Image: Sensirion AG

Simplification of Liquid Flow Sensing

U. Kanne,
Sensirion AG, Staefa, Switzerland

Advances in microsensor technology have the potential to improve performance reliability in microfuidic applications. The technology and its capabilities are described.

Microsensor solutions

The reliable transfer of liquids in microfluidic systems is known to be problematic. To provide top performance and high reliability, fluid systems must identify clogging, leaks and bubbles while handling small volumes of liquid. Constant, reproducible flow rates are essential in a variety of applications, but the pumps used in those applications are either insufficiently stable or too expensive.

A common limiting factor for improvements in this area has been the lack of suitable sensor solutions. Nevertheless, the market and regulatory authorities demand improved safety profiles, process monitoring functions and electronic process recording. The partnership of microsensor technology and lab-on-a-chip technology has made possible the development of an extremely compact and economical generation of microsensors for liquid flow sensing and bubble detection. Point-of-care devices such as blood gas analysers, flow cytometers, anaesthesia vaporisers and drug delivery systems are expected to benefit from this development.

Combining sensors with actuators is known to improve the reliability and precision of all types of mechatronic systems. The mechanical imprecision of valves or pumps can be compensated for by flow sensors, which also enable the detection of clogging and leaks. In the relatively new field of microfluidics, this common strategy has not been widely used as yet, because of the lack of small, cost-effective sensor components. Conventional industrial flow sensor units are at least as large as a computer hard disk drive and even large production volumes do not yield significant price reductions. Providing the necessary functionality in a package shrunk to the size of a fingernail and weighing approximately 1g will open up new opportunities for high volume applications.

Smaller, faster, more efficient

The technological progress being made in microelectromechanical systems (MEMS) technology means that it is now possible to produce innovative, reliable microsensor components that are becoming constantly smaller, more affordable and better suited to low-power applications. This miniaturisation automatically leads to a reduction in time constants, which in turn results in much shorter response times.

The thermal measurement principle is most often used for sensing small liquid flows. Advanced, complementary metal oxide semiconductor (CMOS)-based microsensors contain a miniature heating element that injects minute amounts of energy (100 to 200 microjoules per measurement) into the liquid (Figure 1). A pair of specially optimised, low-noise thermopiles is positioned symmetrically upstream and downstream of the micro heat

→

First published in *Medical Device Technology*, **20**, 6 (October 2009).

Figure 1: The operating principle of thermal flow measurement.

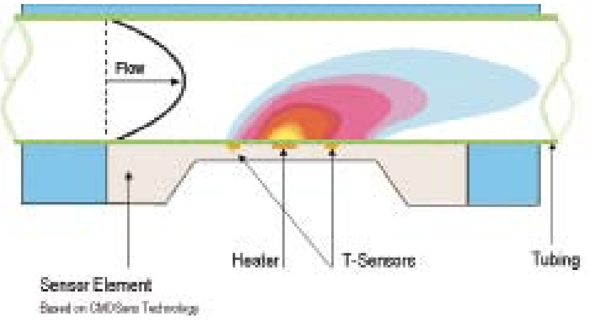
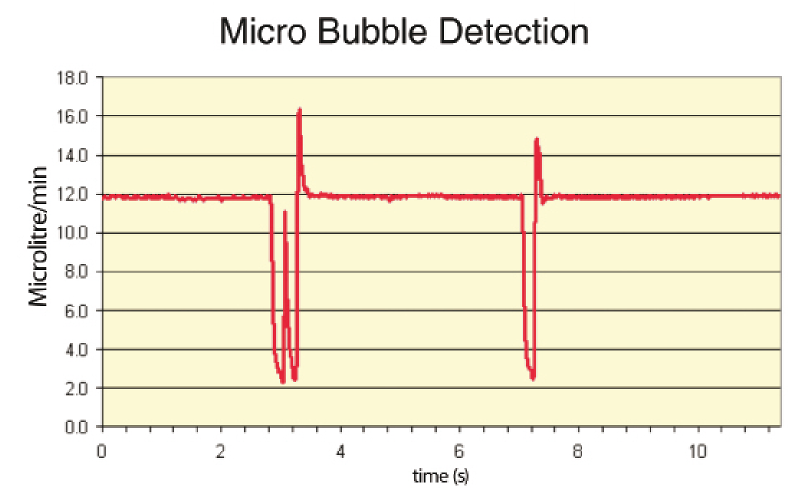


Figure 2: Short response times enable bubble detection.



source. These measure temperatures with a resolution of 15 microdegrees (Celsius) within milliseconds. The differential temperature information is used to determine the actual absolute flow rate or dosage volume (with a typical accuracy of 3%) by utilising individual device calibration data (such as a look-up table). Because of the small dimensions of the microsensor element, the time constants involved are small: the response time for a flow measurement is approximately 30 ms. This means that even highly dynamic changes in the flow rate such as those produced by pulsating pumps can be monitored with this sensor. Proof of this high speed is seen in the instantaneous response to micro bubbles passing the sensor (Figure 2). For signal conditioning, digital CMOS microsensors combine microsensor technology with digital signal processing (for linearisation and temperature compensation) on one single CMOS microchip (referred to as CMOSens technology). These chips also include memory for individual device calibration data, which is an essential feature for disposable applications. This guarantees full interchangeability of sensor components with no need for onsite calibration by the user. Each sensor is individually calibrated as part of the production process. For an overview of the development progress of microsensor technology, see Table I.

Simplicity for high volume products

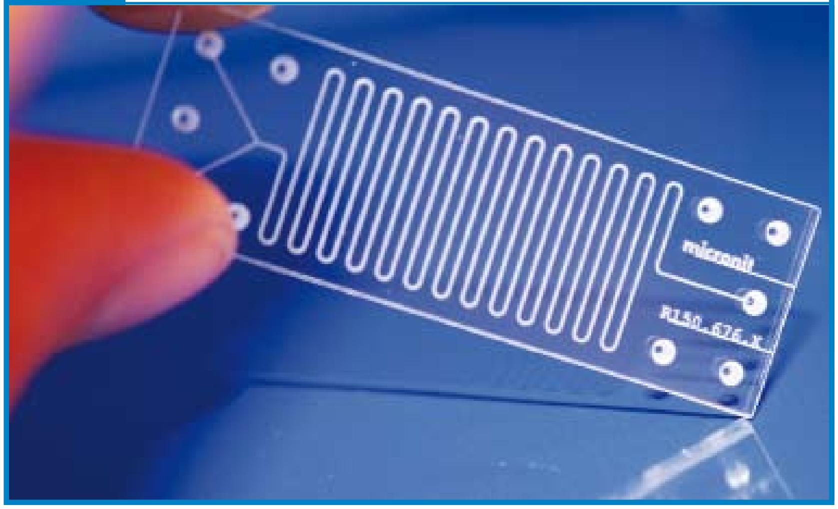
The sensitivity of these latest microsensors means they can measure the temperature difference or flow rate noninvasively through the walls of a flow channel with full media isolation. This channel can be made from glass, plastic, ceramic or steel. The flow channel can also be formed in a planar microfluidic substrate; the technology to make these is the same as used for lab-on-a-chip systems (Figure 3). Providing the thickness of top layer covering the channels is not more than 100 µm, the microsensor chip can be bonded to the outside and flow rate can be reliably measured through this top layer. A metallic coating on the outer surface of the planar substrate provides the circuitry needed for electrical connection between the microsensor chip and the outside world; connection is made using flip-chip bonding, which is commonly used in the semiconductor industry to accurately align and connect two micro parts. Flow sensors based on this new planar packaging technology combine mechanical robustness, electrical contacts and fluidic connections in a device consisting of just two parts: a planar microfluidic chip containing the flow channel and a microsensor chip that measures noninvasively through the top layer of the microfluidic chip (Figure 4).

Two core technologies are merged at this point: microfluidics chips and digital microsensor chips are bonded directly together. Communication is provided by a standard digital I^2C bus interface (an integral part of the digital microsensor chip), which is used to easily read linearised and temperature-compensated flow rate values. Microfluidic chips with flow channels as described above can be produced using standard manufacturing processes according to the

Table I: Successive MEMS sensor generations mark the progress of microsensor technology and can be characterised as follows:

- **First generation**
  MEMS sensor element usually based on a silicon structure.
  Research level for the development of new sensor principles.
- **Second generation**
  MEMS sensor element combined with analog amplification and an **analogue-to-digital** converter on a single microchip.
  Reduced electromagnetic interference, improved signal to noise ratio.
- **Third generation**
  Merging the sensor element with analog amplification, an analogue-to-digital converter and **digital intelligence** for linearisation and temperature compensation on a single microchip.
  Enables efficient reduction of total size and cost.
- **Fourth generation**
  Comprising the same elements as third generation MEMS sensors, plus **memory** for calibration data and temperature compensation data on the same single microchip.
  Fully interchangeable single-chip solution. No further signal processing required.

Figure 3: A typical microfluidic chip. (Source: Micronit Microfluidics BV).



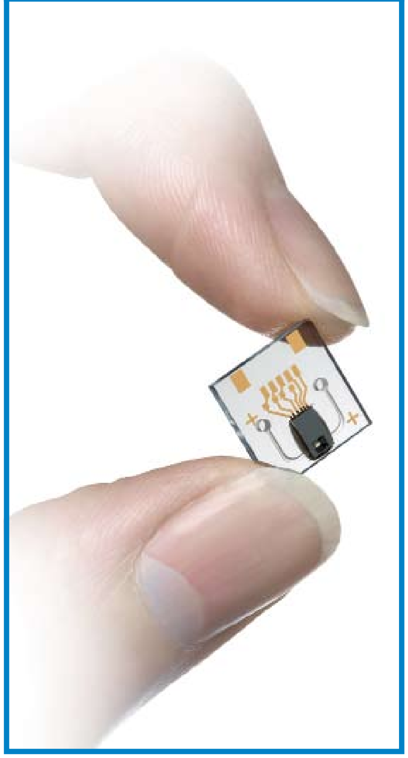
specific requirements of the application. For example, the sensor channel substrate can be a separate lab-on-a-chip system with supplementary flow sensing capability or, as shown in Figure 4, it can be a simple flow channel substrate that forms the basis for a discrete, miniaturised flow sensor element. With the fluid inlet and outlet on the bottom, discrete biocompatible sensor elements of this type can be reliably connected to any fluid manifold system. To measure higher flow rates with these sensor elements, shunt configurations can be used to determine the flow rate of a stream by measuring a well-defined fraction of the stream.

The design quality of sensors is dubious if their reliability and long-term stability have not been proven. Stress tests have been performed on flow sensors of this type based on planar package technology, employing statistically relevant numbers of samples, including tests with 1000 temperature shock cycles from -40°C to +80°C. These have shown that the new sensor technology has passed the hurdle, that is, stability and repeatability of measurements in the range of 1% after these stress tests. Without question, another critical aspect of good sensor design is producibility. This requires extensive expertise in microtechnology, data management and calibration of large product volumes. Experience from the mass production of other types of microsensors provides a reliable foundation for this task and a successful increase to volume production.

Future potential

The trend of further miniaturisation and increased process monitoring is supported by these extremely compact sensor elements, which represent a serious high volume technology. The highly efficient planar packaging approach is a quantum leap in the simplification of liquid flow micro-sensors. They can be combined with actuators such as micropumps or valves for active feedback control or process monitoring, including bubble detection. Solutions of this kind will become increasingly common, for example, in diagnostic devices that work with blood or urine samples. With a higher level of integration, it would be possible to bond the microsensor chips directly to any kind of lab-on-a-chip system or micro reactor chip. Another area for potential innovations based on this technology is the drug delivery sector with intensive care unit infusion systems, insulin pumps, implantable pumps and metered dose inhalers for pulmonary drug administration.

Figure 4: A fingernail-sized noninvasive digital liquid flow sensor.



The scope of technological options for increasing precision and safety while adding supplementary electronic monitoring and control features has been enlarged significantly for low flow applications. Economical, miniaturised sensor/actuator combinations will open up new perspectives. mdt

Ulf Kanne is Director of Sales and Marketing for Liquid Flow Products at Sensirion AG, Laubisruetistrasse 50, CH-8712 Staefa, Switzerland, tel. +41 44 306 4000, e-mail: info@sensirion.com
www.sensirion.com

First published in *Medical Device Technology*, **20**, 6 (October 2009).