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Monolithic integration of micro-channel on disposable flow sensors for medical applications

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Abstract

We report on the integration of a micro-flow channel with a thermal flow sensor chip. Two different technologies were investigated: first the fluid channel is performed at the back side of the standard HSG-IMIT flow sensor chip using a double KOH etching process (DKOH). The second technology consists of a bond process between the flow sensor die and a polydimethylsiloxane (PDMS) sheet containing the channel. Both sensor types can be used for detecting flow rates in the range of 0.1–5.0 μl/min (H2O) and/or pressure differences of 10–600 Pa. Compared to our previous sensor design this leads to reduced packaging costs, increased reproducibility (better than 1%) and in particular a higher sensitivity at low flow rates. Finally a concept of an adhesive-free packaging of the sensor is presented.
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Keywords: Flow sensor; Integration of micro-channel; Adhesive-free packaging; Low measurement range

1. Introduction

At present, flow sensors are mainly used for air flow determination in automotive applications. However an increasing demand is observed for fluid measurements in smallest flow ranges in chemical analytics, medical diagnostics and biotechnological analysis. These new applications require highly precise measurement and reproducibility, short response time, low power consumption, smallest dimensions, adhesive-free packaging and low-cost disposable products [1,2]. Furthermore miniature flow rate sensors are used in a wide range of applications with length scales varying from flow measurements in oil wells to micro-reactors [3]. The flow range to be measured varies over several orders of magnitude. A number of the existing flow sensors are based on measurement of the pressure drop across a narrow flow channel [4–7]. The sensors are based on two separate pressure membranes placed on each side of the flow channel. These sensors are usually used as difference pressure sensor and are not really adequate for flow rate determination. The flow sensor presented here is based on one single membrane sensor similar to [8]. This solution eliminates noise from thermal, electrical and mechanical sources that would affect the two pressure membranes differently. A second possibility to integrate the channel over the sensor is presented by [9], where the silicon die is glued directly on a capillary. This last method presents relative high costs for the adhesive and calibration steps which lead to an expensive sensor.

By the integration of chip-sized micro-channels with the flow-sensor an increased reproducibility (<1%) of the sensor and a measurement range of 0.1–5 μl/min can be attained. However a minimal change of the channel geometry implies a large signal deviation by such small geometrical dimensions. Therefore a very precise alignment of the channel over the active sensor is required as well as very small tolerances for its fabrication. Two different technologies were evaluated to combine a highly precise sensor with a low cost disposable system. Afterwards the chips could be integrated in an adhesive-free packaging.

2. Realization

At first an enhanced traditional silicon technology was used as illustrated in Fig. 1. The channel fabrication is performed by a double KOH etching process (DKOH) at the back side of our standard flow sensor chip [10]. Fig. 2 presents the process flow of the device. The starting material of the sensor fabrication is a (1 0 0) n-type silicon double-side polished wafer with

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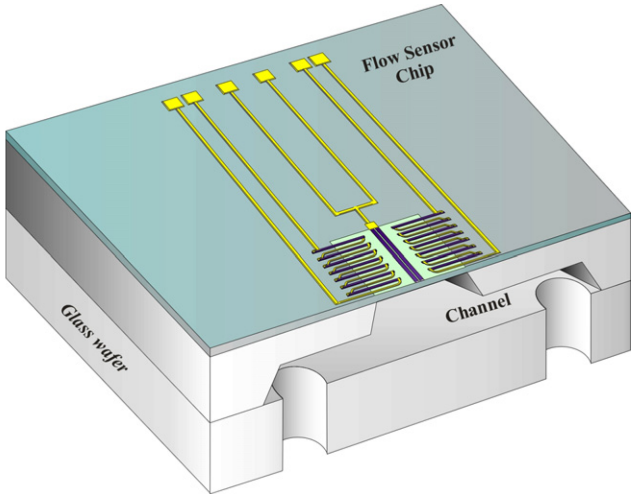

Fig. 1. Schematic cross-section of the flow sensor chip with integrated micromachined DKOH fluid channel performed at the back side of the flow sensor chip. A glass wafer provides the fluidic connection.

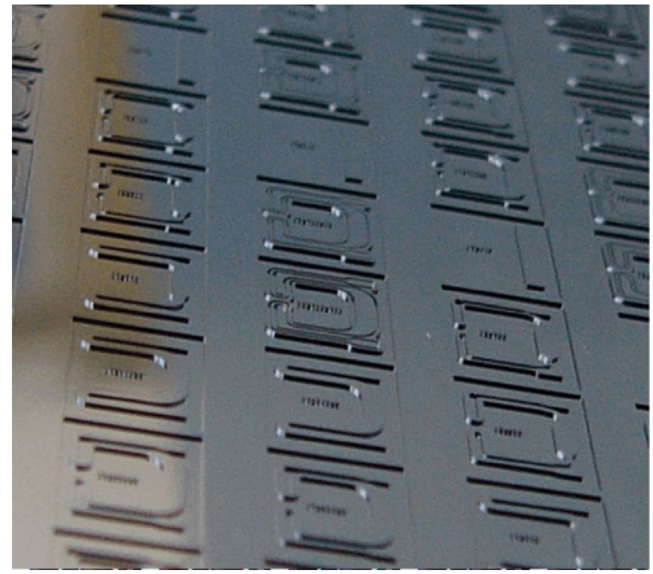

Fig. 3. Detail of the dry etched silicon negative template for the PDMS stamp.

a thickness of 300 nm and a diameter of 100 mm. After the deposition of the membrane materials (150 nm LPCVD silicon nitride layer on a thin oxide) a first KOH etching of 150 μm depth is performed at the back side of the silicon wafer to perform the future cavity under the membrane. The next step is the standard process for the thermopiles fabrication with a 100 nm polysilicon layer and one with 300 nm. This step needs a photolithography adjustment from back to front side. At this point a light deviation in the adjustment can occur. Afterwards – in order to protect the thermal sensor against harsh environments – a PECVD Si_3N_4 layer is applied as passivation. Then the second KOH-etching can be performed for the channel fabrication. This step represents the main delicate process. A too long etching will rapidly cause a membrane enlargement that consequently would change the heat distribution over the membrane. For example an extension of the membrane from 300 to 380 μm width induces a sensitivity increase of about 40% in air for a 1 mm^2 channel cross-section. In order to avoid this problem the last 5 μm silicon are etched using dry etching. In this way the membrane dimensions are well defined and present high fab-

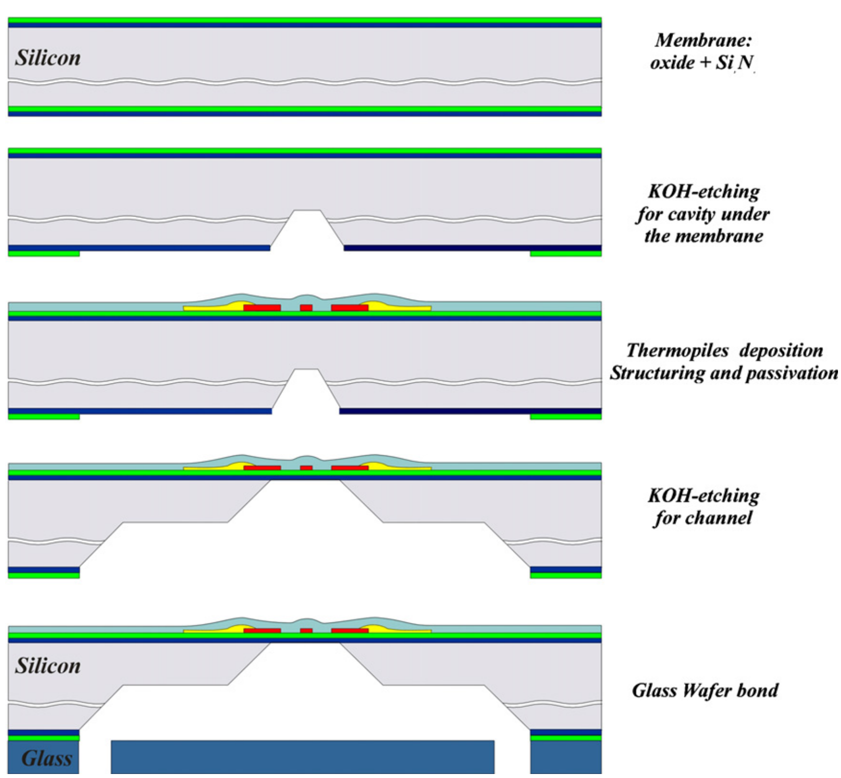

Fig. 2. Schematic drawing of the process sequence for the fabrication of the double KOH etching flow sensor chip.

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