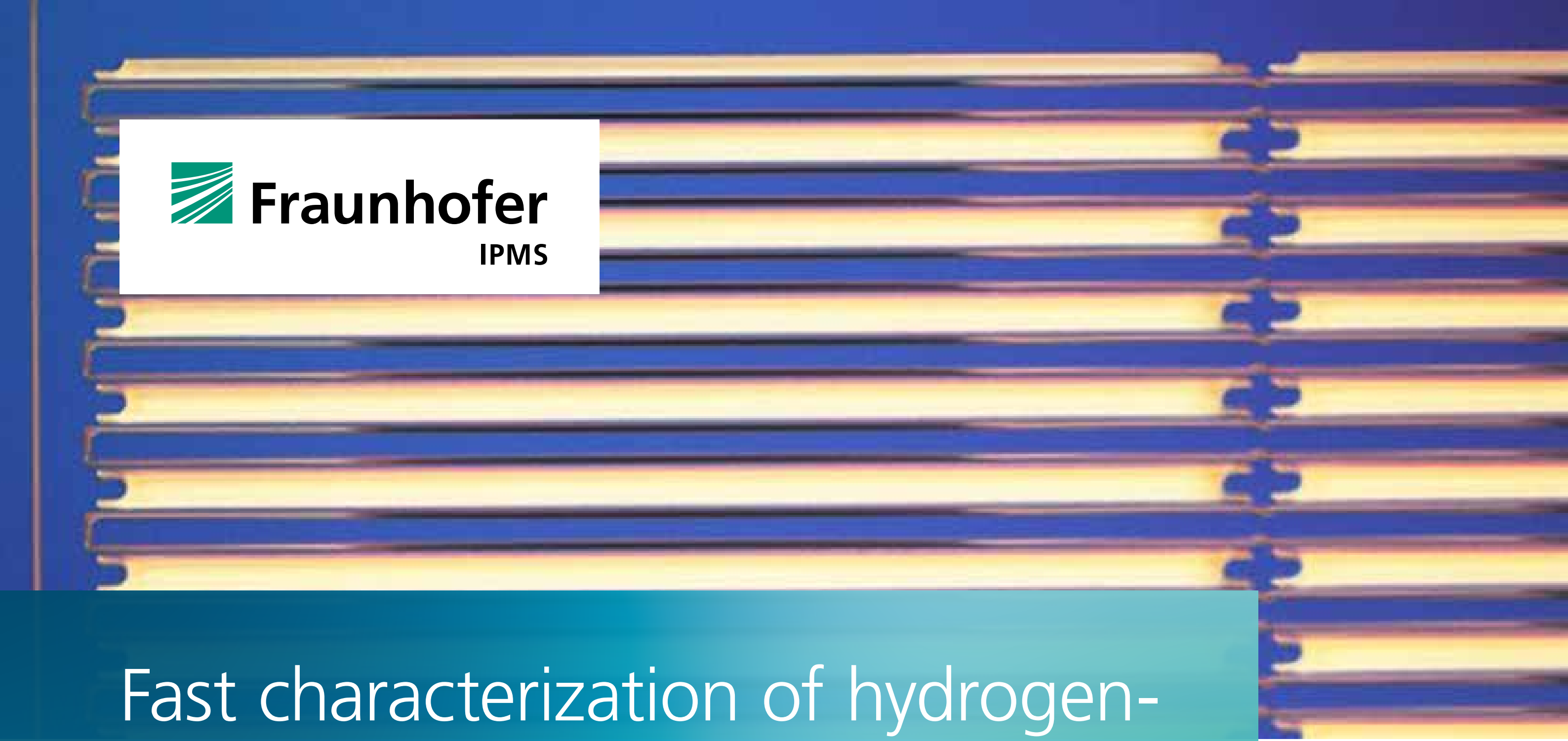

Fraunhofer IPMS

Fast characterization of hydrogen-natural gas mixtures with micromachined ultrasonic sensors

In the coming years, hydrogen will be widely distributed in the German pipeline network as a mixture with natural gas, seeking to enable its application in domestic and industrial environments. The content of hydrogen in this mixture needs to be monitored in different stages of the distribution process, given that it has a lower calorific value (in MJ/m³), as well as a higher diffusivity than natural gas. This monitoring process should particularly ensure that the prescribed safety limits for hydrogen concentration are preserved.

By means of a time-of-flight measurement, ultrasonic sensors can perform a fast and pipeline-integrated characterisation of the content of hydrogen in a binary mixture. When the concentration of a binary mixture is altered, so are the partial pressures of the gases and the overall density, which results in a variation of the speed of sound in this medium. By transmitting ultrasonic pulses along a fixed path, the measurement of the time of flight enables a calculation of the speed of sound in the medium, which is directly correlated to the concentration of hydrogen. For path lengths in the centimetre range, the expected time of flight corresponds to tenths of milliseconds. Furthermore, this method does not require to extract a sample, since the ultrasonic components can be placed at specific sites of the pipeline.

The present prototype is based on Capacitive Micromachined Ultrasonic Transducers (CMUT), which benefit from a small size in comparison to bulk piezoelectric transducers. These devices are capable of transmitting or sensing pressure waves by altering electric field between a fixed and a flexible electrode. In transmit mode, an oscillating voltage is applied between the two electrodes, causing the flexible electrode to displace a volume of air periodically, and so are ultrasonic waves irradiated. In receive mode, ultrasonic waves cause an oscillation of the flexible electrode, which can be measured as a pressure-sensitive capacitance.

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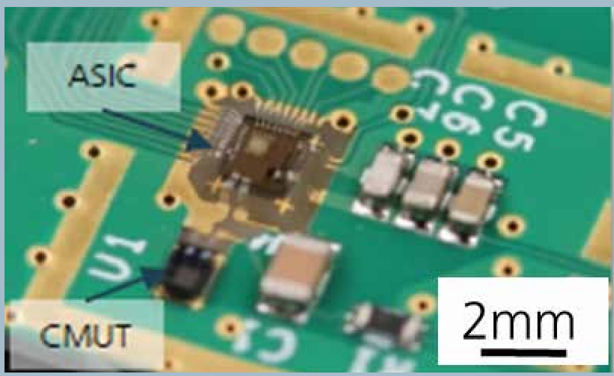
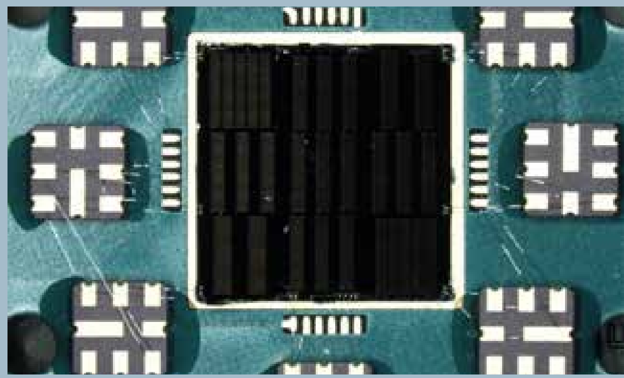


Picture of a CMUT unit connected to an amplifier (ASIC)



Picture of a chip consisting of several L-CMUT units

Fraunhofer IPMS demonstrator

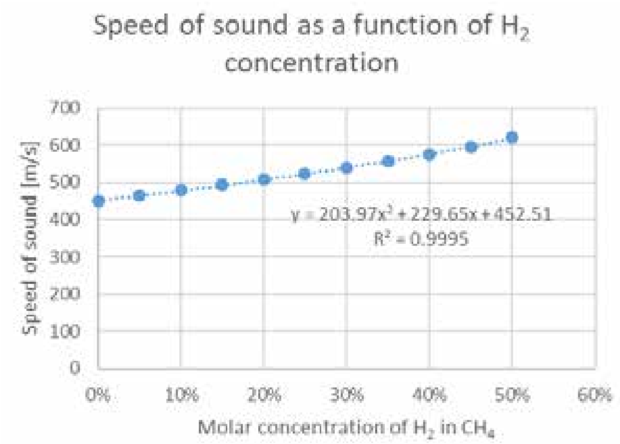
The present gas concentration prototype involves two different CMUT implementations, both developed at Fraunhofer IPMS, which are suited for different frequency bands.

The out-of-plane CMUT (or just CMUT, as it was originally conceived) is based on a membrane that oscillates in the vertical direction, that is, in the direction of wave propagation. This device is designed to operate in the resonance frequency of the membrane, which lies in the MHz-range.

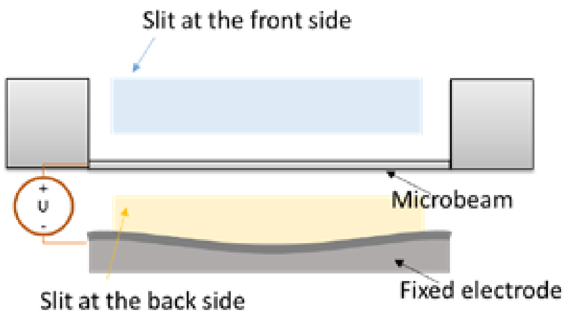
The in-plane CMUT (or L-CMUT) is based on a microbeam that oscillates laterally, that is, perpendicular to the direction of wave propagation. This requires the construction of acoustic chambers in the device through which air can be channelled towards the front- and backside of the chip. The resonance frequency of the microbeams in current L-CMUTs lies in the range of tens of kHz. The CMUT units in this prototype are implemented in both operation modes (transmit and receive), whereas the L-CMUT units are only operated as a transmitter, utilising a commercial MEMS microphone (SPU0410LR5H from Knowles®) as a receiver.

Technical specifications

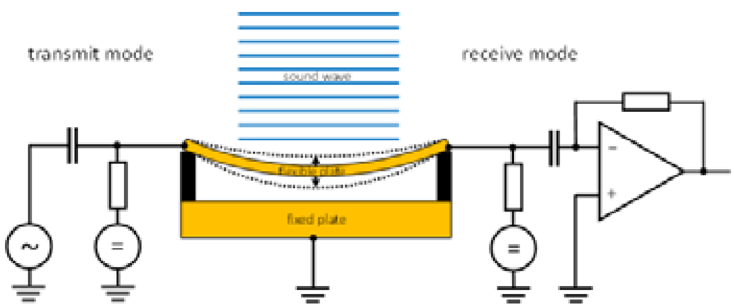
	CMUT	L-CMUT
Operation frequency	1.6 - 1.7 MHz	30 - 40 kHz
Detection range	0 - 40 mm	10 cm - 4 m
Chip size	1 x 1 mm²	10 x 10 mm²
Bias voltage	50 V	20 V
Signal voltage	50 V	20 V



Plot of the speed of sound in a mixture of H_2 and CH_4



Description of the basic element of an L-CMUT unit



Principle of operation of a CMUT in both transmit and receive mode