Fast packaging of polymeric cantilever chip by micromilling

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Abstract
We have used a micromilling machine to fabricate a microfluidic system for packaging of a polymeric piezoresistive cantilever sensor for biochemical detection. The cantilever sensor device requires a fluidic system combined with electrical readout. All the packaging parts including a PMMA housing, tube interconnects in PMMA, moulds for PDMS and a channel in a FR-4 printed circuit board (PCB) have been fabricated by micromilling. The device, including the silicone tubes, is easily assembled and reversible. The major advantage with micromilling is that it is a highly flexible method with good precision that can be used for fast and inexpensive prototyping. The fluid flow and the hydrodynamic forces on the cantilevers have been simulated using Finite Element Simulations (FEM). The device has been tested by pumping liquid through the system, while the deflection of the cantilevers was monitored by measuring the change in the resistivity. The experimental and numerical results were in agreement. Biological measurements using cells and proteins are currently under investigation.

Keywords: micromilling, SU-8, packaging

1. Introduction
Although there is an enormous interest in the future applications of micromechanical devices there are relatively few publications that address the packaging of such devices [1]. Milling is a standard process on the macro scale, but is not as well-known for micromachining. However, the micromilling process can create trench-like features with vertical sidewalls and low roughness using tools with diameters down to a few tens of microns. Furthermore, micromilling is a flexible method for fast and inexpensive prototyping.

2. The chip
The cantilever based sensor is fabricated entirely in the epoxy-based photoresist SU-8, except for the integrated Au piezoresistors [2]. The advantage of using SU-8 instead of Si is that the chip can be made faster and cheaper. Surface stress changes on one side of the cantilever due to adsorption of bio-molecules result in a deflection of the cantilever that can be detected by the piezoresistors. The chip is 5 by 7 mm and about 200 µm thick. The cantilevers are placed in an SU-8 channel having a width of 400 µm. Since the microfluidic channel has no bottom or lid this has to be included in the packaging, see Figures 1 and 2.

Fig. 1. The flip chip bonded SU-8 chip on the PCB. There are four cantilevers in the microchannel.

Fig. 2. View of the packaging parts. The SU-8 chip and the PCB substrate are placed in an inlet and outlet system made of PMMA and PDMS.

2. Packaging
The cantilever device requires a fluidic inlet and outlet system combined with electrical readout. The packaging concept is shown in Figure 2. The electrical readout is obtained by flip chip bonding the polymeric sensor to a FR-4 printed circuit board (PCB) substrate. The substrate is T-shaped and about 15 by 12 mm and 400 µm thick (Printline, Denmark). In the PCB substrate a fluidic channel with a width of 400 µm is made by micromilling (MicroMill 2000, MicroProto Systems, Chandler, Arizona, USA). The channel is required to allow for the cantilever deflection. The bottom of the channel can be made of polydimethylsiloxane (PDMS) and polymethyl methacrylate (PMMA). Instead of milling all the way through the PCB it is also possible to make a trench with a depth of about 200 µm in the PCB, so that no bottom PDMS and PMMA layer is required. Although PCB is an inexpensive and standard material in electronics, examples of microfluidic system based on PCB technology are rarely reported [3].
The PCB substrate is placed in a PMMA housing with fluidic inlets and outlets that are connected to silicone tubes that can be easily and reversibly assembled into the PMMA, see Figure 3 [4]. The inlet and outlet are made by drilling 300 µm holes through a 5 mm thick plate of PMMA. The connection for the silicone tubes are made by milling a circle around the inlet and outlet hole into which the tubes can be attached. As long as the tubes are inserted at least 2 mm into the PMMA the connection is very stable although no glue is applied. On the opposite side of the PMMA plate a recess with the same size as the PCB is milled using a tool with a diameter of 1 mm. This recess allows for easy alignment of the packaging parts. Finally, the plate is cut to around the edges to about 20 mm by 10 mm using a saw or the micromilling machine.

![Image of the assembled device with one of the silicone tubes connected to the PMMA.](image)

To avoid leakage between the PMMA and the SU-8 chip, a PDMS layer with a thickness of 200-600 µm is used. The PDMS is made from micromilled moulds in PMMA. These moulds are filled with PDMS and cured for 2h at 80°C. The PMMA housing, the PDMS layer and the SU-8 chip can be clamped or screwed together. All the packaging parts are fabricated and assembled in a few hours and design changes can easily be made and implemented. The idea is that the SU-8 chip together with the PCB and the PDMS are disposable parts while the PMMA can be reused.

### 2. Flow simulations

For biological measurements on the cantilevers, it is crucial that the fluidic system allows for a homogeneous flow in the channel and that all of the cantilevers in the array are experiencing the same influence from the flow. Normally, bio-molecules are immobilized on one cantilever while the neighboring cantilever is used as a reference in order to reduce signal fluctuations. The hydrodynamic forces exerted on the cantilevers, due to the flow have been calculated by Finite Element Simulations (FEM) [5]. To resolve the large differences in length scales (cantilever thickness of 3 µm and chip width of 2000 µm) a mesh of several hundred thousands of elements was used. The resulting system was solved on a high performance computing (HPC) SUN machine with 4GB of RAM [6]. Figure 4 shows the absolute force on each of the four cantilevers in the channel as a function of \( H \), which is the distance from the fluidic inlet to the cantilever.

![Image of the cantilever signal when water is pumped through the system.](image)

The forces were found to be very small, corresponding to sub-nm deflections of the cantilever. Most importantly, the forces were similar for all cantilevers. This has been verified by pumping liquid through the system, while the deflection of the cantilevers is monitored by measuring the change in the resistivity of the encapsulated piezoresistors, see Figure 5.

### References

6. DTU HPC system, www.hpc.dtu.dk