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The effect of laser irradiation on peel strength of temporary adhesives for wafer bonding

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ABSTRACT

Thin silicon wafers are usually used for many devices and electronic fabrication development. But handling thin wafers are not easy since thin wafers may lose the supporting strength and crack. Using adhesives is the one of the possible solutions for thin wafer handling, and how to synthesize adhesives materials and investigate debonding behaviors for temporary bonding and debonding are an important research. In this work, laser irradiation is considered for debonding temporary adhesives in a 3D multi-chip package process because of its very fast debonding time about few seconds and irradiation stability than thermal or chemical debonding. The thermal curable adhesives were fast cured on high temperature by the laser irradiation. The emphasis is the choice of the specific laser process parameters such as the out-focusing length, the line spacing, and the scan speed. The surface morphology with various sets of these parameters is examined by optical microscopy. Also, peel strength before/after the laser irradiation is investigated. Based on this study, suitable process parameters and conditions are proposed for clean surface of silicon wafers and lower peel strength for easy debonding.

1. Introduction

Adhesive bonding is nowadays an established technology widely employed to join similar or dissimilar materials in a variety of modern industries (e.g. automotive, aerospace, etc.) [1–3]. Wafer bonding enables the fabrication and packaging of complex three-dimensional (3D) microcomponents [4–6]. The commercial applications are in the fabrication of silicon-on-insulator (SOI) substrates [7–10]. The wide variety of wafer bonding techniques include direct bonding [8–10], anodic bonding [8–10], solder bonding [11], eutectic bonding [12], thermocompression bonding [13], direct metal-to-metal bonding [14], ultrasonic bonding [15], low-temperature melting glass bonding, and adhesive bonding [16].

In the most commonly used adhesive wafer bonding processes, a polymer adhesive is applied to one or both of the wafer surfaces to be bonded. After joining the wafer surfaces that are covered with the polymer adhesive, pressure is applied to force the wafer surfaces into intimate contact. The polymer adhesive is then converted from a liquid or viscoelastic state into a solid state, typically done by exposing the polymer adhesive to heat or ultraviolet light. The main advantages of adhesive wafer bonding include relatively low bonding temperatures depending on the polymer material, between room temperature and 450 °C, insensitivity to the topology of the wafer surfaces. Adhesive wafer bonding does not require special wafer surface treatments such as planarization or excessive cleaning. Structures and particles at the wafer surfaces can be tolerated and offset to some extent by the polymer adhesive [1,16].

In the other hands, different temporary bonding approaches being developed enable thin-wafer handling, some of which are commercially available for testing and development of 3D IC processes. Among them, there is the approach primarily developed by Brewer Science Inc., and were originally designed to be compatible with equipment manufactured by EV Group (EVG) [17]. The wafers are processed in a single-wafer-processing mode in each of these processing steps [18]. But this approach has been developed in conjunction with specially designed surface treated carrier wafer and adhesives. Also, it needs longer time for heating in a process.

In this study, UV laser irradiation was used for adhesives debonding. Laser processing is a key technology in new developments in microelectronics. Also, the laser-lift-off process step comes into play as soon as the manufacturing strategy demands for a gentle separation of thin layer system [19]. In order to

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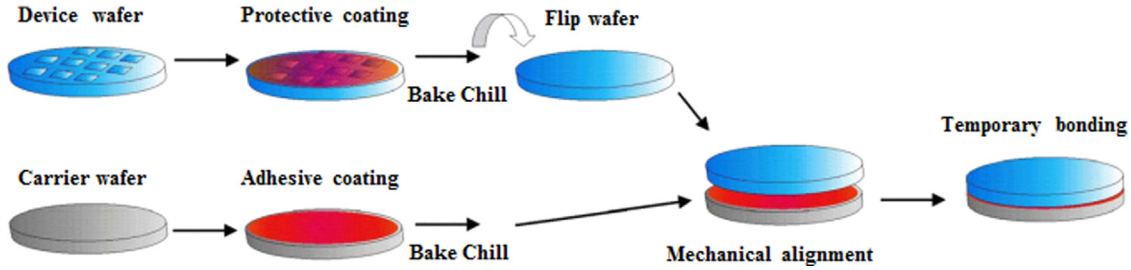

Fig. 1. Temporary bonding process flow [20].

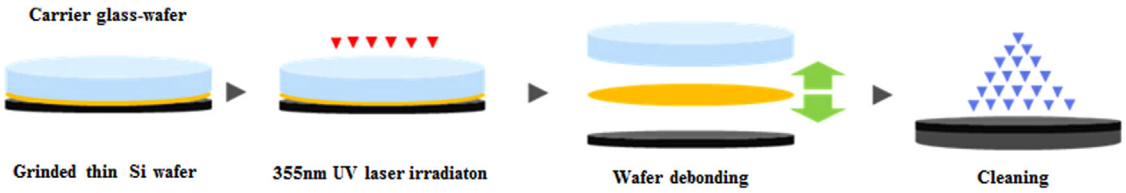

Fig. 2. Laser debonding process flow.

Table 1
Laser process parameters.

Process parameters	Value
Laser wavelength, nm	355
Pulse repetition rate, kHz	100
Average power (P), W	8.3
Out-focusing length (mm)	14–16
Line spacing (mm)	20/30/40
Scan Speed (mm/s)	900/1100/1300

Table 2
Laser debonding conditions of specimen for microscopy observations.

Specimen	(a)	(b)	(c)	(d)	(e)	(f)
Out-focusing length (mm)	14	15	16	16	16	16
Line spacing (mm)	40	40	40	20	30	40
Scan speed (mm/s)	1100	1100	1100	1100	1100	900

investigate laser effect of temporary adhesives on debonding, the adhesives were synthesized with a silicon urethane oligomer for thermal stability and with 2-[3-(2H-Benzotriazol-2-yl)-4-hydroxyphenyl] ethyl methacrylate for UV absorbing material which reacts at wavelength of 355 nm. The morphological analysis using optical microscopy was studied to select a proper combination of the laser process parameters such as out-focusing length, line spacing, and scan speed.

2. Experimental

2.1. Adhesives synthesis

2.1.1. Materials

Hydroxy-terminated carbinol polysiloxane (Shin-Etsu Co., Ltd.) and isophorone diisocyanate (IPDI, Bayer Material Science) were dried at 100 °C. 1H, 1H, 7H-dodecafluoro-1-heptanol (Tokyo Chemical Industry co., Ltd) and pentaerythritol triacrylate were used as end-capping materials without a pretreatment. Approximately 0.1 wt% of dibutyltin dilaurate was added to cause the reaction to take place at a rapid rate as a catalyst in a urethane reaction. 2-[3-(2H-Benzotriazol-2-yl)-4-hydroxyphenyl] ethylmethacrylate (Sigma Aldrich, Korea) was used as UV absorbing material. Hydroxydimethyl acetophenone (Micure HP-8, Miwon Specialty Chemical) was used as the photo-initiator for UV curing. Glycidyl methacrylate (GMA, Junsei Chemicals, Japan) was used as donating epoxy functional group with the carboxyl group of acrylic acid (AA, Samchun Chemicals) for thermal curing.

2.1.2. Synthesis

The total reaction time was determined by observing changes in the FT-IR peak at 2265 cm^{-1} (NCO peak), which decreased with the polyurethane reaction. Initially, IPDI was charged into a dried 300-ml round-bottomed flask equipped with a four-necked separable flask with a mechanical stirrer, thermometer and condenser with a drying tube and an N_2 inlet. The temperature was maintained at room temperature with constant stirring. The hydroxy-terminated carbinol polysiloxane with some of the catalyst (dibutyltin dilaurate) was then added dropwise over a period of 5 h and was maintained for a further 1 h. The reaction temperature was increased to 5 °C using a constant temperature heating mantle with constant stirring. A mixture of 1H, 1H, 7H-dodecafluoro-1-heptanol, and pentaerythritol triacrylate was added dropwise over a period 1 h and was reacted for 3 hours until the NCO peak had almost disappeared. After cooling to ambient temperature, GMA, AA, and 2-[3-(2H-Benzotriazol-2-yl)-4-hydroxyphenyl] ethylmethacrylate were mixed.

2.2. Temporary bonding and laser debonding processes

Temporary bonding process was described in a previous study as shown in Fig. 1 [20]. The bonded samples were irradiated using a UV laser of wavelength as 355 nm operated in pulsed mode (AVIA 355, Coherent) as shown in Fig. 2. A projective optical system directed and defocused the laser radiation on the sample surface. The morphology of a surface after debonding depends on the laser process parameters such as, laser power, line speed and laser wavelength and so on. The parameters considered for this study are shown in Table 1. The experimental work was carried out at ambient temperature and in an atmospheric circumstance.

2.3. Morphology analysis

Optical Microscopy (SV-55, Video microscope system, Sometech) was used for a qualitative analysis of the laser-irradiated samples. Selected specimen and its information are shown in Table 2.

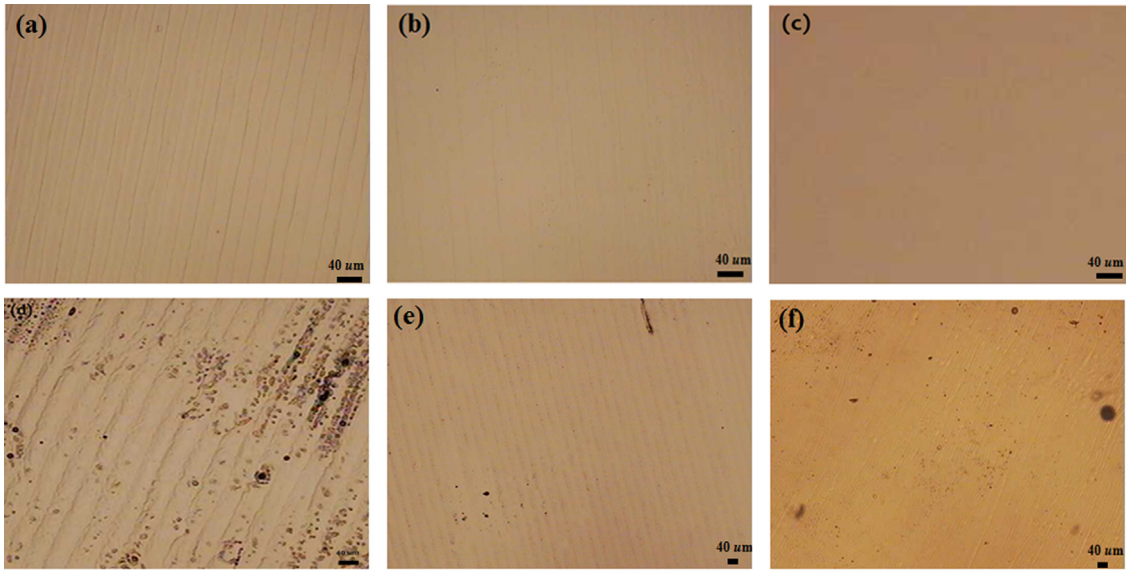

Fig. 3. Microscopy observations of specimen (a)–(f). The laser beam was irradiated from top to bottom.

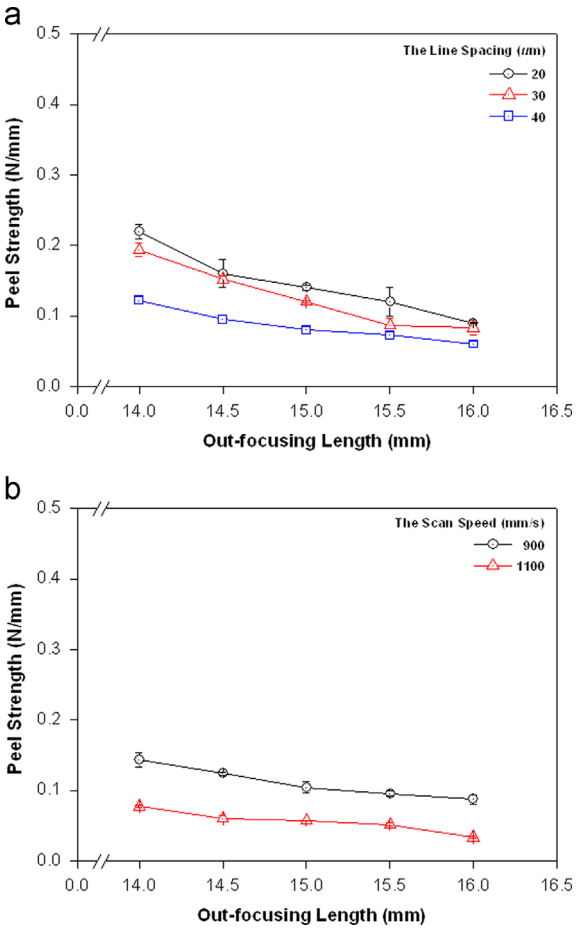

Fig. 4. The peel strength (N/mm) vs. out-focusing length (mm) on (a) the line spacing from 20 μm to 40 μm, and (b) the scan speed from 900 mm/s to 1100 mm/s.

2.4. Peel strength

The bonded specimen size was 8 mm × 8 mm. The 180° peel strength was measured using a Texture Analyzer (TA-XT2i, Micro Stable Systems, UK), a kind of universal tensile machine, after the sample was left to stand at room temperature for 24 h. The peeling speed was 300 mm/min, and the average strength of peeling period was measured five times.

3. Results and discussion

3.1. Morphology analysis

Specimen on out-focusing lengths from 14 mm to 16 mm are reported for comparison in Fig. 3(a)–(c). The surface of the specimen on out-focusing length at 14 mm is scratched and defected, but as increasing out-focusing length the surface of the specimen almost has been flatted. The surface roughness is clearly increased. Using laser irradiation a fraction of the laser beam energy is absorbed by the adhesives, therefore proceeding adhesives melting, surface morphological modifications. If it is compared between from Fig. 3(c) to (e) it can be appreciated as the effect of increasing the laser spacing, on the resulting of surface morphology. For the smaller laser spacing it is not possible to distinguish the different laser scans during the process. Because the surfaces are contaminated by the remaining residue as a result of the adhesives burning. But if the spacing is increased the formation of surface patterns becomes remarkable. Finally, Fig. 3 (c) and (f) show the effect of laser speed when the spacing is held constant at 40 μm. When the speed increases from 900 to 1100 mm/s, the depth of the pattern almost decreases because the time available for the laser beam to heat substrate surface decreases. In order to investigate how the variation of surface morphology affects the debonding of the adhesives the analysis of the peel strength was studied.

3.2. Peel strength

As shown in Fig. 4(a)–(b), the peel strength can be controlled by adjusting the out-focusing length, the line spacing, and/or the speed of the laser. The laser is absorbed mainly and attenuated progressively as it passes through the samples. With the increasing of the out-focusing length, the peel strength decreased slightly regardless of the line spacing and/or the speed in all samples. This was still at an acceptable level because the peel strength is the sum of the energies required to break the bond and deform the backing and the adhesives [21].

4. Conclusion

Handling thin wafers through packaging assembly processes are not easy since the wafers may lose the supporting strength. So, laser debonding has been shown to be a promising technology for the temporary adhesives bonding and debonding process because of its very fast debonding time about few seconds and irradiation stability than thermal or chemical debonding. To investigate laser debonding, the surface morphology, for various sets of the out-focusing length, the line spacing, and the scan speed, was studied by means of the optical microscopy, and peel strength. The thermal curable adhesives were fast cured by heating on the laser irradiation. The results showed that the laser process ensures the adhesives removal thereby removing any weak layer. Among them, the optimum choice of process parameters are 12 mm of out-focusing length, 40 mm of line spacing, and 1100 mm/s of scan speed.

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