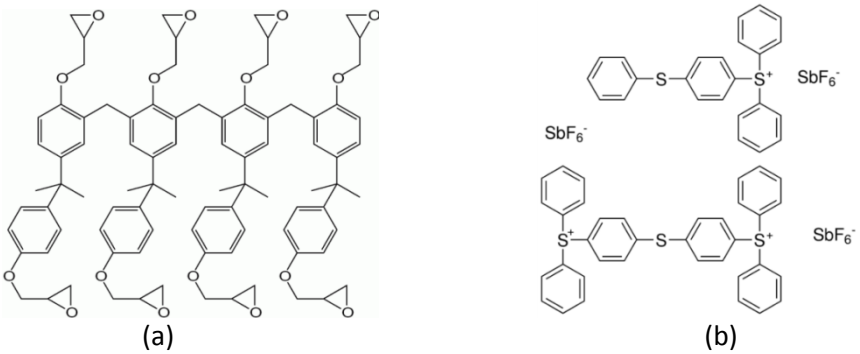
1. Introduction

Integration and packaging of three dimensional microelectromechanical systems (MEMS), nanoelectromechanical systems (NEMS) and optoelectronics are imperative processes to protect the sensitive internal structures from environmental influences such as high pressure, temperature, moisture, and reactive oxidizing species, by ensuring a mechanically stable and hermetically sealed encapsulation. Wafer level bonding at low temperature is strongly demanded because of its low cost and proven compatibility with some already formed structures and integrated circuits. Adhesive bonding using polymers, such as SU-8, benzocyclobutene (BCB), and poly(methyl methacrylate) (PMMA), has been reported to meet this demand.[1,2,3,4] The goal of this project is to perform on-site inspection of adhesive bonding using a typical photoresist, SU-8, through wafer level bonding at Quattrone Nanofabrication Facility (QNF). The present technical note describes troubleshooting on the sample preparation for the SU-8 to SU-8 wafer level bonding.

2. SU-8 photoresist

SU-8 is commonly used as a negative photoresist to fabricate intricate micromechanical structures, owing to its good mechanical properties, water insolubility, biocompatibility, and chemical durability after polymerization.[5] SU-8 is composed of (a) the tetramer of Novolac epoxy compound and (b) triarylium sulphonium salts as a photoacid generator (PAG) or a photo initiator, shown in scheme 1, although some oligomers (monomer, dimer, and trimer) of the epoxy compound and solvent are also present.[6] The name SU-8 comes from the number of the epoxy group ( ).



(a) (b)

Scheme 1. Molecular structures of (a) tetramer of Bisphenol A Novolac epoxy and (b) triarylium sulphonium salts

Typical processes of patterning with SU-8 photoresist involve (1) layer preparation, (2) pre-exposure bake for solvent removal, (3) UV exposure at 365 nm for generation of the photo-acid,[7] (4) post-exposure bake for the cross-link reaction initiated by photo-acid generation, (5) development of the photoresist film. On the other hand, it has been reported that some cracking and/or pits are caused in the steps (2), (4), and/or (5), by the film stress due to intrinsic shrinkage in the SU-8 film.[5,6,8]

3. Materials and cleaning

Microchem SU-8 2050 was used for 50 µm thick film preparation. Free standing 100 µm thick dry films of SU-8 were purchased from DJ MICROLAMINATES (SUEX K100). 4" diameter silicon (Si) and glass (borofloat) wafers were sonicated in acetone and then in isopropyl alcohol (IPA) for 5 min each, and dried using nitrogen gas, before use.

4. Layer preparation

4.1 Microchem SU-8 2050 for wafer level bonding

SU-8 2050 viscous solution was poured into the vial, and was kept still at room temperature overnight to remove bubbles from the solution. The 2050 solution was carefully poured on the 4" Si wafer, and was spread at 500 rpm for 5 sec, followed by spin coating at 3000 rpm for 60 sec. The 50 µm thick SU-8 was baked at 65 °C for 3 min, followed by baking at 95 °C for 6 min, to remove the solvent. However, the thick SU-8 film spin-coated from the viscous solution had an uneven surface and edge bead that lower the yield of wafer level bonding, as depicted in figure 1.

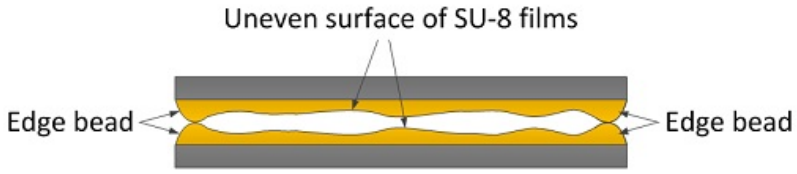
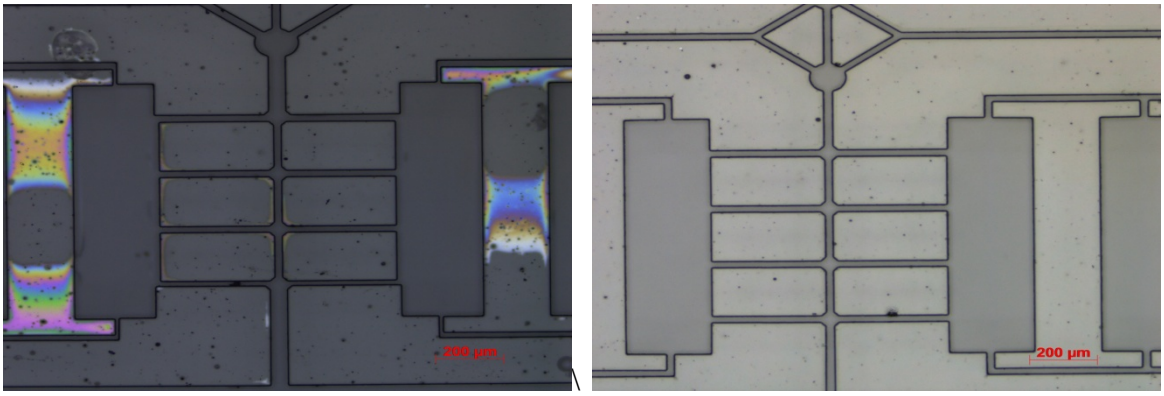


Figure 1. Cross-section of wafer level bonding of SU-8 films spin coated from SU-8 2050 viscous solution

4.2 Lamination of SU-8 dry film for wafer level bonding

The Si and glass wafers were pre-heated at 65 and 85 ^{0}C, respectively, on a hot plate for 2 minutes for improved adhesion and surface quality. The temperature applied to the glass wafer was increased by 20 °C due to relatively poor thermal conductivity of glass. When the pre-heat temperature of the glass wafer was the same as that of the Si wafer, partial delamination of SU-8 film was observed after development. Figure 2 shows optical microscope images of SU-8 films on the glass wafers pre-heated at (a) 65 and (b) 85 °C, indicating interference colors due to the partial delamination of the SU-8 film when pre-heated at 65 °C.



(a) (b)

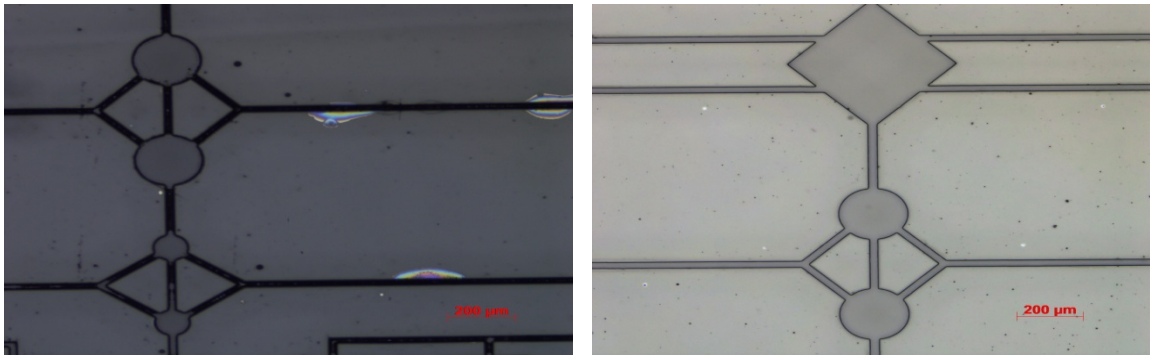
Figure 2. Optical microscope images of SU-8 films on the glass wafers pre-heated at (a) 65 and (b) 85 ^{0}C.

One of the protective PET films sandwiched on the 100 µm thick SU-8 dry film was removed, and was placed it on the Si and/or glass wafer, keeping the other protective film on the top of the SU-8 film. The wafer was rested on a ~ 0.5 mm thick metal plate, and the SU-8 film was laminated at 65^{0}C on the Si or glass wafer by rolling it, with the metal plate on

bottom, through the laminator. The lamination was carried out twice. It was confirmed that the SU-8 film had a flat surface and no cracking. The wafer level bonding was tested using SU-8 dry film based on the above result.

5. UV exposure for generation of the photo initiator using SUSS MicroTec MA6 Gen3 Mask Aligner

The SU-8 films on the Si and glass wafer were pre-baked at 65 and 85 ^{o}C, respectively, for 5 min on a hot plate, and the other PET layer on the SU-8 films were removed. The reason behind the applied temperature difference between Si and glass is the same as stated above in section 4.2. Then, the SU-8 films on the Si and glass wafers were exposed to 365 nm UV light[9] through the photomasks with an exposure dose of 900 and 990 mJ/cm^2, respectively, using SUSS MicroTec MA6 Gen3 Mask Aligner, although it was recommended that the exposure intensity on glass should be 1.5 times higher than that on silicon.[10] Figure 3 shows optical microscope images of SU-8 films on the glass wafers exposed at (a) 1350 and (b) 990 mJ/cm^2. When the glass wafer was exposed with 1.5 time higher intensity, the unexposed area was also cross-linked due to strong back reflection.



(a) (b)

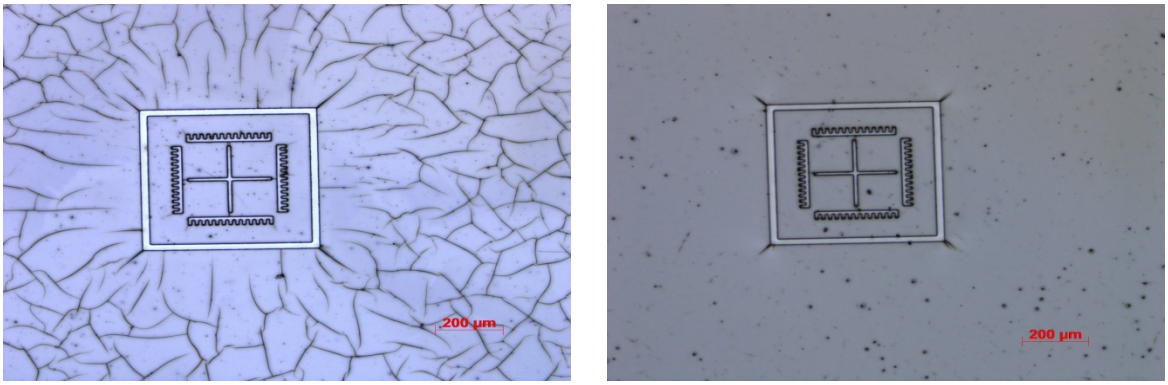
Figure 3. Optical microscope images of SU-8 films on the glass wafers exposed at (a) 1350 and (b) 990 mJ/cm^2.

6. Post-exposure bake for the cross-link reaction

The SU-8 films on the Si wafers were post-exposure baked under the following two conditions; (1) the default, 65 °C for 5 min, and then 95 °C for 10 min; (2) the customized, gradual ramping up of temperature from 65 °C for 5 min via 70 °C for 5 min to 75 °C for 5 min, and then very slow cooling down to room temperature after taking the wafer out of a hot plate for at least 3 hours (preferably overnight). During the cooling down, the SU-8 film was covered with a petri dish to reduce rapid cooling of top surface due to air flow. One side cooling develops comprehensive stress at the active cooled side and tensile stress on the opposite passive cooled side.[5]

Figure 4 shows optical microscope images of the SU-8 films prepared on the Si wafer by (a) the default condition and (b) the customized condition, after development. Figure 4(a) shows many cracks due to the shrinkage in the exposed regions, whereas figure 4(b) indicates no cracking at all. This indicates that thermal stress is a major reason behind the cracking.[5,6] Sudden rise in temperature from 65^{0}C to 95^{0}C during post-exposure bake, longer baking times, and rapid temperature drop due to sudden immersion of hot baked wafer in the cold developer results in enormous stresses, leading to cracks. Exposed resin has a lower coefficient of thermal expansion than the unexposed resin. So, during

cross-linking, shear force due to larger expansion of the exposed resin combined with surface tension causes the exposed SU-8 layer in the upward boundary to develop cracks. A fraction of the volume shrinkage in SU-8 film can also be attributed to the loss of material during development,[6] although it has been reported that a post-development baking can reduce the film stress.[11]



(a) (b)

Figure 4. Optical microscope images of the SU-8 films baked at (a) the default condition and (b) the customized condition after development. The default baking condition was 65 °C for 5 min, and then at 95 °C for 10 min. The customized baking condition was gradual ramping up of temperature from 65 °C for 5 min via 70 °C for 5 min to 75 °C for 5 min, and then very slow cooling down to room temperature (at least 3 hours). During the cooling down, the SU-8 film was covered with a petri dish to reduce rapid cooling of top surface due to air flow.

The SU-8 films on the glass wafers were also post-exposure baked in the manner similar to the above. The customized baking condition was gradual ramping up of temperature from 85 ^{0}C for 5 min via 95 ^{0}C for 5 min to 105 ^{0}C for 5 min, and finally 115 ^{0}C for 5 min, and very slow cooling down to room temperature after taking the wafer out of a hot plate for at least 3 hours (preferably overnight). The wafer was covered with a petri dish during cooling down.

7. Development

The SU-8 films were developed in the SU-8 developer in a fashion that the SU-8 film sides on the wafers were faced up for 5 min with constant shaking and then were faced down for 25 min. The wafers were rinsed with IPA and dried using nitrogen gas.

8. Summary

The present technical note reported the sample preparation for SU-8 to SU8 wafer level bonding, using Microchem SU-8 2050 and SU-8 dry film (SUEX). The SU-8 film spin coated from Microchem SU-8 2050 viscous solution suffered from uneven surface and edge bead that lower the yield of wafer level bonding. On the other hand, the SU-8 dry film did not show such problems. However, the partial delamination of the SU-8 film on the glass wafer, the proximity effect on the glass wafer, and the cracking in the SU-8 film were observed. The partial delamination of the SU-8 film on the glass wafer was solved by increase in the pre- and post-exposure bake temperature by 20 °C to account for the poor thermal

conductivity of glass, for improved adhesion and surface quality. The proximity effect was corrected by decrease in the light exposure. The cracking in the SU-8 film disappeared by optimizing the post-exposure baking temperature.

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