A Novel Sensor System for Liquid Properties Based on a Micromachined Beam and a Low-Cost Optical Readout

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Summary

For the measurement of liquid parameters like viscosity and density vibrating micromachined structures offer useful alternatives to bulky conventional measurement equipment. The evaluation of the shift of resonance frequency and the change of the damping factor of such devices allows the simultaneous determination of viscosity and density. Furthermore, these sensors can even be used for complex liquids like emulsions where other microacoustic sensors like TSM quartz resonators, in comparison to conventional laboratory viscometers, measure in a different rheological domain. In our contribution we present a novel implementation of a viscosity and density sensor system utilizing a doubly-clamped vibrating micromachined beam. The beam deflection is determined by means of a laser pickup head as it is used, e.g., in DVD drives, yielding high sensitivity and a low-cost setup at the same time.

Motivation

We have recently presented a micromachined doubly clamped vibrating beam device[1] (Fig. 1), which can be utilized as a liquid property sensor. The beam vibrations are excited by Lorentz forces. When the sensor is immersed in a liquid, both the resonance frequency ω and the damping D (the reciprocal of the quality factor) of the device are changed depending on the liquid parameters, i.e., density and viscosity. Therefore, a suitable measurement method aims at determining ω and D, and thus requires the measurement of the actual beam deflection. In principle, the change of the effective device impedance due to piezoresistive and induction effects can be used to measure the actual deflection of the beam. However, for the considered micromachined design these effects are in the range of only several ten milliohms. Therefore, a readout featuring higher sensitivity is required.

Results

The liquid property sensor system presented in this contribution utilizes a micromachined vibrating beam and a highly sensitive optical readout which is based on a pickup head as it is used, e.g., in DVD drives. The use of those pickup heads for sensor applications combines advantages of high sensitivity, large bandwidth, and a low cost[2]. Figure 2 depicts the entire measurement setup. A sinusoidal current $i(t)$ and a magnetic field B excite beam vibrations in z-direction. The laser pickup is focused on the center of the vibrating structure. The resulting output signal (RF) is proportional to the variation of the distance between the beam and the lens of the pickup head. This signal can be used to measure the actual beam deflection, and to obtain the phase shift φ between the excitation voltage $u(t)$ and the beam deflection. To demonstrate the feasibility of this sensor setup we have carried out a number of measurements using a variety of sample liquids (Fig. 3). From these results the resonance frequency and damping factor have been obtained. To first order, the damping factor is dominantly influenced by the viscosity of the respective liquid[3], which is confirmed by the results given in Fig. 4. However, the shift of the resonance frequency of the vibrating beam is also influenced by the density of the liquid. This fact is confirmed by the results presented in Fig. 5. The resonance frequency shifts for immersion in cyclohexane, ethanol, and 1-propanol (which approximately have the same density) lie on a single trend line, whereas the measurement with the beam immersed in toluene results in an additional frequency shift caused by the higher density of this sample liquid. In our contribution, we provide a detailed description of the prototype system setup, and present more results together with the parameter extraction technique demonstrating the feasibility of this novel sensor system (Fig. 6).

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[1] E. K. Reichel et al., Proc. Eurosensors XX, Göteborg, Sweden, Sept. 17-20, 2006.

[2] N. Scuor et al., Meas. Sci. Technol., vol. 17, pp. 173-180, 2006.

[3] C. Riesch et al., Proc. IEEE Sensors, Daegu, Korea, Oct. 22-25, 2006, pp. 1070-1073.

Figures

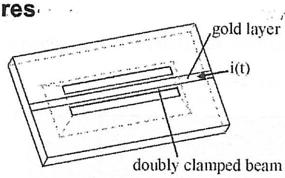

Fig. 1: Doubly clamped beam device featuring a micro-machined silicone nitride (Si_3N_4, SiN_x) beam and a conductive path (gold layer), allowing for Lorentz force excitation. The beam has a length of 320 µm, a width of 40 µm, and a thickness of 1.3 µm.

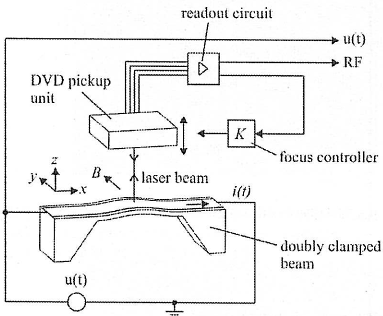

Fig. 2: Schematic diagram of the sensor system. The beam vibrations are excited by Lorentz force caused by *i*(*t*) and the magnetic field *B*. From the RF signal the actual beam deflection in *z*-direction is obtained.

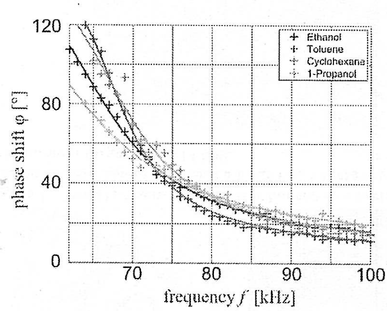

Fig. 3: Phase shifts near resonance between the excitation signal *u*(*t*) and the actual deflection of the beam immersed in various sample liquids. The phase shift provides a better signal to noise ratio than the amplitude characteristics and is thus used to extract the resonance frequency and the damping.

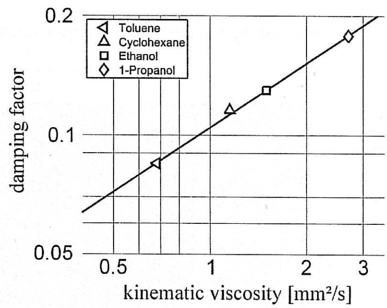

Fig. 4: Measured damping of the vibrating beam vs. kinematic viscosity of the sample liquids.

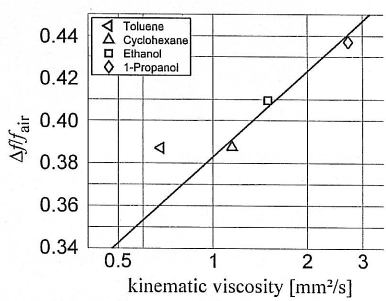

Fig. 5: Shift of the resonance frequency of the vibrating beam vs. kinematic viscosity of the sample liquids. Due to a different density toluene lies off the trend. This confirms the dependence of the frequency shift on density and viscosity.

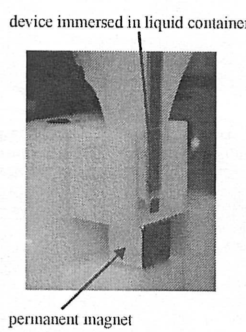

Fig. 6: Prototype setup with micromachined device immersed in the sample liquid. The static magnetic field is excited by the permanent magnet below.