# COST-EFFECTIVE PROCESSING OF A PIEZORESISTIVE MEMS CANTILEVER SENSOR

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***Abstract* — In this paper cost-effective methods for fabrication of a piezoresistive cantilever sensor for industrial use are focused. The intended use of the presented cantilever is a medical application. A closer description of the cantilever design is given. The low-cost processing sequence is presented and each processing step is explained in detail. Results from electrical probing and mechanical strength test are given. The results demonstrate that the chosen low-cost processing route results in high yield and a mechanical robust device.**

***Keywords :* MEMS Processing, Micro Cantilever, Medical Sensor**

## I - Introduction

In this paper we focus on cost-effective methods for fabrication of a piezoresistive sensor element for industrial use. The production of a great many MEMS devices described in research papers has the aim of proof of concept to demonstrate a sensor, or an actuator principle, or to verify a new processing step or processing route. For this purpose the main interest is to get some - or at least one - working device. When developing a working device for the industry, however, a cost-effective production method with high yield is demanded.

For high-end products the costs are not necessarily critical; the obvious advantages of MEMS with small size, low energy consumption and reliable characteristics are often crucial, and the willingness to pay may be high to achieve these characteristics. For products in the low-end range, however, the MEMS industry has to compete with other engineering solutions, where price-per-element is the most critical factor.

One of the first MEMS elements ever realized for industrial use was a cantilever sensor developed by SI, Norway (now SINTEF), in the 1960s [1]. The cantilever sensor presented in this paper is designed for medical applications with respect to size and measurement range. However, MEMS cantilever devices have a number of application areas;

- measurement of mechanical properties as position, pressure, force, and acceleration [2-3]
- detection of attachment of biomolecules and DNA strands for use in biosensors [4-7]
- detection of changes in resonance frequency [8]
- actuating element [9]

For all the above mentioned application fields, alternative solutions do however exist. To ensure commercial success for MEMS cantilever devices, cost-effective fabrication methods and process flow are therefore necessary.

## II - Cantilever Design

The presented device is a piezoresistive Si/glass cantilever die used as a position sensor (Figure 1). The die consists of two parts; the silicon cantilever with integrated piezoresistors, and the glass support, which is bonded to the cantilever for assembly and easier handling. To obtain a mechanically robust device, the die is designed with a beveled transition area between the support and the cantilever arm for reduced stress-concentration (Figure 2).

Outer dimensions of the Si/glass cantilever die are (length, width, height): 6450 µm × 1040 µm × 1055 µm. Detailed measures of the die are given in Figure 3. The size is determined by the specific medical application. Reduced consumption of Si, and thereby reduced price-per-chip, is also a motivation for making the device very small. On a 6” Si wafer there are 1536 active dies.

Figure 1*: A piezoresistive silicon/glass cantilever die for position sensing*

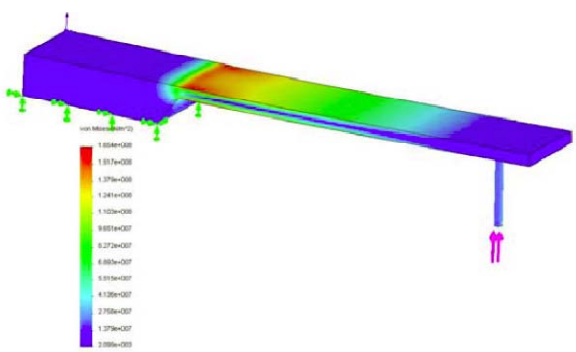

Figure 2: *FEM simulation of cantilever design. Red color indicates area with high stress concentration*

Four p-type piezoresistors form a Wheatstone bridge configuration. The nominal resistor values are 5 kΩ, and the bridge is designed for a 5 V bias voltage. A resistor equal to the bridge resistors is placed on the support of the cantilever and is not sensitive to strain induced in the cantilever. This resistor can be used for compensation of temperature induced effects. The bond pads and conductors are made of Al. The conductors stop 130 µm from the p-doped resistors to minimize tension induced by thermal expansion of the metal. The cantilever is designed for a maximum deflection of ± 70 µm.

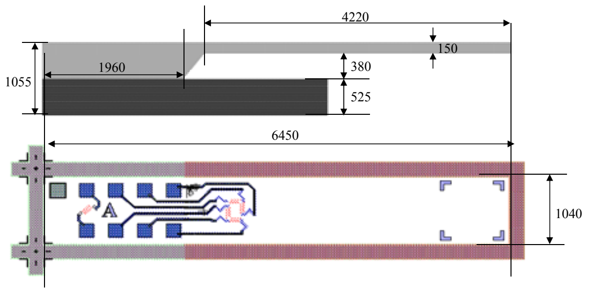


Figure 3: *Outline of the Si/glass cantilever die with a Wheatstone bridge and a fifth resistor for temperature compensation.*

When making the wafer design, the dies were arranged with every second column rotated 180 degrees. This gave the densest positioning of the dies on the wafer. To ensure the mechanical stability of the wafer during processing, a row across the wafer was not removed in TMAH etch.

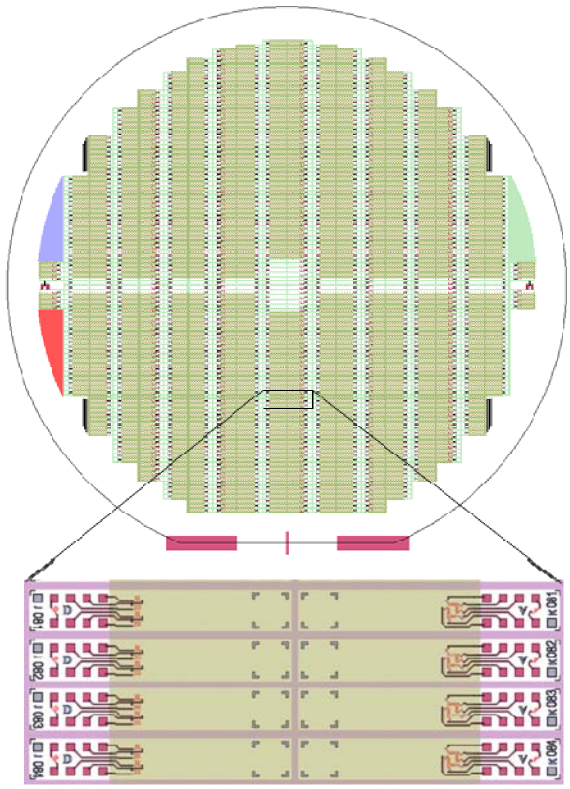

Figure 4: *Wafer design showing the die distribution on the wafer.*

**III – Fabrication and Characterization**

The silicon dies were fabricated on 6" BSOI wafers composed of a 150 µm n-type silicon device layer, a 500 nm buried oxide (BOX) layer and a 380 µm handle wafer. The processing sequence was as follows:

1. Ion implantation of resistors (moderately doped p-type)
2. Ion implantation of conductors (highly doped p-type)
3. Reactive ion etch (RIE) of backside oxide
4. Opening of contact holes
5. Metallization (Al)
6. Definition of the cantilever arm by anisotropic TMAH etch
7. Bonding of silicon wafer to glass wafer
8. Electrical probe test
9. Dicing

With this process flow, steps 1-6 could be done as standard batch processing, and only the bonding and the dicing were done on single wafers.

After step 6) the oxide thickness was 370 nm on both sides of the wafer. The back side oxide was patterned and used as mask for the TMAH etch. The thickness of the cantilever arm was precisely defined by the device layer as the BOX layer worked as an effective stop layer for the TMAH etch process.

To avoid damage on the already present metal pads and lines during the TMAH etch, a front side protection was required. The polymeric protective coating ProTEK™ (Brewer Science), which allows for batch processing, was chosen. The ProTEK™ was spin-coated on the wafer surface.

The oxidized silicon device wafer and the glass substrate were laminated by anodic bonding. This process is compatible with metallized wafers and provides high resulting bond strength. Anodic bonding was performed using a SB6e substrate bonder from SUSS MicroTec. The device wafer was bonded to a 525 µm thick, double-sided polished glass wafer (Pyrex 7740) by applying a bias of 1000 V at 400 °C for 2.5 min.

Before dicing, the wafers were electrically probed using a TSK A-PM-90A automatic probe station with a dedicated probe card. The cantilever dies were characterized electrically by measuring the resistor values, the bridge breakdown voltage, the bridge offset and the leakage current. The measurements were performed in a dark environment at room temperature.

Individual Si/glass cantilever dies were released by dicing. Due to the glass support wafer underneath the Si structure, a multi-step dicing process was required. The glass support was formed by dicing through the glass-wafer from the back side, removing the glass underneath the movable cantilever (Figure 5, 1). Subsequently, the individual dies were released by dicing (from the Si front side) through the full thickness of the bonded wafer stack (Figure 5, 2).

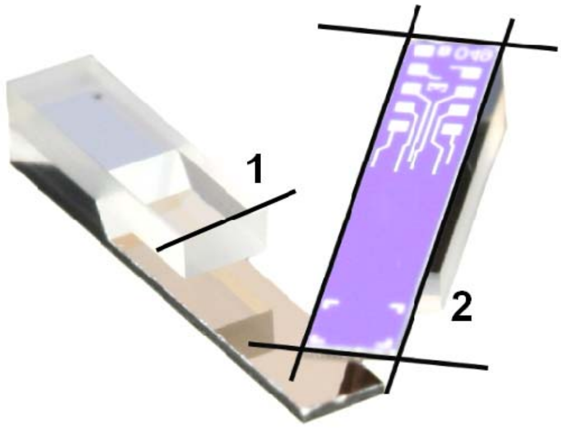


Figure 5: *Illustration of the multi-step dicing process of the silicon-glass stack for release of individual units*

Mechanical strength was tested in a test jig where assembled cantilever components were deflected until breakage (Figure 6). Both upwards and downwards deflection was tested.

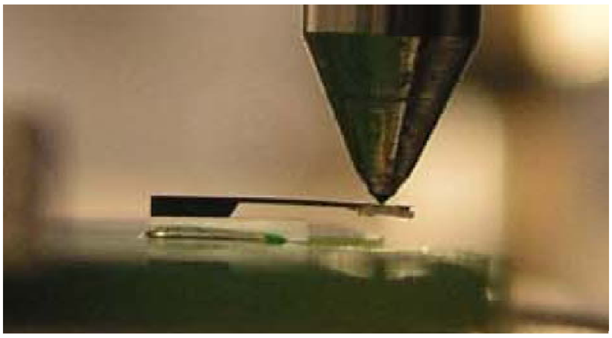

Figure 6: *Test of mechanical strength of an assembled cantilever component*

## IV - Results and Discussion

### *A. Electrical Characteristics*

The results of electrical probing together with acceptance criteria are shown in Table 1. A total yield of 90.5 % was obtained for dies from 4 wafers.

Table 1: *Results of electrical probing*

| **Parameter** | **Specifications** | | **Measured** | | |
|---|---|---|---|---|---|
| | **min** | **max** | **avg.** | **std.** | **unit** |
| $V_{breakdown}$ @ -100 nA | 30 | - | 50.9 | 3 | V |
| $I_{leakage}$ @ -15 V | - | - 2 | - 0.0075 | 0.2 | nA |
| Bridge resistance | 3.5 | 6.5 | 5.05 | 0.1 | kΩ |
| Zero Bridge | -50 | +50 | 13.6 | 13 | mV |

### *B. Mechanical Strength*

The results of mechanical strength tests are shown in Table 2.

Table 2: *Results of mechanical strength test*

| | Deflection [µm] |
|---|---|
| Max downwards deflection before breakage | 127 |
| Max upwards deflection before breakage | 98 |

### *C. Cost-effective Fabrication*

The process sequence for the cantilever was carefully selected for low-cost production. All photo lithography steps were done before the TMAH etching and wafer bonding; hence the wafers could be batch processed without special care during the photo steps.

Forming the cantilever arm by anisotropic TMAH etch with stop on buried oxide, removed the need for other tuning of the etch depth. The device layer formed the cantilever, and the thickness was precisely defined by the wafer producer.

Another benefit from the anisotropic TMAH etch was a mechanically robust device with a beveled transition area achieved through the highly orientation-dependent etch rate in Si. The test results of mechanical breakage showed that the cantilevers could withstand a load causing a deflection substantially larger than the requirement specification of ±70 µm.

The use of a dry front side single wafer holder was an alternative method to ProTEK™ for protection of the wafer front side during the TMAH etching. However, a dry front side holder does not allow for TMAH batch processing. The ProTEK™ coating displayed good protective properties. One wafer was etched in TMAH for 60 hours (more than 2 x nominal etching time) and no defects on the wafer front side were observed.

Anodic bonding was successful, i.e. a positive net voltage appeared on the Si surface even though several oxide layers were present in the Si wafer.

The first back side dicing could have been replaced by pattering of the glass wafer by e.g. etching or sand blasting prior to the wafer bonding. However, dicing is a less expensive method. Dicing also allows the anodic bonding to be done without alignment of the (un-patterned) glass wafer to the silicon wafer before bonding.

The release of the cantilever itself could have been done with e.g. DRIE from the front side. With the chosen design and processing route, the mechanical element was however released in the same dicing process as the final die dicing. Again, the dicing is cost effective and a final dicing process is unavoidable to attain individual devices.

**V – Conclusion**

A cost-effective processing route for a piezoresistive MEMS cantilever sensor element was described. The presented device was designed for medical applications, but MEMS cantilever devices have a wide range of application areas

The cantilever die was processed on 6" BSOI wafers. Anisotropic TMAH etch was used to form the cantilever arm with automatic termination of the etch process against the oxide layer. ProTEK™ provided sufficient protection of the front side metal lines and metal pads during the TMAH etch. A glass support die wafer was anodic bonded to the device wafer through several oxide layers (box layer and backside oxide) present on the device wafer. The final release of individual elements was done by a multi-step dicing process. Electrical probing of fabricated units showed a yield of 90.5%. Mechanical strength test showed that the cantilever die was a robust design.

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