SU-8-Based Fluidic Devices

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Introduction

During the last years SU-8 has become a widely used material for MEMS and miniaturized fluidic devices. It can be deposited by spin- or spray coating in a wide range of layer thicknesses. Because of the low UV absorption of the resist a standard UV mask aligner can be used for exposure, even for thick layers. Processing of SU-8 includes the following steps:

1. Deposition of the resist by spray- or spin coating

2. Drying at 95 °C on a hotplate

3. Exposure

4. Post exposure bake (PEB): Crosslinking of exposed resist

5. Development: unexposed resist is dissolved

6. Hardbake: The remaining structures are completely crosslinked. The resist gets its final mechanical strength and chemical stability.

Flow cell for Infrared Detection in Capillary Electrophoresis Systems

To use FTIR-spectroscopy as a powerful detection method in capillary electrophoresis an infrared transparent flow cell had to be designed because the fused silica capillaries normally used in CE are not transparent to IR. An appropriate material for infrared transparent devices is CaF_2. It shows very good optical properties, i.e. high transmittance in the mid-IR range (wavenumber 4000...700).

Fabrication of the CE cell

The cell consists of two plates of CaF_2, each 1 mm thick (see Fig. 1). On one of these plates there is a Titanium layer which acts as an optical aperture. This is necessary because with the given optical setup the IR-beam cannot be focused inside the flow channel only. The 200 nm thick titanium layer is deposited by evaporation and patterned by conventional lift-off technique. This metal structure must be completely isolated from the flow channel, otherwise gas bubbles would be produced by electrolysis.
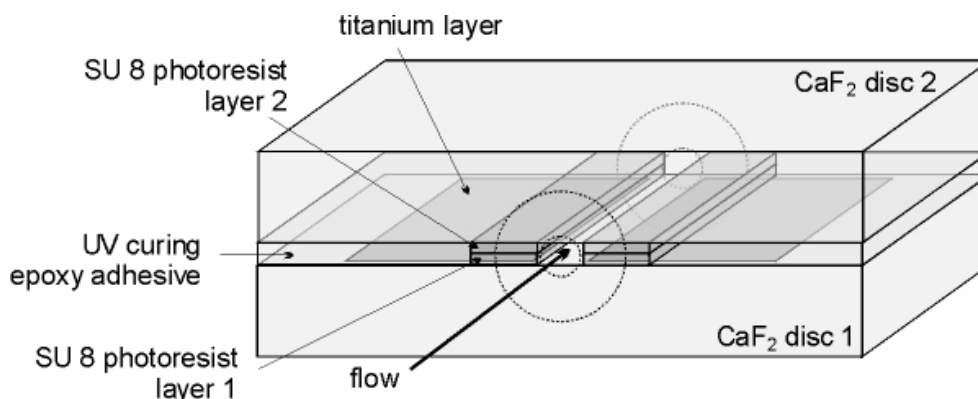
Fig. 1 Schematic drawing of the CE-cell

The channel is formed by two lines of SU-8 on each CaF_2 plate, each of them 100 µm wide. The distance between these two lines and thus the width of the channel is 150 µm. The height of the SU-8 lines is 7.5 µm, half of the desired height of the cell. The CaF_2 wafers (diameter 30 mm, thickness 1 mm) are spin-coated with SU-8 and softbaked. After UV-exposure using a SUSS MJB3 mask aligner and an appropriate photomask the resist is post-exposure-baked (90 °C for 10 min.) and developed. The unexposed and therefore not crosslinked areas are dissolved during the development process. The developer used is PGMEA (propylene glycol monomethyl ether acetate).

Two wafers (one with and one without metal structure) are superimposed, aligned and pressed against each other during the hardbake process. Consequently a bond is established between corresponding SU-8 structures because the hardbake temperature of 200 °C induces the complete crosslinking of the SU-8. This hardbake is necessary to achieve the full mechanical strength and chemical resistance of the SU-8.

Finally the area outside the SU-8 lines is filled with UV-curing epoxy adhesive (Delo Katiobond 4653) and the waferstack is diced with a dicing saw. We get 40 devices from one waferstack with a diameter of 30 mm. The final dimension of the cell is $2 \times 5 \times 2$ mm^3. The capillaries (I.D. 50 µm, O.D 360 µm) are coupled to the cell by means of a metal support and an elastic gasket that is applied to the tip of each capillary [1].

The two surfaces of each cell where the capillaries are coupled (inlet and outlet of the flow channel) are polished with 3 µm lapping film to achieve a tight connection between the capillaries and the cell. Results obtained with the help of this setup are discussed elsewhere [1], [4].

Micromixer for FTIR-Spectroscopy

This mixing device is used for the investigation of chemical reactions by FTIR-spectroscopy combined with in-situ mixing of two reactants. The IR-beam directly passes the mixing chamber. The optical pathlength (the height of the mixing chamber) is 10 µm (see Fig. 2). The optical pathlength should not exceed 20 µm because of the strong absorption of water and organic solvents in the mid-IR region, which otherwise would result in a bad signal-noise-ratio.

The mixing device is Y-shaped. Two sheets of liquid are superimposed inside the mixing chamber and mixed by diffusion. Because of the cross-section of the mixing chamber (1 mm wide, 10 µm high) the mixing time is approx. 50 ms. The mixer is used in the "stopped-flow-mode", i.e. the two liquids are injected by means of a double syringe pump. The two streams are separated by the separation membrane until they meet

inside the mixing chamber. This membrane is a 2 µm thick silver membrane. During the injection there is hardly any premixing. Then the flow is stopped, the reactants are mixed by vertical diffusion and the chemical reaction takes place. This reaction is investigated by time resolved FTIR-spectroscopy [2], [3]. The micromixer is fabricated by means of a 2-layer lithography, which combines SU-8 and metal, together with a polymer-based wafer bonding technique.
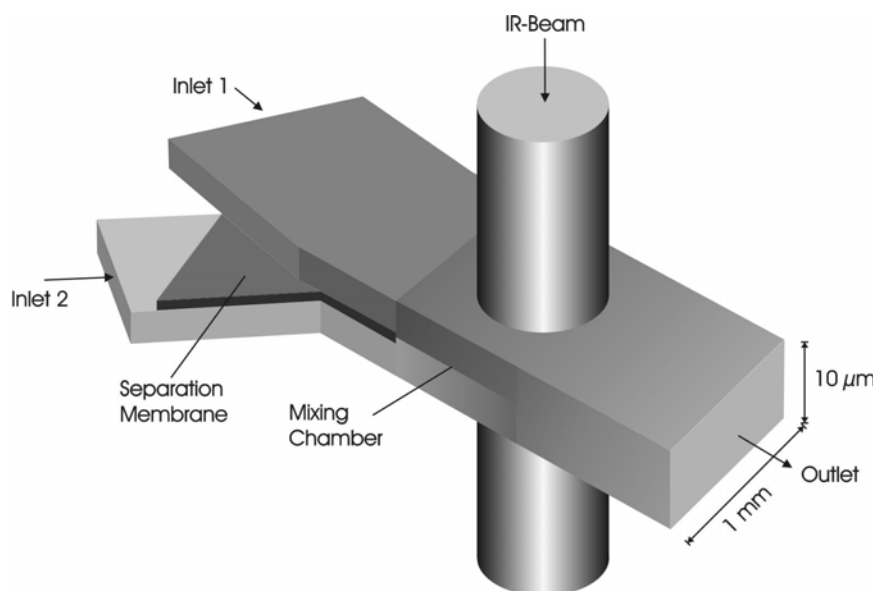

Fig. 2: Principle of the Micromixer (drawing not to scale)

Preparation of the Micromixer

As mentioned above, Calcium Fluoride is used as substrate material. The wafers which are used have a diameter of 100 mm, a thickness of 1 mm and are double side polished. A 4 µm thick layer of SU-8 is deposited by spin-coating onto both wafers. To achieve this layer thickness, the SU-8-50, which has a rather high viscosity, has to be diluted 4:1 (vol.) with GBL (gamma-butyro-lactone). Spin coating is done at 5000 rpm. After spin-coating the wafers are softbaked at 90 °C for 30 min. Exposure of wafer #1 is done by means of a SUSS MA 150 mask aligner. Wafer #1 is the bottom wafer. It carries the structures for inlet 2 and the separation membrane (see Fig. 2). Exposure is followed by a post-exposure bake at 90 °C for 10 min. The baking processes are performed using a hotplate.

To form the separation membrane a 2 µm thick metal layer is deposited by evaporation on top of the exposed (but undeveloped) SU-8 layer. We choose Ag as a material for this layer for two reasons: Evaporated Ag layers show no internal stress and therefore they do not bend when released. Additionally, it is possible to deposit Ag by thermal evaporation with relatively low power at a temperature well below 1000 °C. Consequently no UV light is generated, which would otherwise expose the wafer during the evaporation process, because the SU-8 layer is still sensitive to light. Evaporation is done in a Balzers BAK 550 evaporation system.

The Ag layer is then covered by positive photoresist AZ 1512 HS. The photoresist is processed as usual and the Ag layer is wet etched to form the structure of the separation membrane. As an etchant a 45% (WT) solution of $Fe(NO_3)_3$ in water is used. This solution does not attack the SU-8. The photomask for the Ag layer is compensated for the underetch of the Ag structure.

Finally the AZ positive resist is removed by undiluted developer AZ 400k and the SU-8 structure is developed with PGMEA. To dissolve unexposed SU-8 underneath the metal structure takes quite some time (approx. 2 hours for channels of 1 mm length). Wafer #1 now carries the structures of inlet 2 and the separation membrane (see Fig. 3). The narrow SU-8-lines inside the flow channel are necessary to guide the flow and to keep the Ag membrane in place.

On wafer #2 (the top wafer) the structure of inlet 2 is fabricated as usual from a 4 µm thick layer of SU-8. Subsequently the holes for 2 inlets and 1 outlet per mixer are drilled by means of a high speed spindle and diamond tools. So far the SU-8 structures on both wafers are not hardbaked and therefore the polymer is still able to establish a bond to other materials during hardbake.
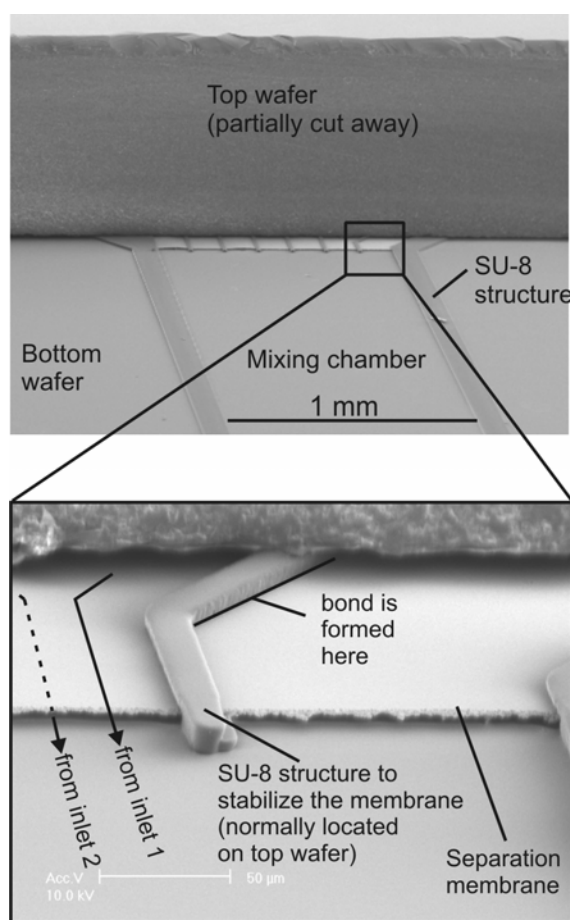
Fig. 3:   SEM micrograph of the mixing device with the top wafer partially cut away

To complete the production process of the micromixer both wafers need to be bonded together in order to form a closed fluidic structure. The simple bonding process which was described in this paper for bonding of the CE cell wafers can be applied for the micromixer as well, but shows a poor yield in this case.

SU-8 Wafer Bonding

Both wafers are superimposed to form a sandwich configuration, and aligned. Hardbaking is done in an EVG 501 wafer bonder. The wafers are pressed against each other with a contact force of 2000 N and heated to 180 °C for 1 hour. Because of this high

temperature the SU-8 is hardbaked and a bond is established between the SU-8 structure on the top wafer and the SU-8-Ag-structure on the bottom wafer (see Fig. 3).

A drawback of this bonding method is the fact that the layer thickness uniformity of spin-coated SU-8 layers is limited. For a layer thickness of approx. 4 µm we were able to achieve thickness differences as low as 0,05 µm. Due to these differences the corresponding structures are not completely in close contact. Therefore some voids remain after bonding.

To overcome this problem it is possible to increase the contact force. SU-8-structures which are not hardbaked are plastic and can be deformed. Consequently some gaps or voids can be closed if a higher contact force is applied. The required force depends on the contact area as well as on the aspect ratio of the structures to be bonded. For this reason this method is feasible for the CE-cell (higher structures, smaller wafers), but not for the micromixer (lower structures, larger wafers). If the structures are deformed too much, the desired shape and height of the fluidic structures can not be maintained and will vary throughout the wafer area.

Another way to avoid insufficient bonding is to add some soft "adhesive" which fills the gaps caused by non-uniform layer thickness. Again the material of choice is SU-8, but this time without UV exposure. Unexposed SU-8 is thermoplastic, and it even fills gaps because of capillary forces. SU-8 is crosslinked when heated to 150...200 °C – it behaves like thermally cured epoxy adhesive.

If SU-8 is used for building fluid structures and – in unexposed form – for waferbonding, the unexposed SU-8 has to be patterned. This method is described in Fig. 4:
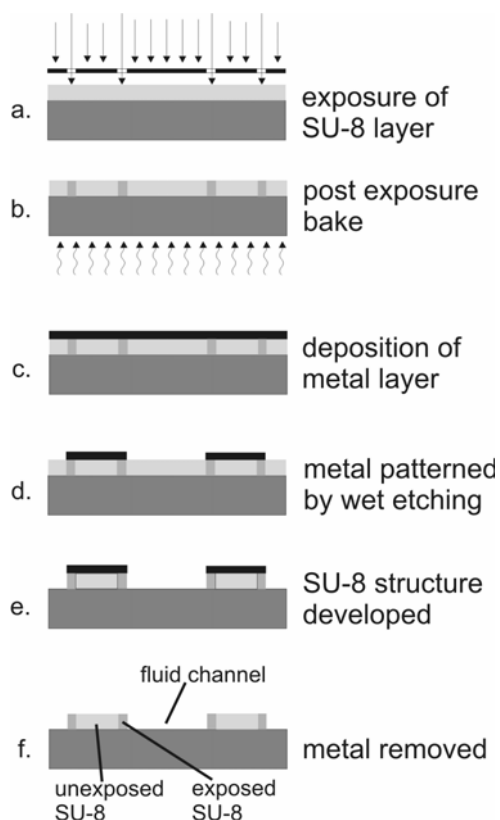

Fig. 4: Preparation of the top wafer for bonding. The drawing shows the cross-section of a channel and its sidewalls

After exposure and PEB (see Fig 4 (a) and (b)) a metal layer is deposited on top of the SU-8 layer by evaporation. This metal layer (1 µm Ag) is patterned by wet etching (see Fig. 4 (c) and (d)). Now the areas where unexposed SU-8 is necessary for bonding are surrounded by narrow lines of exposed (hard) SU-8 and covered by metal. After development of SU-8 and removal of the metal layer (see Fig. 4 (e) and (f)) the wafer is ready for bonding.

With this bonding method it is not necessary to apply a high contact force, because remaining gaps are closed by the unexposed (soft) SU-8. Therefore the structures are not deformed and their correct height and shape is maintained during the bonding process.

Alignment of the wafers for bonding is done in an EVG AL6 mask aligner. Then the waferstack is clamped to the bond tool and inserted into an EVG 501 wafer bonder.

Bond parameters are as follows:

1. Contact force of 1000 N is applied. Temperature of top and bottom heaters is ramped up to 180 °C with a ramp of 3 °C/min.

2. Temperature of 180 °C is maintained for 1 h

3. Temperature is ramped down to room temperature with a ramp of 2 °C/min.

4. Contact force is removed

Conclusion

With the method described in this paper it is possible to manufacture miniaturized fluidic devices in a batch process. The combination of SU-8 and metal layers allows building up structures which contain fluid channels in more than one plane.

Wafer bonding with SU-8 is a method for the batch fabrication of closed fluidic devices. If infrared transparent wafers are used these devices can be used for IR spectroscopy.

If hard and soft (i.e. exposed and unexposed) SU-8 is used in combination, this wafer bonding method is a means to overcome the problem of non-uniform layer thickness of the SU-8 layers. Additionally, this method allows the bonding of wafers which contain e.g. conducting lines or other structures that cause a topographic surface.

References

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