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Electromagnetically actuated microcantilever for chemical and biochemical sensing in static mode

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Abstract

In this work, we present the method of bending and stress measurements with electromagnetically actuated cantilever in sensors application. Proposed method compensate the bending of the cantilever induced under stress. Bending can be translated into surface stress difference which is a measure of intermolecular interactions. In proposed method Lorentz force is a balancing force to restore the cantilever to its original position. Additionally Lorentz force give us possibility do drive cantilever bidirectionally. The bending of cantilevers is measured using optical beam deflection (OBD) method and useful signal is derived from the feedback loop, that maintains the cantilever in a fixed position by balancing the deflecting force and the balancing force.

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Keywords: cantilever sensor, Loreznt force, closed loop, biochemical sensor, surface functionalization

1. Introduction

Microcantilever sensor have evolved into a very versatile tool for wide range of disciplines including chemical and biochemical sensing [1]. There are a tools for fast and reliable detection of small amounts of analyte in gas phase and solution. In static mode, the sensor works as a nanomechanical transducer of intermolecular interactions. The top and bottom surfaces of the sensor can be coated with different functional layers, one serves as a sensing

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layer that reacts on the presence of target species, the other being insensitive to them or giving an opposite response [2]. For example for the gold surface the thiol molecules can be used for fabricated Self Assembled Monolayer (SAM).

2. Experimental setup

Figure 1 shows a three types of a microcantilever with integrated current loop. Cantilever fabrication process were described in our previous work [3].When the device is placed in an external magnetic field B which is perpendicular to the active part of metal loop the current flowing in the loop interacts with the magnetic field and induces a Lorentz force that causes deflection of the cantilever. The direction of deflection largely depends on the direction of the current and the magnetic field vector. As a source of magnetic field we used a NdFeB permanent magnet. The acting Lorentz force can be described as:

$$F = l(I \times B) \tag{1}$$

where l - length of the part of the current loop perpendicular to magnetic field, I - the current vector, and B - the magnetic field vector.

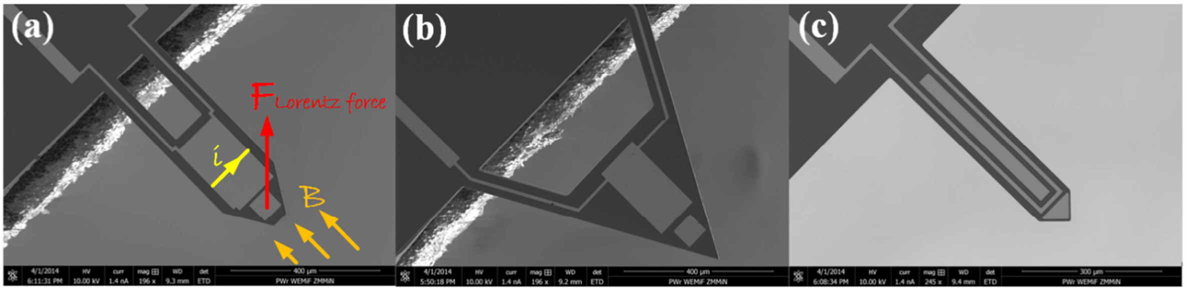

Fig. 1. SEM image of three type (a-c) of electromagnetically actuated cantilevers fabricated in Institute of Electron Technology in Warsaw. Their top side is coated with gold which serves also as a mirror for the readout laser beam and a substrate for self-assembling monolayers (SAMs) and current loop for Lorentz force actuation.

The equations (1) indicate that: the total deflection is proportional to B and I. The deflections are linearly with current and magnetic field.

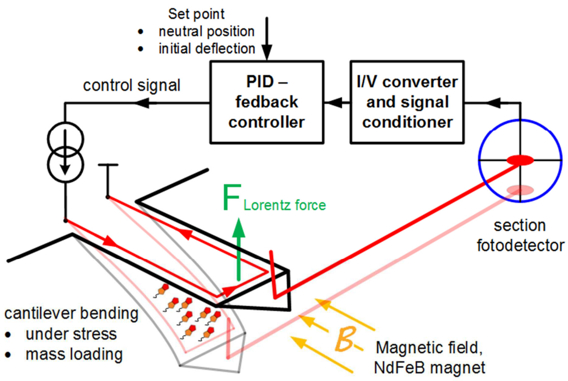

Fig. 2. The block diagram of a proposed method using Lorentz force as a balancing force to restore the cantilever to its original position

In our work, we present the method of bending and stress measurements with electromagnetically actuated cantilever in sensors application. Proposed method compensate the bend of the cantilever induced under stress or mass loading. In proposed method Lorentz force is a balancing force to restore the cantilever to its original position. The method schematically is shown in Fig. 2. Using the Lorentz force can keep the cantilever in a fixed position regardless of the resulting mass loaded or surface stress, providing work in the linear range of the photodetector. Additionally Lorentz force offers possible do drive cantilever bidirectionally. The bending of cantilevers is measured using optical beam deflection (OBD) method. Useful signal is derived from the feedback loop, that maintains the cantilever in a fixed position by balancing the deflecting force and the balancing force. For characterization and measurements of cantilever sensor, we use a homemade system dedicated software written in LabView environment (National Instruments). The parameters of cantilever as a stiffness were extracted from intrinsic thermal noise by fitting Lorentz curves.

3. Results and discussion

Figure 3 shows the cantilever working in closed-loop. To maintain the cantilever deflection in one position we used an analogue proportional-integral-derivative (PID) controller, provide current supply in the loop. The current values depends on the initial set point and interactions on the cantilever surfaces. The resulting response time of feedback loop was approximately 2 ms, as shown on Fig. 3b.

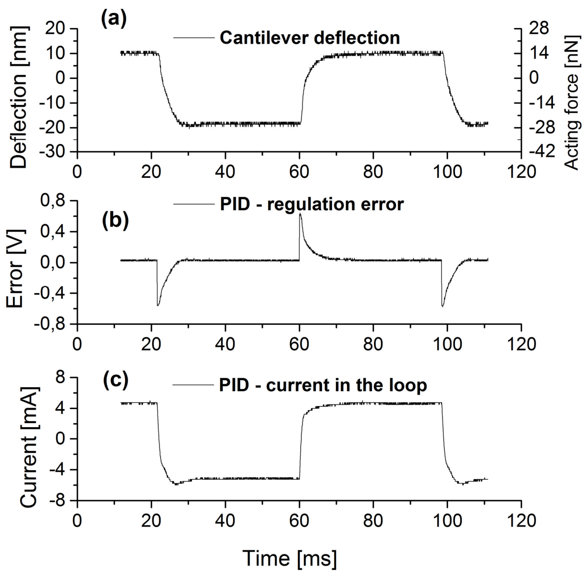

Fig. 3. Feedback signals of a cantilever working in closed-loop, (a) deflection, (b) error signal from PID regulator, (c) output signal from PID – current through in the loop

Furthermore, for the large values of current we have observed that cantilever deflection is different when same of current, but with different sign is passed. This indicates that while Lorentz force actuation is truly bidirectional, the thermally induced causes only downward bending (coefficient of thermal expansion CTE for gold is larger than CTE for silicon).

To test system working as a sensor we use the thiophenol molecule. It is aromatic compound from the group of thiols. Due to the presence of the sulfur atom in thiophenol molecule, it from SAM layer on gold surface. Additionally the substance has a high molecular weight (110.19 g/mol) with good vapor pressure (1.9 hPa at 20 °C). This allows to deposition the SAM layer on the gold cantilever surface from the gas phase. Before the experiment cantilever (Fig. 1a) surface was cleaned in the piranha solution in the 30s, next was washed in water, alcohol and dried in air. The cantilever was mounted in the gas flow cell. In 20 ml air-filled syringe in one drop of thiophenol was placed, and allowed to stand for an hour to form pairs of thiol. Then slowly the thiophenol vapor was injected in portions of 2 ml into the cell in three minute intervals.

The results of monitoring cantilever functionalization with thiophenol and injection vapor process are visible on Fig. 4.

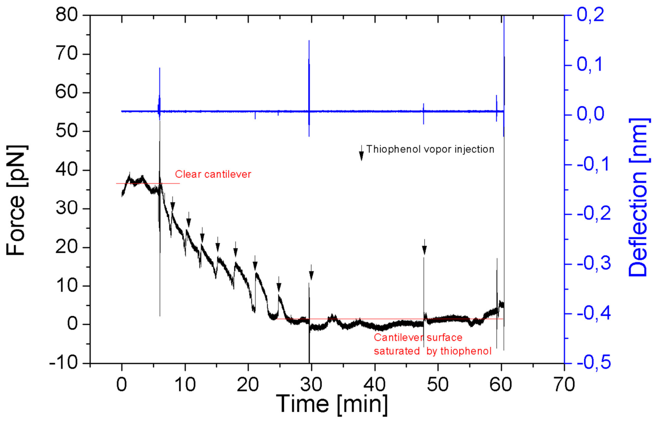

Fig. 4. Deflection and Force measured during the deposition of thiophenol molecules on cantilever gold surface. The temperature drift has been removed from the force graph.

The cantilever reacts on tiphenol assembly by increasing the force needed to keep the cantilever deflection on the same level. This process is related with repulsion of thiophenol molecules bonded to a gold surface. The stress increases until the whole gold surface were covered by SAM. After 25 minutes of thiophenol deposition, the cantilever surface was saturated. Additional portions of thiol vapors did not cause significant changes in the measured Lorentz force. This process is caused by the occurring stress due to the formation the SAM layer on gold surface. Change the Lorentz force caused by the substance deposition on the cantilever was approximately 37 pN.

4. Conclusion

We have demonstrated electromagnetically actuated cantilever working in static mode applied as a biosensor. The proposed method compensates the bend of the cantilever induced under stress or mass loading. In proposed method Lorentz force is a balancing force to restore the cantilever to its original position. We used this technique to monitor the self-assembly process on the cantilever surface.

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