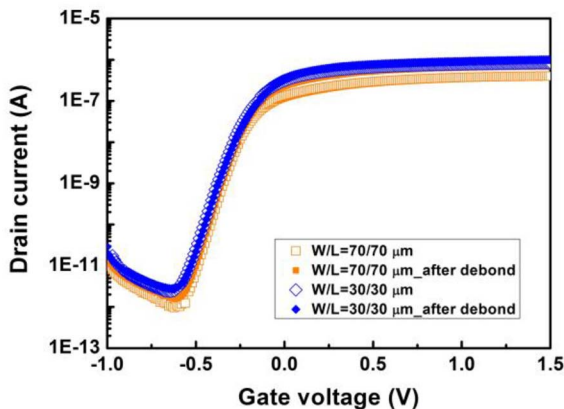
Thermal stability test is another emphasis for the post integration process, which includes PECVD and permanent bonding after temporary bonding procedure. Therefore, the pull test investigation for the post annealing process with



**FIGURE 5.** Pull-test results at different bonding temperature from 180°C to 220°C and environmental reliability assessment.



**FIGURE 6.** Pull-test results at different assessment temperature within 10 min, 30 min, and 60 min.



**FIGURE 7.** Id-Vg behavior of a-IGZO TFT in gate length of 30 μm and 70 μm.

nitrogen flow in the oven from 150°C to 350°C within 10 min, 30 min, and 60 min are assessed with estimated error of 15% on the bonded structure respectively. Fig. 6 shows that when the annealing temperature is at and below 300°C, the bonding strength has only a slight variance without degradation with an increased in annealing time. As a result, great thermal stability for the temporary bonded structure can be realized at temperature below 300°C.

#### IV. A-IGZO TFT ELECTRICAL BEHAVIOR BEFORE AND AFTER LASER ABLATION

To consider the applicable laser release process for real device applications, two types of amorphous IGZO thin-film transistor device have been assessed. Almost overlapping results without deterioration of drain current before and after the laser ablation process in TFT gate length of 30 μm and 70 μm demonstrate reliable electrical characteristic as shown in Fig. 7. The results prove the high reliability of this temporary bonding platform using amorphous silicon and adhesive polymer bonded structure during the laser ablation procedure.

#### V. CONCLUSION

In this study, a temporary bonding scheme with polyimide adhesive layer and amorphous silicon inorganic release layer has been successfully demonstrated. With a 250-nm-thick high UV absorption coefficient release layer of amorphous silicon, excellent bonding quality at bonding temperature of 210°C, great chemical resistance, mechanical strength, thermal stability below 300°C, and reliable electrical behavior before and after laser release process are achieved. In addition, the low-cost 355-nm diode-pumped solid-state (DPSS) laser de-bonder and auto-mechanically applicable ablation direction in meander path lead to high throughput fabrication for laser ablation procedure. The successful implementation and assessed results indicate the feasibility of amorphous silicon as a promising candidate for temporary bonding in 3D integration and advanced packaging.

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