Universität Bremen

MCB

Thermal Flow Sensor

The Microsystems Center Bremen (MCB) develops thermal flow sensors based on a new high-temperature fabrication process. The key advantage of this new fabrication process is a high-temperature LPCVD (Low-Pressure Chemical Vapour Deposition) passivation layer that makes the sensor superior for liquid applications, such as in hydraulic systems, or for medical and biological sensing. These flow sensors are also excellent for measuring gaseous flow in pneumatic systems or for wind-speed measurement devices.

The thermal flow sensor consists of a central heating element and two high-precision thermometers up- and downstream of the heater (figure 1). These components are placed on a thin membrane of silicon nitride. The freestanding membrane is used for thermally isolating the electrical components and is responsible for the superb dynamic behaviour due to the minimised thermal capacitance and the high grade of miniaturisation. A thermal time constant of 2.6 ms has been measured.

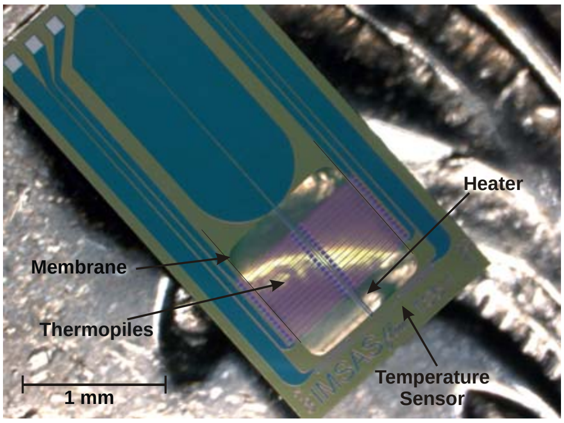

Fig. 1: Thermal flow sensor with the key components (heater and the two thermopiles) placed on a coin.

The heat distribution in the fluid is measured by the two thermometers. Heat – dissipated by the heater – is symmetrically distributed when there is no flow rate. In case of a fluid flow over the membrane, the temperature profile becomes unsymmetrical. The result is a temperature difference between the two thermometers proportional to the flow rate. This measurement principal even allows bidirectional flow measurements.

The flow sensor developed by the MCB uses thermoelectric thermometers – thermocouples connected in a row to thermopiles with 15 thermocouples each. Thin-film thermopiles are used as monolithically integrated high-precision thermometers in many fields of sensor applications such as infrared detectors, thermoelectric gas sensors and thermal flow sensors.

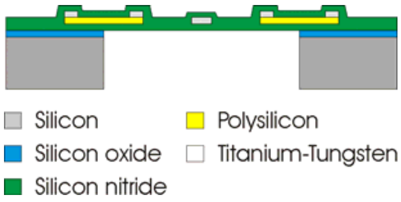

Fig. 2: Schematic cross section view of the thermal flow sensor showing the different materials used.

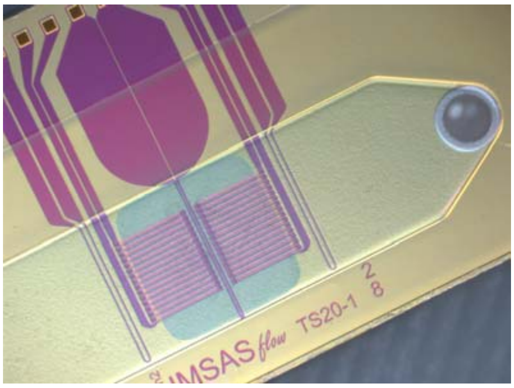

Fig. 3: Thermal flow sensor with monolithically integrated channel structure for the measurement of flow rates of a few tens of nanoliters per minute.

Thermopiles measure differences in temperature between two different points. Based on the Seebeck effect the thermopower is proportional to the temperature difference between two junction points of the materials. In the case of IR-detectors and flow sensors, the hot junction is placed on a membrane or free-standing bridge close to an absorbing area or heater. The cold junction is placed on the bulk material acting as a heat sink.

Figure 2 depicts a schematic cross section view of a flow sensor. The heater and the thermopiles are embedded between two low stress LPCVD silicon nitride layers. Polysilicon is used as the first thermopile material. An alloy of titanium and tungsten (WTi) is used as the second thermopile and as well as heater material. The use of WTi and a diffusion barrier of reactively sputtered titanium nitride allow a high-temperature protective coating due to the high thermal stability of the thermopiles.

This new high temperature LPCVD passivation has a very low tendency towards defects and pinholes combined with very good step coverage because of the high surface mobility of the deposited molecules. The thermopiles have a measured thermopower of 4.3 mVK^{-1} which corresponds to a thermopower of 287 µVK^{-1} for each thermocouple. This is comparable to commonly used Al-polysilicon or Au-polysilicon thermopiles. The membrane is finally released by DRIE (Deep Reactive Ion Etching) which leads to vertical sidewalls of the etched cavity and a reduction of the chip size.

The actual flow sensor with monolithically integrated channel structures for the measurement of very low flow rates is shown in figure 3. Several sensors for different flow velocities have been designed, fabricated and tested. Figure 4 shows a typical characteristic curve of a silicon based flow sensor with a temperature compensation circuit using air as the medium at different fluid temperatures.

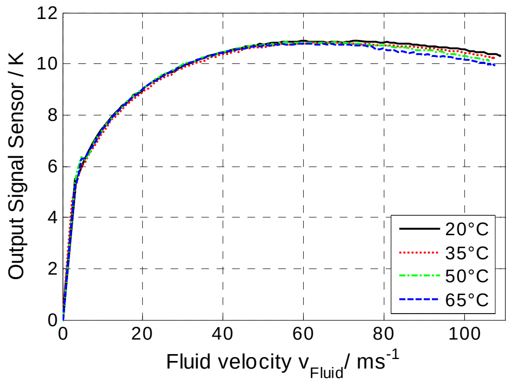

Fig. 4: Difference in voltage (mV) vs. flow rate (ms^{-1}) of air measured at different fluid temperatures to visualize a fluid temperature compensation circuit.

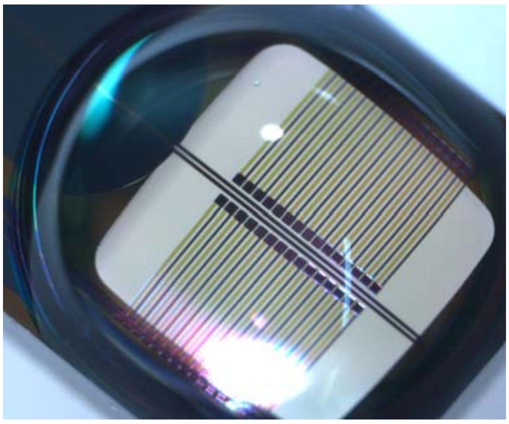

Fig. 5: Thermal flow sensor used to characterize impact of small liquid droplets.

Currently MCB is realising systems for different flow sensing tasks in order to transfer the new thermopile fabrication process to other measurement applications such as droplet characterisation. In addition, an electrical feedthrough for the flow sensor will be developed in order to simplify the packaging.