

A Novel Combined Rheometer and Density Meter Suitable for Integration in Microfluidic Systems

Erwin K. Reichel, Christian Riesch*, Bernhard Jakoby

Institute for Microelectronics, Johannes Kepler University, Linz, AUSTRIA, erwin.reichel@jku.at

*Institute of Sensor and Actuator Systems, Vienna University of Technology, Vienna, AUSTRIA

Summary

In this contribution we present a combined membrane rheometer and density meter based on two vibrating membranes carrying electrically conductive paths for excitation and readout. The liquid is contained in a 100 μl volume between the rectangularly clamped membranes. The vibration is excited by Lorentz forces arising from a static magnetic field provided by a permanent magnet and the current through the excitation path going back and forth on the vibrating part of the membrane. The sensor element is designed in a way that the viscous liquid is subjected to shear stress. Additional conductive loops on the membrane perform the sensor readout by means of the induced voltage due to motion in a static magnetic field. The measured frequency response in a range from 500 Hz to 15 kHz allows the determination of the fluid's mass density and viscosity. This novel sensor design is best suited for miniaturization and the integration in microfluidic platforms.

Motivation

In many fields of application such as oil condition monitoring, biomedical analysis, and the investigation of phase transitions in liquids, an online viscosity sensor is required. A common solution is evaluating the resonant behaviour of quartz discs vibrating in thickness shear mode. However, the rheological regime probed by these devices, characterized by small vibration amplitudes and the high operational frequency, often limit the application, e.g., to Newtonian liquids¹. Vibrating cantilever structures operating in the kilohertz range provide a suitable alternative but induce a high amount of spurious compressional acoustic waves in the fluid². The parallel motion of the membranes in our design impress significant shear stresses in the liquid (see Fig. 1) and therefore operate in a similar rheological regime as laboratory viscometers.

Results

A sketch and photograph of the sensor element are shown in Fig. 2 and Fig. 3, respectively. Injection needles are used as inlet and outlet for the sample liquid. The layout of the conductive paths (copper thin films) with a thickness of 1 μm on the polyester based foils (thickness 50 μm) is schematically shown in Fig. 4. The excitation path is connected to the signal source, i.e. a Stanford Research SR830 lock-in amplifier. The readout path is connected to the lock-in amplifier's input.

The resonance spectra of the device operating in air and in the test liquids, given in Table I (ethanol, isopropanol and DI-water) are shown in Fig. 5. It can be seen that the higher density of water results in a lower fundamental resonance frequency whereas the higher viscosity of propanol causes increased damping. From the analysis of various vibrating structures in liquid³ it is well known that the damping is primarily depending on the viscosity-density product, which corresponds to the almost equal damping in water and in propanol.

In our contribution we provide more details on the fabrication and the extraction of the viscosity and density values from the frequency response. Furthermore we discuss the integration of the device in a microfluidic system.

¹ B. Jakoby, A. Ecker, M. J. Vellekoop, "Monitoring macro- and microemulsions using physical chemosensors", *Sensors and Actuators A* 115 209-214, 2004

² A. Agoston et al, "Evaluation of a Vibrating Micromachined Cantilever Sensor for Measuring the Viscosity of Complex Organic Liquids", *Sensors and Actuators A* 123-125, Elsevier, p. 82-86, 2005

³ E. Reichel et al, "A Novel Micromachined Liquid Property Sensor Utilizing a Doubly Clamped Vibrating Beam", *Proc. 20th Eurosensors Conference, Göteborg/Sweden, 2006*

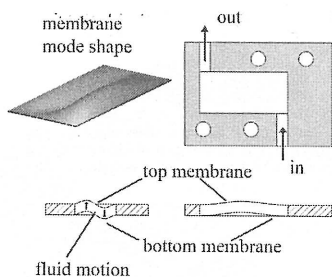


Fig. 1. Measurement principle: The liquid between the vibrating membrane is subjected to a considerable shear displacement gradient. The membrane resonance frequency is significantly shifted mainly depending on the fluid's density. This setup can be included in microfluidic systems.

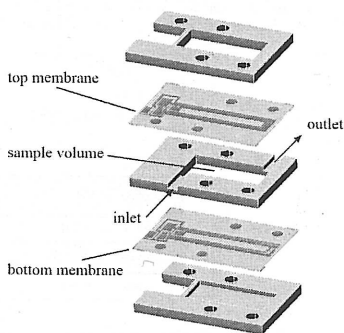


Fig. 2. Schematic of the sensor element. For the prototype setup, the solid frames clamping the membranes are fabricated in low-cost fiber-glass composite resin technology.

Liquid	ρ kg/m ³	η mPa · s	f_{res} kHz
-	775	1.12	3.3
EtOH	785	2.09	3.2
PrOH	1000	0.89	2.9

Table I

Material parameters η and ρ for the test liquids and the measured resonance frequency f_{res} .

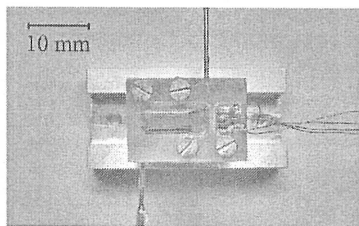


Fig. 3. Photograph of the sensor setup.

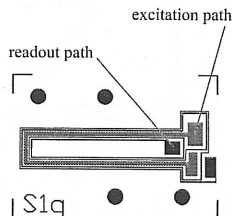


Fig. 4. Layout of the conductive paths on the polyester based foil forming each of the vibrating membranes.

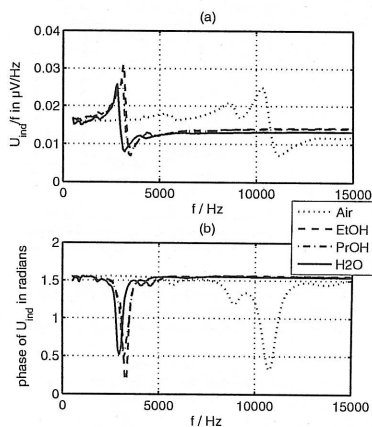


Fig. 5. Measurement results: The sensor was characterized in air and with the test liquids ethanol (EtOH), isopropanol (PrOH) and deionized water (H₂O). The measurement signal U_{ind} is divided by the frequency f as this value is proportional to the average membrane deflection. The frequency response is determined by the liquid's density and viscosity.