A Novel Generation of MEMS Ultrasound Spirometers on a CMUT Platform

Motivation

Chronic and acute respiratory diseases such as asthma, COPD and COVID-19, are a challenge for healthcare systems due to an aging disease-prone society and the fast spread of pathogens due to globalization. The early detection of severe courses of illness improves the patient outcomes and reduces costs by enabling early-stage disease therapy. By recording physical parameters such as respiratory rate and volume, signs of illness can be recognized earlier than usual and, above all, non-invasively and thus particularly for patients.

The trend towards transfering care to the home environment to relieve the burden on hospitals, or the unavailability of adequate medical care, demand a continuous patient monitoring using portable systems in the non-clinical environment. The requirements for precise parameter acquisition, reliable data acquisition with connection to a multi-sensory telemedical application and sustainability are not yet met with the currently available ultrasound spirometer systems.

Fraunhofer IPMS tackles this need with a MEMS ultrasound spirometer.

Basic Operating Principle

An ultrasound spirometer acquires physical respiratory parameters (e.g. respiratory volume and rate) based on the measurement of respiratory gas flows in a tube by means of ultrasound waves. For this purpose, a pair of opposite ultrasound sensors is arranged at an angle to the direction of flow. The sensors receive the ultrasound waves of the respective other sensor, with breathing movements leading to a time-dependent offset of the sound propagation times. Ultrasound spirometry has the following advantages over other methods:

- Latency-free bidirectional measurement of respiratory airflow
- Calibration free

Innovative CMUT Technology

Fraunhofer IPMS is utilizing capacitive micromechanical ultrasound transducers (CMUTs) for overcoming the drawbacks in previous ultrasound spirometer generations. These ultrasound modules, manufactured using microsystems technology processes, offer decisive advantages for ultrasound spirometry compared to conventional lead-based piezo ultrasound sensors:

- High ultrasound sensor precision
- Miniaturized sensor units with an unmet level of integration
- Scalable and reliable quality in production

A spirometer system equipped with CMUTs is characterized by the following benefits:

- Advantages of ultrasound spirometry combined with precise CMUT technology
- Sustainable elimination of toxic materials (RoHS compliant)
- Sensor-integrated disposable mouthpiece to meet hygiene standards

Leistungszentrum mikro I nano

Forschungsfabrik Mikroelektronik Deutschland

Contact

Björn Betz
+49 351 8823-4656
bjoern.betz@ipms.fraunhofer.de

Fraunhofer Institute for
Photonic Microsystems IPMS
Maria-Reiche-Str. 2
01109 Dresden
Germany

www.ipms.fraunhofer.de

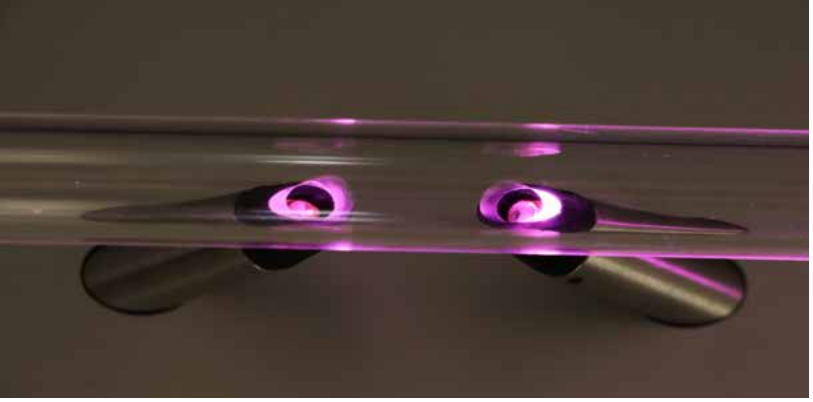

Figure 1: CMUT flowmeter by Fraunhofer IPMS

Figure 2: Ultrasound spirometer by Fraunhofer IPMS

Ultrasound Airflow Systems

Fraunhofer IPMS has built a proof-of-concept flowmeter demonstrator for airflow measurement and respiratory analysis based on the CMUT technology that has been verified under lab conditions (figure 1).

In parallel, a spirometer demonstrator was developed for comparison (figure 2, table 1). It consists of a tube, equipped with piezo-ultrasound sensors and a control unit accessible through a graphical user interface, that allows the extraction of sensor data for physical respiratory parameters (figure 3). The functionality of these system modules was clinically verified.

Novel Generation of Ultrasound Spirometers

The fusion of the presented airflow systems at Fraunhofer IPMS will enable for the first time a portable CMUT-based ultrasound spirometer for the precise measurement of physical respiratory parameters.

Integration of the CMUT sensors into the disposable mouthpiece and the miniaturization of the overall system into a compact handheld in combination with the interface to virtual monitoring systems enable an improvement of treatment and patient safety in telemedicine applications in the field of respiratory diseases.

Parameter	Ultrasound Spirometer
Ultrasound frequency	0.4 MHz
Dynamic range [volume flow]	-200 ... 200 l / min
Resolution [volume flow]	0.10 l / min
Breathing frequency	0 ... 120 / min
Data output frequency	600 / min
Tube diameter	24 mm
Tube length	200 mm
Tube material	PLA
Weight [tube and sensor]	0.25 kg
Operating voltage	5 V
Portability	Yes

Table 1: Technical parameters of the ultrasound spirometer system.

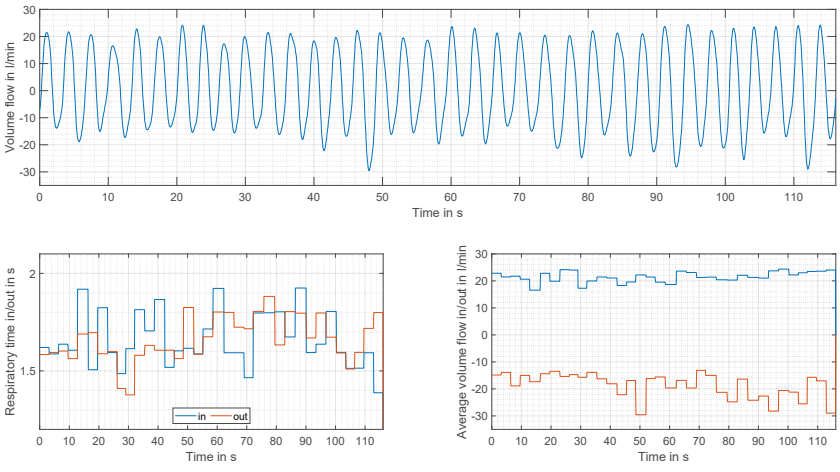

Figure 3: Respiratory data obtained with the ultrasound spirometer.