Design of Feedback Control System for MEMS as thermal Sensor

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Abstract— **In this paper, we present the designing of control system for cantilever based MEMS sensor. We propose to fabricate the digital feedback control system which will take care of providing the pre-deflection of the cantilever beam to maintain the constant gap between the electrodes which is the major problem in fabrication. The control system is carried out with digital modules and is implemented using ATmega16 microcontroller.**

Keywords-MEMS sensor ,Micro cantilever, Feedback system.

I. INTRODUCTION

Micro-Electro-Mechanical Systems (MEMS) is the integration of mechanical elements, sensors, actuators and electronics on a silicon substrate through micro fabrication technology[1]. MEMS device have been used as thermal sensors and the resulting chips can allow sensitive, rapid, and real-time measurements. We can detect the change in temperature through the use of micro-scale cantilever sensors on a chip. In the cantilever sensors, by stress sensing method, the bending of cantilever can be detected due to change in surface free energy. Since the stress detection method used with cantilevers is based upon a change in surface energy, it can be speculated that there is uniform change in temperature over the area of cantilevers, results in a uniform surface stress change, resulting in the cantilever bending [2]. Change in the temperature induces thermal stress on the surface of the cantilever. These surface stresses bend the cantilever. Bending of the cantilever can be detected by various methods as optical reflection, piezoresistive, interferometric, piezoelectric, capacitive and electrical detection [3, 4, 5, 6]. From that various methods we are using electrical detection method.

The major problem related to fabrication is to achieve the gap between the cantilever and the electrode. To overcome this issue we are designing the Feedback controller for the system.

The detection method for cantilever based sensor is discussed in section 2. The feedback control system for cantilever is discussed in section 3. Section 4 gives the details of design. The controller solves the fabrication defects faced to maintain the precise gap between the electrodes.

II. CANTILEVER BASED THERMAL SENSOR

Cantilever is used as nano mechanical sensor, micro fabricated with the standard Si technology. There sizes are in micrometer or nm ranges.

Figure 1. Cantilever beam with thermal sensor

Figure 1 shows basic schematic diagram for cantilever based thermal sensor with electrode. When the deflection due to thermal stress occurs, the cantilever beam touches the electrode, resulting in increasing current as the contact area between electrode and cantilever beam increases.

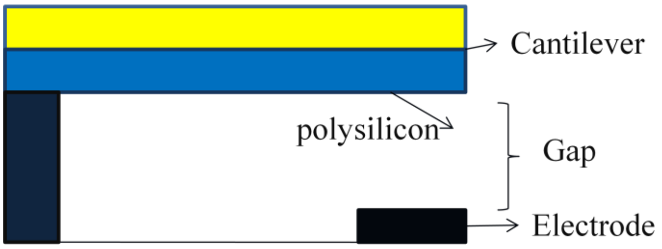


Fig.1

Increase in the thermal stress on the surface of cantilever lead to a bending of cantilever. The surface stress is very small of the cantilever to the tune of a few tens of nanometer. The major issue for the device fabrication is the creation of gap between the electrodes of this order.

III. DESIGN OF CONTROL SYSTEM

Feedback control of the cantilever that attenuates the thermo-mechanical fluctuations from the observed cantilever motion to minimize vibration of the cantilever tip. The displacement of the cantilever is detected by an electrical method and the control voltage is applied to the cantilever by the feedback control system [8].

Feedback controller of the cantilever must be such that it attenuates the thermo-mechanical fluctuations from the observed cantilever motion to minimize vibration of the cantilever tip.

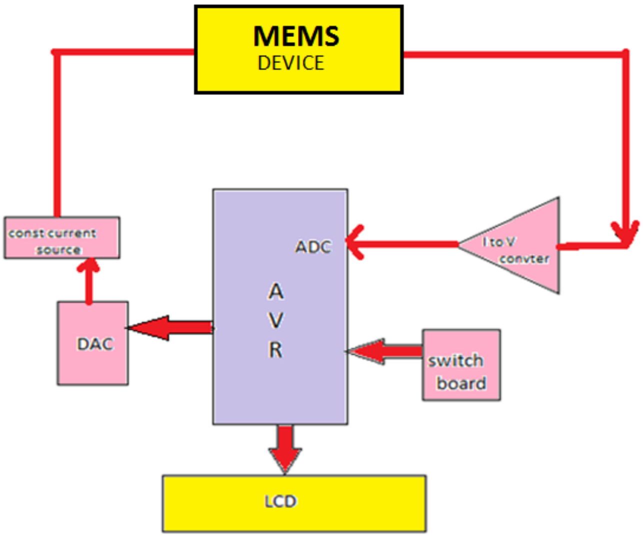


Fig.2

We will employ the control system for our sensor as in Figure 2. Feedback control system consists of ATmega16, DAC, I to V converter, current limiting circuit, switches and LCD for user interface.

A. Device Working

The working of the digital control system is divided in two parts i.e. 1.callibration 2.detection. Initially we have to calibrate our temperature sensor with the standard temperature values. Under normal condition, current through the MEMS device will be zero. So, the output of I to V convertor will be zero. When the temperature across cantilever increases then bending of cantilever occur but it is of few tens of nano meter so the cantilever will not touch to the electrode and thus output of I to V will remain zero. Micro controller continuously monitors the output of I to V converters. As long as the cantilever does not touch electrode, micro controller will increase voltage across the cantilever so as to make contact. It will increment the DAC input accordingly. This input value is then converted into analog voltage by DAC and applied to the MEMS device . Due to the applied voltage, the cantilever gets deflected and thus the gap between cantilever and electrode gets decreased. As the gap is not reduced to zero, current will be zero and the process gets repeated till the current starts flowing through the cantilever and the electrodes. The moment when the current starts flowing through the device, that means the cantilever beam is attached to the electrode. This voltage value for which cantilever touches electrode is now known and accordingly pre-deflection voltage is calculated and saved in look up table. For different temperature there will be different pre-deflection voltage values. When we have to measure certain temperature then the pre-deflection voltage according to the temperature to be measured is set across the cantilever to get the pre-deflection. When temperature increases and touched that particular value then the current starts flowing through the device which is detected by a micro controller.

IV. CONTROL SYSTEM

We are using 8 bit microcontroller which is having advanced risc architecture. It has 16 Kbytes of In-System Self-programmable Flash program memory, 512 Bytes EEPROM. It has peripheral features like two 8 bit timer and one 16 bit timer, 10 bit ADC. Its operating voltage is 4.5-5.5 volts and operating frequency is 16 MHz. Current limiting circuit is used to limit the current through the MEMS sensor upto 1 mA so that it should not damage the device. We are using DAC 1008N having 10 bit resolution and is capable of driving at the supply voltage of 15v. We have used lookup table for input to DAC equivalent to the voltage required at the output of DAC. The value for equivalent input to the DAC depends on one step change in voltage of DAC. According to our requirement of 15v Vref and 10bit resolution, the one step change in voltage is equal to 15mV.

DAC has designed by using the equation (1) as

$$\text{Out} = \sum_{N=0}^{n} \frac{Vref}{2^{N+1}}$$

Where, out is the output of DAC; Vref is reference voltage for DAC; n is number of bits required for resolution. We are using Op-amp for I to V converter.

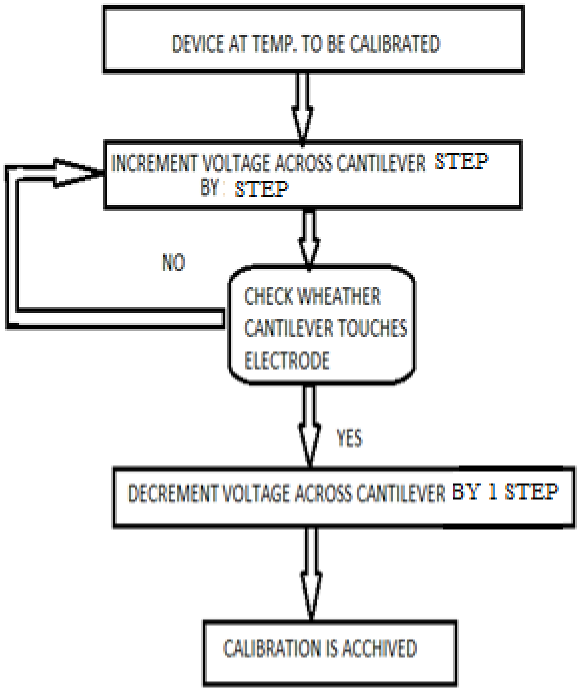
V. SOFTWARE

Programming part is divided in two steps.

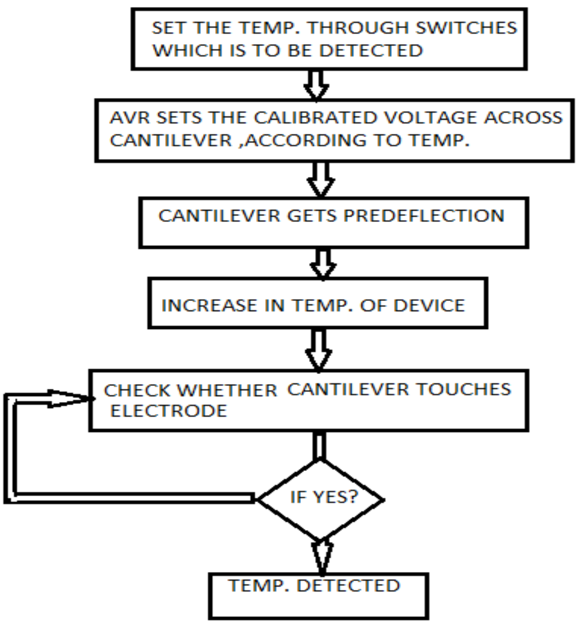
1. Calibration
2. Detection

Flow chart of these two steps is given below

Calibration



Detection



Conclusion:

We have designed Feedback control system for cantilever based biosensor. This method is used for all the readout methods where the gap between electrodes is very small. Our digital feedback control system will solve all the major fabrication issues. The gap between electrodes is adjusted by electrostatic actuation.

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