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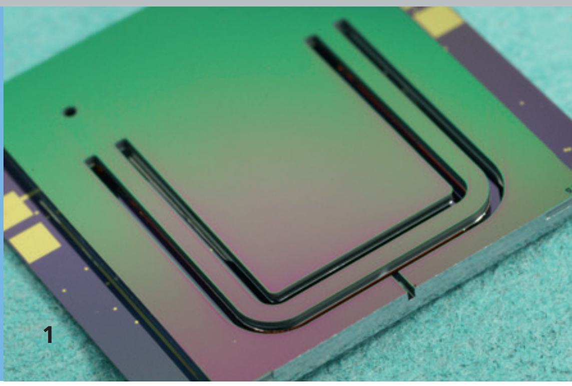

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1 *Miniaturized u-tube resonator chip*
2 *A matter of density: coffee liqueur, cream liqueur and rum join for a B52*

HIGH PRECISION DENSITY MEASUREMENT OF MICROLITER SPECIMEN

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Density measurement

In many fields of industrial production, such as chemistry, pharma, food and beverage and petrochemical industries, the measurement of a fluid's density is a widely used method for monitoring and quality control of media, processes and products.

Off-line lab analysis devices such as hydrometers, oscillators or mass weighting devices are well-established tools. Oscillation, radiometry or coriolis force based measurements are common for inline density measurements.

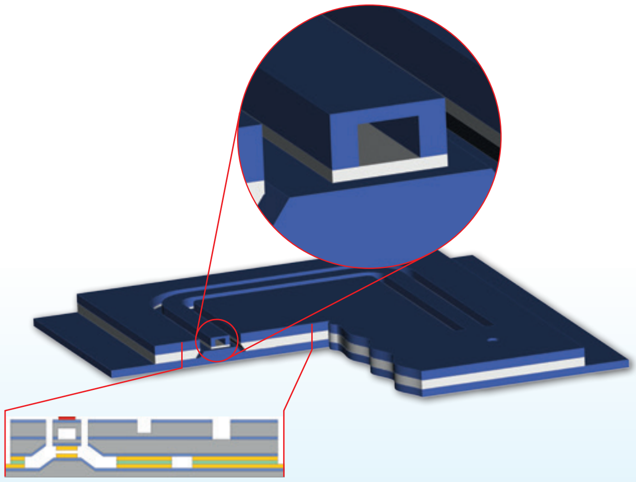
However, for applications with limited space and / or limited sample volume, these devices are often too bulky and require miniaturized solutions. This applies in particular for applications such as space, automotive or in-field analysis.

Furthermore, miniaturized devices require only small amounts of liquid specimen to measure density at high precision.

Miniaturized u-tube resonator

The measurement principle is based on a miniaturized, silicon-based vibrating u-tube resonator perfused with the specimen. A change in density will result in a changed overall mass of the resonating feature, thus shifting its resonance frequency.

Excitation of the vibrating u-tube resonator is induced by an alternating electric field. After the tube is resonating, its excitation



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is stopped and the decay of the free oscillation is measured. The resonance frequency has a linear dependency on the sample's density.

MEMS manufacturing

The u-tube resonator consists of a silicon channel having a cross-section of 300 x 450 µm and a length of 10 mm. These microchannels are realized on wafer-level by anisotropic deep silicon etching (ASE). After bonding to a second silicon wafer the u-tube resonators are liberated in further etching steps and the required electrodes are created. Then the wafer-stack is diced and the resulting chip is soldered to a second chip carrying the counter electrode for excitation.

The process workflow needs a well-tuned sequence of dedicated MEMS processes such as spray coating lithography, lift-off processes and deposition and etching techniques.

Read-out

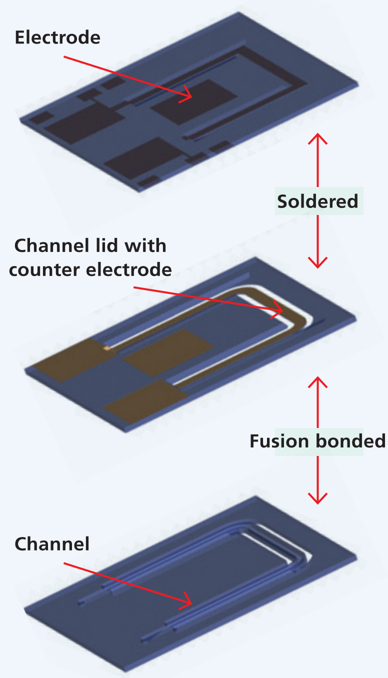
The read-out of the oscillating u-tube resonator can either be performed by laser interferometry (giving its actual best precision) or can be achieved by an integrated piezo resistive resistor, thus enabling an even smaller overall volume of the device.

Temperature dependencies can be compensated by integration of a temperature sensing and / or an electric heater element.

Results

Bench testing of the device showed that a measurement uncertainty of better than 0.3 kg/m³ can be reached. This is a competitive precision for many lab or inline density measurement devices. However, none of the above mentioned standard devices is able to cope with a tiny sample volume of only 1.5 µl.

Exploded view:
Assembly of 3 silicon parts building the fluid channel and electrodes.



Pure substances	Density Si chip [g/cm³]	95% CI single meas. [g/cm³]	Density reference [g/cm³]	Deviation [g/cm³]
Water	0.99310	0.00021	0.99281	0.00029
Isopropanol	0.76850	0.00023	0.76890	- 0.00040
Isooctane	0.67604	0.00004	0.67610	- 0.00006
Butanol	0.79446	0.00007	0.79505	- 0.00059
Mean		0.00014		- 0.00019
SD		0.00010		0.00039

3 *U-Tube resonator chip: drawing with cut-out; channel dimensions: 300 x 450 µm, 10 mm length; 3 wafer design with electrodes (yellow) and piezoresistive readout (red)*