# Bonding and contacting of MEMS-structures on wafer level

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## Abstract

Effective and cost favorable procedures for hermetical encapsulation of MEMS-structures on wafer level can be fabricated by wafer bonding technologies like the seal glass bonding and by suitable connection technologies routing the electrical potential through the chip structure. Within the paper the parameters of the print and bonding process will be presented and the print process limits will be demonstrated by means of print and bonding results.

## Screen printing and bonding process development

Screen-printing is a method for the selective layer deposition of a specific material on flat surfaces. During the print process the material will be pressed through a textured screen (see Figure 1). For encapsulation of micro mechanical components by seal glass bonding it is necessary to create small structures of seal glass like bond frames at one of two substrates. To achieve this aim two different material types of screen fabric layers were evaluated. The two materials were polyester and stainless steel. The experiments showed that screens made of stainless steel are more suitable for printing smaller (< 200 µm) structures than polyester screens. A second important value to deposit enough glass material on the substrate is the mesh opening of the screen-printing fabric. After evaluating different sizes, a mesh opening of 50 µm proved to be the best solution.

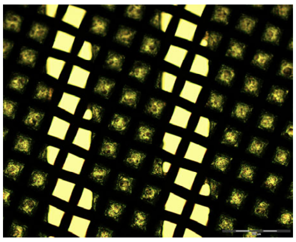


Figure 1: Structure of a textured stainless steel screen

Two different seal glasses were used for our experiments. At first the seal glass paste FX11-036 from Ferro Corp. was tested. The greatest thickness, which could be achieved with this glass, was 35 µm after printing. That means this structure is approx. 25 µm high after sealing. Such a printed line shows a typical profile. After printing an edge bulge of approximately 5µm height is visible on the feature edges. This bulge can prevent the direct contact between both substrates during the bonding process.

The seal glass needs three temperature-stepped treatments after deposition on the substrate. This procedure is necessary to evaporate all solvents, to drive out organic substances and to melt the glass. The parameters of these thermal treatments are given in figure 2. The annealing steps led to a reduction of surface roughness of glass paste but not to a decrease of the bulge height.

To bond with seal glass a temperature is needed, which enables the glass to decrease its viscosity. For FX11-036 this is at 450 °C. At this temperature a bond between two wafers can be established. For a good bond it is necessary to apply a pressure. The amount of pressure depends on the contact area between the wafers. Typical values are between 0.5 bar and 5 bar [5].

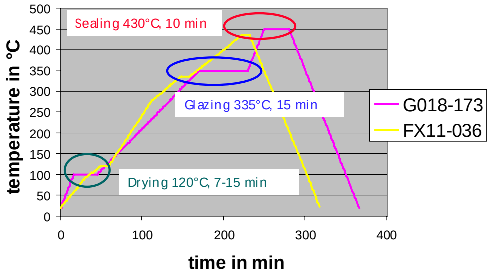


Figure 2: Thermal treatment of FX11-036 and G018-173 after printing

## Fabrication of gas-proof, electric feed throughs

A very simple version to fabricate electrical feed-through is the direct print of glass paste over prefabricated conducting paths. Our investigation concerning the electrical resistance and material interactions have shown that there is no influence from the paste material on the aluminums lines used as conductor material. It is also possible to embed the aluminum lines in the paste to create tight bonds.

Silicon Direct Bonding (SDB) is one of the most frequently used wafer level integration methods. In further experiments an improved SDB process with embedded access lines is investigated to fabricate a hermetical encapsulation with electrical connection from inside to outside of sensor components. This process may be utilized for the packaging of high quality factor micro sensors such as accelerometers or micro gyros.

## Fabrication Process

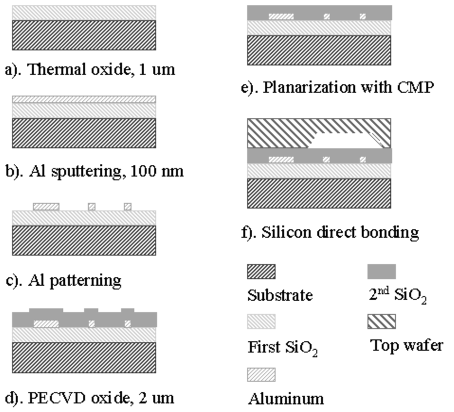


Fig 3. Major steps of the process procedure

The fabrication sequence of the proposed process is depicted in Fig 3. First, a layer of thermal oxide was formed on the surface of the substrate to act as insulation (Fig 3.a). Then a 100 nm thick aluminum film was sputtered (Fig 3.b). After the aluminum film was patterned (Fig 3.c), another layer of PECVD oxide was deposited directly onto it (Fig 3.d). The uneven surface of this shield oxide layer caused by the conductor lines underneath and was planarized afterwards by a Chemical Mechanical Polishing (CMP) process to achieve a bondable interface (Fig 3.e). Finally the wafer with embedded aluminum lines is bonded with a counter wafer to form a sealed encapsulation (Fig 3.f).

## Experiment Results

After the bonding process, the wafer pair was examined using an infrared (IR) microscope to verify the bonding quality. Fig. 4 presents the IR photo of a post-bonding chip. The absence of interference stripes indicates that the chip has been substantially bonded.

To further inspect the integrity of the interface and of the electrical connection after bonding, the bonding pair was divided into chips with a diamond cutter. The cross section of the wafers was observed using a Scanning Electronic Microscope (SEM). Fig 5 shows the results of such an examination, no gap was found along the bonding interface (Fig 5a). The connectivity of the Aluminium conducting lines was also retained after the dicing process, which guarantees the signal accessing ability of the encapsulated devices (Fig 5b). Note that the breaking process induces the ripples formed like waves in Fig 5a. They can be used as an indicator for the interface between the two wafers.

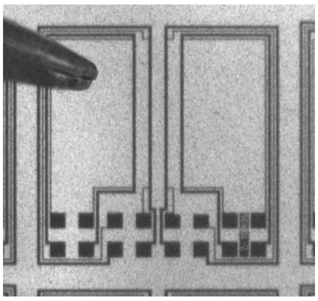
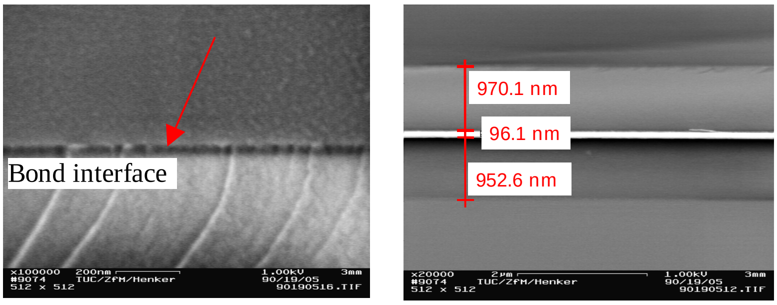


Fig 4. IR photo of a post bonding chip



a). Bonding interface

b). Embedded Al conducting lines

Fig 5. Cross-section SEM pictures of the wafer pair.

## Application

After successful investigation the process was applied to the fabrication of micro mechanical sensor, which should be packaged with vacuum inside. With this in mind a design was created. A cap wafer with wet etched holes for contacting was bonded, using the seal glass on a wafer with vibration sensor structures. In Figure 6 and 7 a cross section of the principle of such a capped sensor wafer and a SEM Picture of the mounted device are presented. In this example the electrical contacting of the MEMS structure is done by aluminum feed-throughs, which are going laterally through the seal glass. The contact pads located outside of the sensor cavity were wire bonded to bond pads patterned on the top of the cap wafer. The wire bonds are firmed with globe top. To contact the whole sensor system bumps for flip chip bonding are applied. Figure 8 shows the infrared image of such a sealed structure. The wiring layer on the top of the cap wafer, the holes in the cap wafer for wire bonding and the seal glass frame are visible.

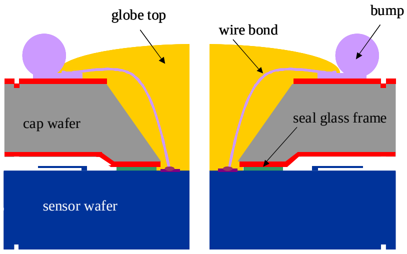


Figure 6: Cross section of a design for wafer level mems packaging

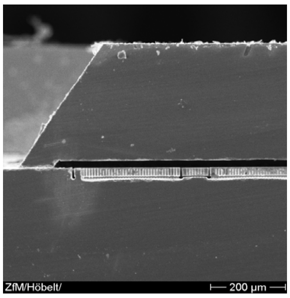


Figure 7: SEM cross section of seal glass bonded active structure with cap

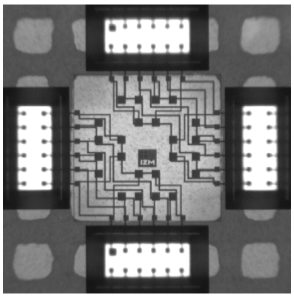


Figure 8: IR image of a seal glass bonded structure

## Conclusion

Our investigations of bonding and electrical connections have shown that it is possible to packages micro mechanical elements like vibrations sensors and to create a hermitically tight encapsulation of these devices. In our experiments the smallest achievable structure, fabricated by patterned deposition of glass paste with screen-printing, is between 170µm and 200µm wide and about 25 µm thick after sealing.

The electrical feed-throughs can be fabricated by printing the glass paste directly over the conducting lines leading the electrical signals through the bond frame or with aluminum lines embedded in oxides and nitride layers. Using this second version the components can be bonded together with a silicon direct bonding technique after a final polishing process creating smooth surfaces in the bond regions. The presented techniques are applicable to a wide spectrum of micro mechanical devices.

## References

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## Key words

Seal glass bonding, Glass frit bonding, Electrical feed-throughs, Micro mechanical devices, Screen-printing, Silicon direct bonding, Silicon micro machining