Analysis and Fabrication of Micro-Device as Liquid Sensor

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Abstract

Microdevices are the transducers that convert energy from one form to another. In the case of microsensors, the device typically converts a measured mechanical signal into an electrical signal. There are certain phenomena that can be applicable to sense the properties of liquids. In this work, the design and fabrication of poly dimethyl siloxane (PDMS) based micro-device and their analysis as liquid sensor is presented. A finite element analysis has been studied for selection of appropriate dimensions and material. A micro-cantilever beam is fixed inside the channel for determination of liquid that flow across the channel. The proposed device is fabricated by considering step by step optimization of geometry involving lithography process. The experimental results evaluated by fabricated device showed some interesting properties.

Keywords: Micro-device, liquid sensor, micro-cantilever, lithography, PDMS.


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Introduction

Sensing the type of liquid using thermal principles possess several advantages especially for the measurement of flow velocities, such as volume flow rate and mass flow rate [1]. Different techniques exist to measure the fluid flow. At the macroscale and microscale, different design challenges are encountered, and flow measurement systems can have different advantages and disadvantages. The primary differences that arise are the ease of manufacturing, and the fluid flow regime. At a large size scale, more complex flow sensor designs can be manufactured, but turbulence in the flow is more common, causing unpredictable sensor response [2]. At the microscale, the fluid flow is almost always laminar, but sensor designs must be very simple for fabrication to be possible.

Sensing different liquids as per their densities is one of the most significant thermophysical properties and has viable applications especially in crude oil exploration and production, milk quality assessment, and the automotive industry [3-5]. Several researchers have already explored the field of micro-device based sensors [6]. Usually, in micro-sensors, the sensitive element include microcantilever. The working principle of microcantilever based sensor is based on their resonant frequencies. Thus, the fluid density may be estimated by the resonant frequency of the microcantilever [6] [7].

In this paper, piezoelectric microcantilever sensor is developed to measure the fluid density. According to the experimental results the fluid density can be measured easily and rapidly using a
novel method measure fluid density by the MEMS sensor.

**Finite Element Analysis**

Let us consider a rectangular channel of height $h$ and width $w$, the pressure drop $\Delta p$ over a length $L$ is related to the volumetric flow rate $Q$ as

$$Q = \frac{wh^3 \Delta p}{12\mu L} \left[1 - O\left(\frac{h}{w}\right)\right] \quad \text{(i)}$$

where, $O\left(\frac{h}{w}\right)$ is approximately given as

$$O\left(\frac{h}{w}\right) = \frac{6(2)^5 h}{\pi^3 w} \quad \text{(ii)}$$

The scaling with $h^3 w$ demonstrates the significant impact of changes in the smallest dimensions [8].

To numerically solve the interactions between the fluid and the solid structure, the flow is assumed to be laminar Newtonian, viscous and incompressible [9]. The fluid domain is again governed by the incompressible Navier-Stokes equations and the continuity equations [10] is as follows

$$\frac{\rho \mathbf{u}}{\partial t} - \nabla \cdot (-p I + \eta (\nabla \mathbf{u} + (\nabla \mathbf{u})^T) + \rho (\mathbf{u} \cdot \nabla) \mathbf{u}) = \mathbf{F} \quad \text{(iii)}$$

where, $-\nabla \cdot \mathbf{u} = 0 \quad \text{(iv)}$

In above equation, $I$ is the unit diagonal matrix, $\mathbf{u} = (u, v)$ is the velocity field, $p$ is the fluid pressure and $\mathbf{F}$ is the volume force affecting the fluid [13]. Since the gravitation and other volume forces affecting on the fluid are negligible, thus $\mathbf{F} = 0$. For each flow rate, the fluid velocity at the entrance of the microchannel is provided as the boundary condition for the inlet [11]. The pressure at the outlet is set to atmospheric pressure. At all other boundaries, no-slip condition is considered $u=0$. The fluid flow loading acting on the micro-cantilever is defined by the force per area given as

$$F_T = -n.(-p I + \eta (\nabla \mathbf{u} + (\nabla \mathbf{u})^T)$$

where $n$ is the normal unit vector of the boundary, $u$ is the velocity field on the cantilever surface pointing out from fluid. $F_T$ is the fluid loading consists of pressure and viscous forces. The first term in equation (v) is the pressure gradient extracted from the fluidic simulation results. The second term is the viscous component of the force depending on the velocity and the dynamic viscosity of the fluid.

**Fabrication**

A microchannel is developed by making mold of SU8 over p-type Silicon wafer. Iron oxide mask plate is patterned using laser writer system in MEMS designing software. Si substrate is dehydrated and then the SU8-2000 resist is spin coated on Silicon wafer for attaining the appropriate thickness. Patterning is done using lithographic technique. Lithography is performed using EVG-620 lithographic system. After lithography, the substrate is developed by keeping in SU-8 Developer. The micro-channel is developed by taking the replica at PDMS from the SU8 mold. For this, a PDMS membrane is first spin-coated on the wafer and then this silicon wafer containing spin coated PDMS over it is baked. Then the PDMS is peeled off from the SU8 mold by tweaking it around the edges with a sharp sample holder. Thus, the as-fabricated micro-channel is finally prepared. After this, another Si substrate is taken, cleaned and dehydrated. Positive photo resist (PPR) is spin coated on Si substrate. Fabrication of ZnO nano-thin film based cantilever is done using lithographic technique and lift-off process. Two steps lithography is done followed by lift-off process. First, for deposition of molybdenum (Mo) and then, for deposition of piezoelectric (ZnO) thin film over molybdenum layer. Mo is deposited using metal sputter system while ZnO is deposited using dielectric sputter system. To remove the deposited materials from undesired portions, lift-off process is carried out by dipping the wafer in “CMOS Grade” acetone. The molybdenum (sacrificial layer) is then etched by hydrogen peroxide ($H_2O_2$), and the ZnO based micro-cantilever beam structure released. Finally, the micro-cantilever beam is placed inside the micro-channel and the whole device is mounted on a glass slide as shown in Fig 1.

![Fig 1. Image of the as-fabricated device](image-url)
Results and Discussions

Scanning electron microscopy (SEM) characterization of the as-fabricated micro-cantilever beam is studied using and is shown in Fig 2.

![Fig 2. SEM of the as-fabricated micro-beam](image)

The performance of micro-cantilever suspended within the PDMS microfluidic channel is tested for three different fluids. All liquids were injected one by one into the microdevice through the inlet using a syringe pump with constant flow rate while the deflection of the piezoelectric micro-cantilever is monitored through the digital storage oscilloscope (DSO). The deflection has been converted into the electrical displacement. The flow introduced into the microfluidic device through the inlet, induces the loading force on the microcantilever to bend it and is transferred out toward the outlet. The graph shown in Fig 3 illustrates the results for fabricated device.

![Fig 3. Voltage observed on DSO while considering different fluids](image)

The results showed that the voltage displayed on DSO is 0V until the fluid interacts with the cantilever. As the fluid comes in contact with the cantilever, there is sharp increase in voltage and then the voltage starts decreasing and again settles to 0V.

Conclusion

In this work, a PDMS based microfluidic channel has been fabricated after considering finite element analysis as liquid sensor. The performance of the liquid sensor has been tested by introducing three different liquids into the microfluidic device and observing the change in voltage generated due to displacement of micro-cantilever beam on DSO. The piezoelectric micro-cantilever yields minimum voltage change for acetone while for water, the observed change in voltage was maximum. The result showed variation in voltage change in accordance with the variation in the dynamic viscosity for the liquids. Thus the device is sensitive to the dynamic viscosity of the liquids.

References


