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ADHESIVE BONDING WITH SU-8 AT WAFER LEVEL FOR MICROFLUIDIC DEVICES

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Abstract. The present work proposes an adhesive bonding technique, at wafer level, using SU-8 negative photoresist as intermediate layer. The adhesive was selective imprint on one of the bonding surface. The main applications are in microfluidic area where a low temperature bonding is required. The method consists of three major steps. First the adhesive layer is deposited on one of the bonding surface by contact imprinting from a dummy wafer where the SU-8 photoresist was initially spun, or from a Teflon cylinder. Second, the wafers to be bonded are placed in contact and aligned. In the last step, the bonding process is performed at temperatures between 100^{O}C and 200^{O}C, a pressure of 1000 N in vacuum on a classical wafer bonding system. The results indicate a low stress value induced by the bonding technique. In the same time the process presents a high yield: 95-100%. The technique was successfully tested in the fabrication process of a dielectrophoretic device.

Keywords: wafer-to-wafer bonding, adhesive bonding, SU-8 photoresist, contact imprinting.

1. INTRODUCTION

The bonding at wafer level is an industrial proven fabrication process very common in packaging of MEMS devices. The available bonding techniques used for industrial or research applications can be classified as: silicon fusion bonding [1], low temperature direct bonding [2], anodic bonding [3], eutectic bonding [4], glass-frit bonding [5] and adhesive bonding [6-9].

Silicon fusion bonding requires processing at high temperature (usually 800-1100^{O}C) also the roughness of the surface is a very important parameter. As a result, the application area is limited. Low temperature bonding of silicon wafer is a process that starts to be developed recently using plasma activation of the surface. The bonding temperature is sensitively low (200-400^{O}C) but the bonding quality is influenced by surface roughness, particles, and planarity of the wafers. Anodic bonding is a well establishes process in MEMS industry. The bonding temperature is in the range of 300-450^{O}C and the process requires a good quality of the surface. Eutectic bonding is another low temperature process but is a technique with a reduced yield and very sensitive to contamination. Glass frit bonding starts to be used in industry, especially due to the low cost fabrication process, as an alternative to anodic bonding. It is considered to be a "dirty" process and for this reason is applied more on not active surfaces.

Aadhesive bonding enables joining of silicon or glass wafers at lower temperatures (usually below 200°C). The technique is less dependent of the substrate material, particles, surface roughness and planarity of the bonding surfaces [6]. The opportunity of using standard microfabrication deposition and patterning collaborated with the low demands on the wafer surface offer low-cost processing solution.

Several lithographic patternable materials such as bencocyclobutene (BCB), positive and negative photoresist have already been studied as intermediate layers for adhesive wafer bonding. Beside BCB the epoxy based negative photoresist SU-8 shows best results in bonding experiments [7, 8]. The advantages of SU-8 are its flexibility of layer thickness up to several hundreds of micrometers, its high chemical and thermal stability as well as its good mechanical properties.

Here, we propose an adhesive bonding method at wafer level using SU-8 photoresist as intermediate layer. The layer was selective deposited on one of the bonding surface by contact imprinting method. The proposed technique is suitable in applications where the classical method for coating (spinning) cannot be successfully used (wafers with non-planar surface or with free standing structures) such as microfluidic devices.

2. SELECTIVE IMPRINTING

For some applications the adhesive layer cannot be applied directly using classical spinning method. An exemplification can be a cover die for a pressure sensor bonded using SU-8. If the adhesive layer is applied, for example, by spinning on one of the pressure sensor surface, the performance of the device can be affected by modification of the elastic properties of the diaphragm, by the stress induced in the piezoresistors and also by changing the diaphragm thickness. For this reason a deposition of this layer on pressure sensor wafer is not possible. The deposition of the adhesive layer on silicon cover die by spinning is also not possible due to the nonplanarity of the wafer (the cover wafer, has an etching area of 20 µm deep that allows the diaphragm deflection). The layer deposited by spinning on a non-planar wafer cannot be uniform. For these reasons the only solution available for an adhesive bonding is stamping the layer on one of the surface, followed by the alignment and bonding process.

The first step for the adhesive bonding process is the selection of the solution. The SU-8 negative photoresist is fabricated in a large range of viscosity according to the thickness range of the targeted layer. For bonding application where a thin interlayer is desired an adhesive with a low kinematic viscosity such as SU8-5 (265 cSt) was selected. The thickness of the deposited layer can play an important role in the stress induced in the very sensitive MEMS structure (a thick adhesive layer can generate a high value of stress).

The main steps of the contact imprinting bonding process are presented in Figure 1. For exemplification a cover wafer was bonded over a wafer with membranes. First a thin layer of SU8-5 is applied on a dummy silicon wafer that was first treated with HNO_3 to obtain a hydrophilic surface. The SU-8 5 photoresist was spun in two steps (for a uniform thickness of the layer) using a CEE spin coater: 500 rpm / 15 seconds and 3000 rpm /60 seconds. The resultant thickness of the SU-8 5 layer was 12 µm (Figure 1a). The cover wafer was then brought in contact with the transfer wafer (Figure 1b). The detachment between these wafers (Figure 1c) was performed on a vacuum hot plate at 150 ^{O}C using a blade. Heating the SU-8 5 on this temperature (for a short time) will decrease the viscosity and will help the release of the cover wafer. The adhesion of the SU-8 5 on the contact surface of the cover wafer was good (hydrophilic surface). In the next step, both structured wafers were aligned and brought in contact (Figure 1d) using an EVG mask aligner. The last step wafer-to-wafer bonding was performed on an EVG wafer bonder at different temperature between 100 ^{O}C and 200 ^{O}C for 30 minutes at an applied force of 1000 N in vacuum at 10^{-3} mbar (Figure 1e).

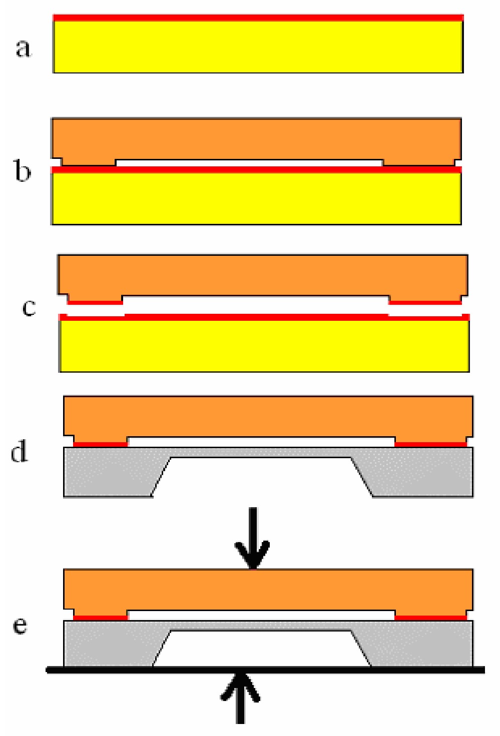

Figure 1. a) Spinning of SU8-5 photoresist on a dummy wafer, b) contact imprinting of SU8-5 photoresist by attachment of cover wafer on the dummy wafer, c) detachment of cover wafer d) alignment and contact, e) wafer-to-wafer bonding.

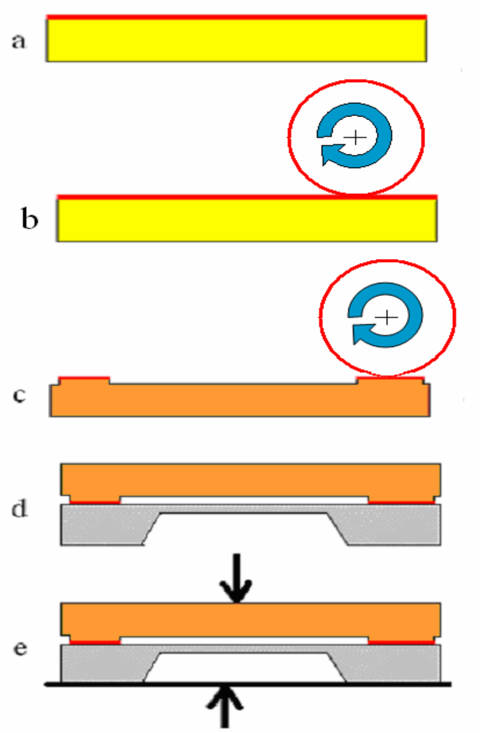

Figure 2. a) Spinning of SU8-5 photoresist on a dummy wafer, b) contact imprinting of SU8-5 photoresist on a Teflon cylinder, c) imprinting of SU8 from the Teflon cylinder on the wafer surface, d) alignment and contact, e) wafer-to-wafer bonding.

Another technique was developed specially for devices where the bonding area is quite large (lets say more then 70%). In such cases the adhesion between the dummy wafer and the bondable surface of the wafer is high, so the detachment can be very difficult. A solution is to use a Teflon cylinder for transferring the SU8 adhesive. The process is illustrated in Figure 2. For the first step (Figure 2a) a large silicon wafer (6”) was used for the deposition of the SU8 photoresist. The wafer preparation and the deposition were similar with the process previously presented. The next step is the transfer of the adhesive layer onto the surface of a Teflon cylinder with a diameter of 38 mm and a length of 120mm. The process is illustrated in Figure 3. In the next step, the cylinder is rolled on the bonding surface and the adhesive layer is partially transferred on this surface (Figure 2c). The last two steps of the process: aligning of the wafer (Figure 2d) and wafer bonding (Figure 2e) are identical with the process previously described in Figure 1.

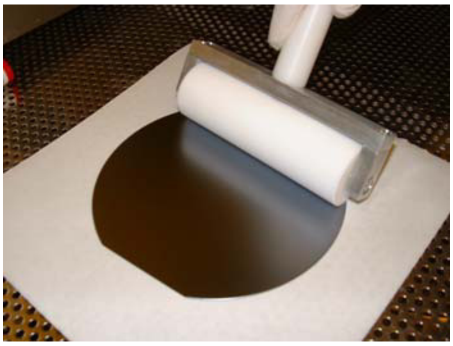

Figure 3. Imprinting of the SU8 layer from a dummy wafer (6”) to the Teflon cylinder.

The testing of this technique was performed on planar and non-planar wafers (20 µm deep etched areas). For a quick analysis of the bonded surface, one of the bonded wafers was selected to be glass. In this way the unbonded areas can be observed without any special equipment. For the non-planar wafers a square pattern 3mm x 3mm, on a square chip 4mm x 4mm was etched 20µm deep using deep RIE (Adixen AMS 100) through a 2µm thick aluminum mask. The results show a fully bonded area even for planar wafers. Figure 4 shows the cross section of bonded wafers. The images were performed after the bonded wafers were diced on DISCO 3350 equipment. The dicing process can be considered as a bonding test - the bonding must be strong enough to overcome the generated force during the dicing. In Figure 5a, a detailed image is presented with the resultant thickness of the adhesive layer. It can be observed that the thickness of the SU-8 layer after the bonding is around 2 µm. Figure 5b shows that the surplus adhesive is deposited in the vicinity of the bonded area (the cross-sectional area is around 20 µm x 20 µm).

Figure 5 presents the optical image with fully bonded and partially bonded areas. The yield of bonding process was high (in the range of 95% to 100%), similar to the performance with anodic bonding technique.

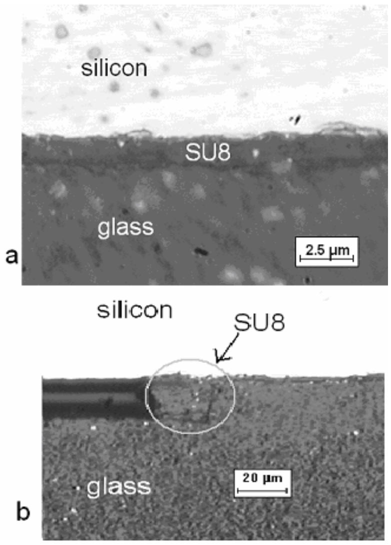

Figure 4. Optical image with cross s

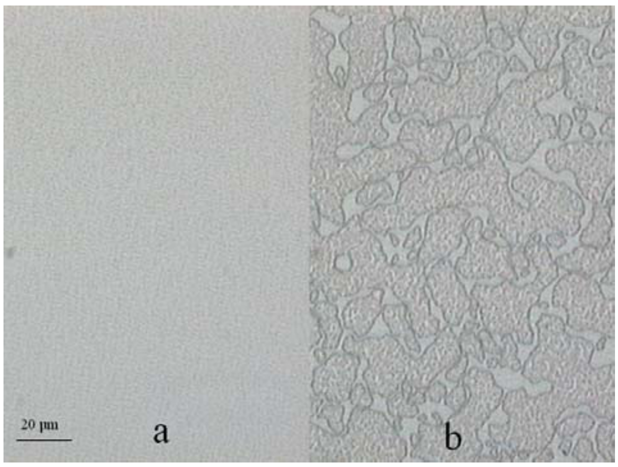

Figure 5. a) Fully bonded area and b) partially bonded area.

3. CHARACTERIZATION OF THE SU8 LAYER AND BONDING TECHNIQUE

For the wafer-to-wafer bonding process a critical parameter is the stress induced by the bonding technique resulting as the residual stress in the adhesive layer. The residual stress in the adhesive layer was measured using a classical stress measurement system (KLA Tencor). A 12 μm- thick SU-8 5 layer was deposited by spinning. After curing at 65^{O}C for 2 minutes and at 90^{O}C for 10 minutes the layer was UV exposed with a dose of 100 mJ/cm^2. The results indicated stress value in the range of 20 to 40 MPa tensile. These values as well as the good elastic properties (Young modulus in the range of 2 to 4 GPa) and its high chemical and thermal stability (glass-transition temperature above 200°C) shows that SU-8 photoresist is a suitable material for wafer-to-wafer adhesive bonding.

For the bonding strength test the full bonded wafers were diced using DISCO 3350 equipment into pieces of 6 mm by 6 mm. The dies were tested on an Instron 5848 microtester with a special design tool for shear strength measurement. The results indicated value in the range of 18-25 MPa for shear strength.

4. APPLICATION: MICROFLUIDIC DEVICES

The bonding technique described here was used in the fabrication process of dielectrophoretic (DEP) chip with 3D electrodes. The microfluidic device consists of three dies: two glasses (top and bottom) that formed the ceiling and the floor of the microfluidic channel and one conductive silicon die which defined the walls and at the same time the electrodes of the DEP device. In a first version presented in [9] the fabrication process was designed with two anodic bonding steps. The first anodic bonding was performed at a relatively low temperature (305^{O}C) and high voltage (1000 V) till the bonding current decreases to 40% of the initial value. In the second bonding process, the temperature and the voltage were increased (at 450^{O}C and 1500 V respectively) in order to increase the conductivity of the glass and the electrostatic clamping of the structure. A simplified process can be performed with the second bonding with SU-8 photoresist as the adhesive. As a result, the first bonding process can be completely performed (the bonding current decrease below 10% of the initial value). The second bonding process does not require a polished surface of the silicon, so the fabrication cost is decreased. The process assures a fully bonded area, without bubbles. The residual quantity of SU-8 photoresist, which is extracted from the interface during adhesive bonding process (due to the applied bonding pressure) does not affect the good functionality of the device. Figure 6 presents the results of the wafer-to-wafer bonding process (wafer with dielectrophoretic chip) while in Figure 7 the cross section through a microfluidic device fabricated in glass using adhesive bonding. The microfluidic channel is 20μm depth.

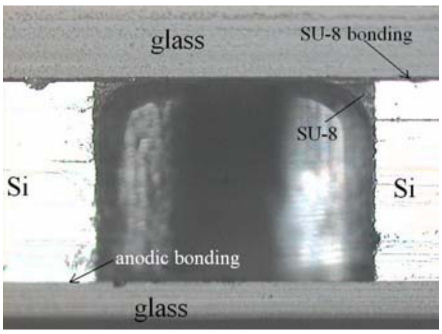

Figure 6. Microfluidic channel with bulk silicon walls and glass as ceiling and floor.

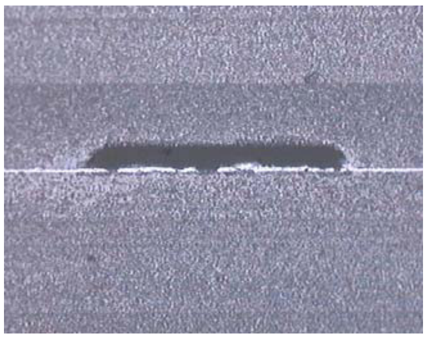

Figure 7. Microchannel performed using SU-8 photoresist adhesive bonding.

5. CONCLUSIONS

This paper presents a new bonding technique using SU-8 negative photoresist as the adhesive layer and contact imprinting as the method for photoresist deposition. The main advantages of the method are: low cost, high yield, low bonding temperature, low stress induced by the bonding process. The method is suitable especially when the classical spinning method cannot be performed due to the surface topography or device functionality. The bonding process was successfully tested for fabrication of microfluidic channels of bioMEMS devices.

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