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Nathan E. Glauvitz

LaVerne A. Starman
Air Force Institute of Technology

Ronald A. Coutu Jr.
Air Force Institute of Technology

Richard L. Johnston

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Effects of SU-8 Cross-linking on Flip-Chip Bond Strength when Assembling and Packaging MEMS

Nathan E. Glavitz, LaVern A. Starman, Ronald A. Coutu Jr., and Richard L. Johnston

Air Force Institute of Technology, 2950 Hobson Way, Dayton, OH 45433, USA

Abstract

New methods to assemble, integrate, and package micro devices are always needed in attempts to simplify and expedite fabrication methods to maximize throughput. Our paper focuses on assessing SU-8 as a viable material for packaging and flip chip bonding processes for MEMS and micro devices. In this paper, we vary the level of cross-linking through post exposure bake (PEB) times and assess rectangular ring test structures bonding strength following flip chip bonding through applied tensile loads. In addition, we performed initial assessments on the etching resiliency of varied cross-linking of SU-8. From initial results, the bonding strength is maximized following a 3-min PEB. Cross-linking appears to have minimal effects on SU-8's etch resiliency as all tested samples etched approximately 1.25 µm. From our initial results, SU-8 appears to be a viable and inexpensive material for wafer bonding, assembling and packaging MEMS devices.

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Keywords: SU-8; flip-chip bonding; cross-linking; MEMS

1. Introduction

New methods to assemble, integrate, and package micro scale devices are always in high demand to reduce costs and increase throughput. This paper reports on a systematic investigation of bond strength when using SU-8 as a flip chip bonding material. Currently, literature contains very few published works in this area. In fact, a single reference reports on photonic devices and microelectromechanical systems (MEMS) structures being flip bonded together using SU-8 as the bonding material [1]. In that paper, Ochoa *et al.* demonstrate that 2µm-thick, 50µm x 50µm SU-8 bond pads, flip bonded at 135°C with a 1-kg applied load, provides the highest bond strength for their optical MEMS application. Bond strength was described qualitatively by how well the bonded pieces stood up to additional processing. The "best"

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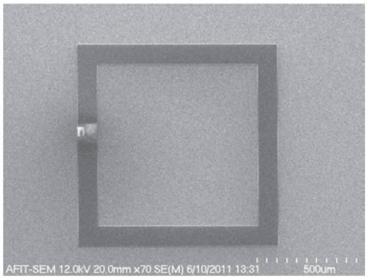
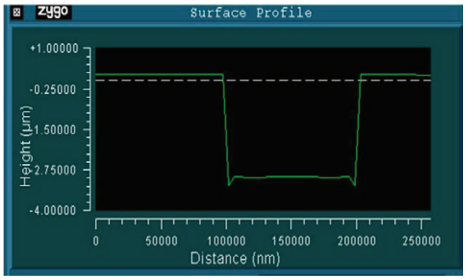
bonds withstood all additional processing steps but the bond strength was not quantified and the state of the SU-8 material was not discussed. In this study, flip bonding parameters (i.e. temperature and applied load) were held constant while the level of SU-8 crosslinking was systematically varied.

2. Fabrication

A series of SU-8 rectangular ring test structures (Figure 1a) were designed and fabricated to be used to test the bonding strength and resistance to etching with respect to various cross-linking levels. The silicon wafer was coated with SU-8 at a spread cycle of 500 rpm for 5-sec and immediately followed by a spin cycle of 3000 rpm for 30-sec. From an interferometric microscope surface profile, the spin cycle results in an SU-8 step height of ~3 µm thick. Next, a two step pre-exposure soft bake was performed at 65°C for 3-min followed by a 95°C bake for 10-min. The soft bake is performed to evaporate the solvent and densify the film [2]. All samples underwent an 8-sec UV flood exposure followed by a 65°C, 3-min post exposure bake (PEB). The test samples then had an 110°C PEB which varied from 1-min to 10-min in an attempt to vary the cross-linking between samples. Cross-linking is controlled by adjusting either the UV flood exposure time or the PEB time [2]. The samples are then placed in MicroChem's SU-8 developer for 2-min followed by a 1-min DI water rinse. The samples are then bonded together for strength testing.



(a)



(b)

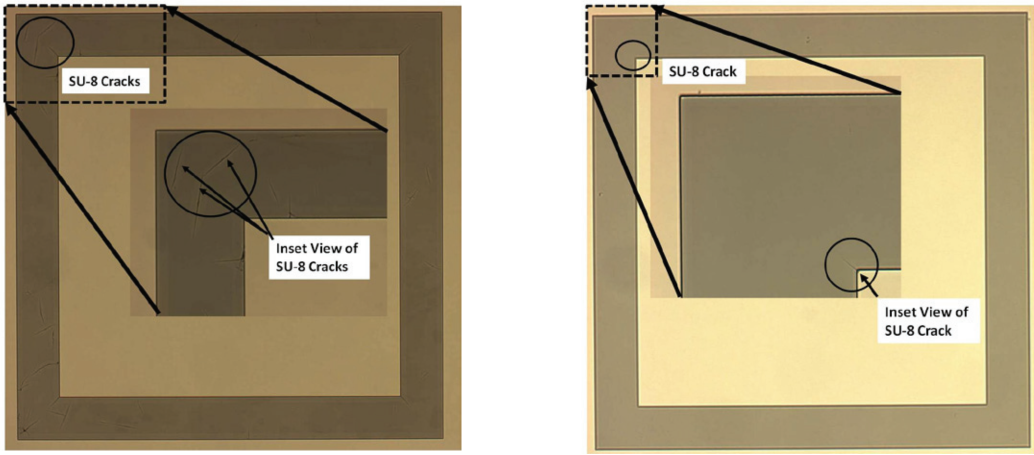
Figure 1 (a) Scanning electron microscope (SEM) image of a pre-bonded 1mm x 1mm SU-8 rectangular bonding ring (150µm-wide) test structure, (b) IFM surface profile of the SU-8 ring showing ~3 µm step height of the SU-8 rectangular ring.

3. Bonding Sequence

Rectangular ring test structures were bonded together using a Semiconductor Equipment Corp. Eagle 860 flip chip bonder. During the flip chip bonding sequence, both the stage and tip had a set point temperature of 125°C. Both the stage and tip would rapidly heat up to 150°C during the actual bonding phase. The bond pressure was set to 50 grams, once the 150°C bonding temperature was reached, the bonding pressure rapidly increased to 100 grams for 10-sec. The bonding cycle is composed of three steps: 1) the ramp up time (time required to reach 150°C) was ~9-sec, 2) bonding phase (temperature at 150°C and 100 gram load) set for 10-sec, and 3) the ramp down time (cooling to 125°C) took ~15-sec utilizing nitrogen air flow. The entire bonding sequence from die alignment to bonding sequence was expedited to minimize temperature effects on the SU-8 cross linking.

4. Experimental Results

Catastrophic adhesion failure, severely negative sidewalls and excessive cracking often indicate an under cross-linking condition. Methods to correct this problem include increasing the exposure dose and/or increasing the PEB time [2]. Through optical observation, noticeable cracks were present on all samples regardless of PEB time. The 1-min PEB sample had significant cracking throughout the rectangular ring as shown in Figure 2(a). Samples with 3-min or longer PEB still showed cracking but to a far lesser degree with cracks primarily confined to the inner corners of the ring as shown in Figure 1(b). As stated, a longer PEB should provide a higher degree of cross-linking in the SU-8 polymer material. Further analysis of cracking was assessed using an SEM, but no noticeable cracks are visible on either the 1-min (Figure 3(a)) or 10-min (Figure 3(b)) PEB samples. Cracks may still exist but were not visible due to significant charging of the SU-8 surface and the angle of incidence.



(a) (b)

Figure 2. Optical images of cracking following SU-8 110°C post-bake and development (a) 1-min post bake, (b) 10-min post bake

(a) (b)

Figure 3. Close up SEM image of an SU-8 rectangular ring corner showing no noticeable cracks, a) 1-min PEB, b) 10-min PEB.

Following the flip chip bonding of the test samples, the bond strength was systematically tested through the use of applied tensile loads. Bonded 2mm x 2mm rectangular bonding rings with the SU-8 ring being 200 μm-wide were tested. Various levels of SU-8 cross-linking and surface features are examined and correlated to bond strength. From initial testing results shown in Table 1, it appears there is an ideal PEB time which provides optimal packaging bond strength. To assess the resiliency to etching of the various cross-linking samples, an O_2 plasma etch was performed on the SU-8 samples. To mitigate etching variations, all samples were etched simultaneously for 4-min in a reactive ion etch (RIE) with the RF power set to 100 W, pressure set to 0.5 Torr, with an O_2 flow rate of 21.05 sccm. From initial results, PEB times appear to have minimal effects on SU-8 resiliency to etching since all samples etched approximately 1 to 1.25 μm.

Table 1. PEB times to correlate level of cross-linking to bond strength

PEB Time (minutes)	Separation Load (grams)
1	35
2	50
3	190
4	30
10	20

Figure 4a shows an optical pre-bond structure (3-min PEB) while Figure 4b is the identical structure after being separated with ~170-g tensile load. Figure 4b shows material transfer between the upper and lower rings, on the left side of the structure, indicating areas of high bond strength between structures. In comparison to other measured PEB bond strengths, these results indicate a direct connection between bond strength and degree of cross-linking. Feng and Farris found the glass-transition temperature to be an important factor in establishing the degree of cross-linking in SU-8 thin film layers [3].

(a) (b)

Figure 4. Optical images of pre-bonded post-test SU-8 structures (a) pre-bonded structure (b) post-test structure after separation with ~160-g tensile load.

5. Conclusion

In this paper we presented the initial results of our experimental testing to quantify the effects of SU-8 cross-linking on the bond strength and etching resiliency. SU-8 appears to have an ideal cross-linking level which maximizes the bond strength for potential packaging of MEMS or other micro devices. From our results, the level of cross-linking has minimal effects on SU-8's resiliency to etching.

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