OPTICAL AND DIELECTRIC FORCE GRADIENT ACTUATION SCHEMES FOR EXCITATION OF TRIPLE COUPLED MICRO CANTILEVER SENSOR IN MASS SENSING APPLICATIONS

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ABSTRACT

We apply dielectric gradient force actuation scheme to the central cantilever of triple coupled cantilever system. The oscillation amplitude and frequency of all the three modes is measured. We have shown that a dielectric cantilever can oscillate when a static voltage is applied with a modulation signal because of the polarization effect. This actuation scheme is also compared with the traditional optical actuation scheme.

Keywords: micromechanical resonator, mode localization, sensors, dielectric actuation scheme.

1. INTRODUCTION

Polarization force is very interesting for the actuation of micro mechanical structures. A dielectric micro cantilever made with Silicon Nitride is placed over the gap of two coplanar gold electrodes. The cantilever is then attracted towards the electrode gap that is towards the maximum electric field intensity. This force is called Dielectric force, hence dielectric gradient force actuation scheme. Mechanical detection for biological measurement is calibrated through the use of Micro and Nano mechanical cantilevers. Micromechanical resonators attracted a growing interest as the ultimate family of biological sensors [1]. Beside single resonators, mainly cantilevers and double clamped bridges, very few examples of complex architectures have been proposed. A. Qazi *et al*. proposed two asymmetric cantilevers facing each other in a driver-follower configuration [2]; M. Spletzer *et al*. [3] and E. Gil Santos *et al*. [4] used mode localization in two coupled cantilevers for mass detection. H. Okamoto *et al*. fabricated a GaAs based coupled clamped beams [5], where the dielectric asymmetries. Pakdast *et al*. [6] proposed to use three identical cantilevers and to monitor the motion of the central one, which, for symmetry reasons, is particularly sensitive to mass adsorption. Following the resonant amplitude variation of this cantilever, Pakdast and coworkers were able to detect the adsorption of a single silica bead - less than 1pg of mass, on a 10ng cantilever, with Dm/m= 10-4, comparable with the performances of frequency shift detection of cantilevers operated in vacuum. The use of cantilevers in microtechnology became popular with the invention of the Atomic Force Microscope (AFM) in 1986 and nowadays they are very important tools within the research area of micro- and nanofabrication. A cantilever is a beam that is clamped at one end and free-standing. The length L and the width W define the cantilever plane and typically the thickness t is at least an order magnitude lower than the other dimensions. In the AFM, a sharp tip is added at the free-standing extremity and the surface of the sample is scanned while measuring the deflection of the cantilever, which is caused by the interaction of the tip with the sample. In controlled conditions, with extremely sharp tips and proper samples, the tip-sample interaction is dominated by the attractive and repulsive forces at atomic level, hence the name of atomic force microscopy. The low spring constant of the cantilever allows a high out-of-plane deflection of the cantilever upon small changes of the topography. In the 1990s, a large variety of sensor technologies based on microcantilevers were applied as mass sensors, such as biological, physical, chemical, medical diagnostics and environmental monitoring. One of the advantages of micromechanical biosensors is that micro cantilevers are produced using a micro fabrication process, which allows parallel production of micro cantilevers at low cost, and with a very low structure error. It has been demonstrated that micro cantilevers can be used for the identification and detection of bio/chemical molecules, evaluation of hydrogen storage capacity and monitoring of air pollution. Cantilever sensors can be applied in three different areas: *surface stress*, *change in temperature* and *change in mass*, where the different areas are explained. Surface stress: The surface of the cantilever is coated with a detection layer. When the target molecules bind to the detection layer, will induce a surface stress, typically originated from the increase in volume of the bound molecules, thus causing the cantilever to bend. Change in temperature: When there is an exothermic or endothermic reaction, it will change the temperature of the cantilever. In the case where the cantilever is made of several materials with different Coefficient of Thermal Expansion (CTE), it will bend due to the bimorph effect. Change in mass: The resonance frequency of the cantilever is depending on the mass of the cantilever upon the added mass the resonant frequency of the dynamic system will alter.

Considered as sensors, the main advantage of Triple coupled cantilever (TCC) systems over single cantilevers is that the former are less affected by a-specific adsorption. Indeed since the TCC respond to the symmetry break induced by the mass adsorption on one cantilever, a

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diffused and uniform a-specific mass deposition on the whole TCC structure should not affect the system response. A second promising feature of TCC system rely on the fact that the three oscillators are intrinsically entangles but can be actuated and measured independently. Taking advantage of the non trivial transfer function determined by the TCC entanglement, active signal processing devices could be designed. In literature few examples of coupled mechanical resonators used to implement building blocks for mechanical logic devices have been already introduced. H. Yamaguchi *et al* implemented logic circuits in a single mechanical resonator [7] and an RF nanoelectromechanical XOR logic gate has been demonstrated by Sotiris C Masmanidis *et al*. [8]. In this letter we report on the development of a dielectric force gradient actuation strategy to the electrodes of TCC system with the purpose of better integration into a more complete MEMS architecture following the original proposal by E. Weig *et al* [9]. They proposed a method for controlled and local transduction upon the applications of dielectric gradient forces of nanoelectromechanical systems. A strong dipolar momement in the cantilever is induced by applying static potential to experience an alternative force; this force is directed towards the electrodes. Modulation voltage with an RF signal gives rise to an oscillation force that drives the cantileverperpendicular to the sample plane. The polarization is responsible for the dielectrophoretic force is defined by the properties of the neutral object to be moved. The force resulting from the polarization of the dielectric material is called the dielectric force. The dielectric force is defined by the bulk material properties of the involved dielectrics.

1.1 Dielectric force gradient excitation

Any polarized body experiences electric force, which is placed in inhomogeneous electric field is well known postulate in macro world where water jet is deflected when it is approached by charged object. Our approach is based on application of dielectric gradient force for the controlled and local transduction of nanoelectromechanical systems (NEMS).To induce electric field gradient, a set of onchip electrodes are used to polarize the dielectric resonator and influence it to an attractive force that can be modulated at higher frequencies which is broad band, scalable and universal actuation scheme. It enables simple voltage tuning of mechanical resonance over a wide range of frequencies, because dielectric force strongly depends on resonator electrode separation and reverse actuation principle is used for dielectric detection. An attractive forse is influenced by polarizable material in a directed inhomogeneous electrical field strength. A static voltage V_{dc} (direct current, d.c) applied to electrodes induces a strong dipole movement in resonator that in turn experiences an attractive force directed towards electrodes. Modulating V_{dc} with R.F signal V_{rf} gives rise to an oscillating force component that drives resonator perpendicularly to the chip plane. The force exhibits maximum at a distance that is comparable, through somewhat smaller than our resonator-substrate separation d approximately 300 nm.

An quantitative validation of dielectric gradient force actuation and readout mechanism schemes for Nano Electro Mechanical systems, bound to be advantages. Without being bound by specific requirements, it thus enables mechanical quality factors of the resonator. The quality factor of the mechanical resonator scales with sensitivity [1]. As the actuation schemes is capable of addressing individual resonator [2, 3], ideal for biosensing applications. This scheme can be used for larger arrays where individually addressable resonators are used. We demonstrate that by using this actuation scheme results strong electrical field-effect tuning of both resonance amplitude and frequency.

1.2 Optical excitation

In order to find the resonant frequency, the micro structures are excited in dynamic mode with corresponding eigen states and in parallel vibrational amplitude is calibrated. In optical excitation the theory results that induced bending movement of micro mechanical resonators as a function of excitation frequency, geometry of structure and materiel properties. The bending of resonator also depends on absorption length of material penetration depth of thermal wave and thickness of resonator [1]. It is shown that the effectively of opto-thermal transduction improved by absorbing layers only in case of materials which are transparent. Several possibilities have been described for optical excitation in literature [2.3].The absorbed optical power creates thermal distribution in structures, which in turn gives rise to mechanical movement in the beam. Thermal movement of beam defined as fallows.

$$MT(t) = \int_0^h \theta(y,t).\left(\frac{h}{2} - y\right)dy$$

Where h is thickness of the beam(y-direction) and Θ is temperature.

The mechanical movement is directly proportional to thermal movement M_T (t) [4]

$$M(t) = Ebh\beta MT(t)r^2$$

E is termed as Young's modulus, b is beam width and β is thermal expansion coefficient.

Optical properties of organic laser materials excited by quasi-continuous wave optical excitation demonstrated so far employed pulsed (t=100 fs-10ns) optical excitation. Sources like nitrogen laser or frequency- tripled YAG laser provides pulses of ultraviolet radiation (λ=350nm) with energies in excess of lasing thresholds in the organic thin films [5]. The nonlinear parameter of dispersive avalanche photo diode was extracted using DC optical excitation. In this regard nonlinear model of avalanche photo diode was considered as a two port network and vector reflection measurement was carried out using microwave transition analyzer in

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pulsed RF mode in conjunction with synchronized optical stimulus on the photo diode [6]. The pulse excitation scheme was used for the analysis wide-band characteristics of optical wave guides in this excitation scheme a Fourier series is proposed to analyze the wide band response of optical wave guides. To validate these results a wave guide with high reflection coatings and wave guide grating are analyzed using the finite difference time domain method [7].

Optical excitation scheme also demonstrates activation of micro transducer for efficient generation of narrow band longitudinal ultrasonic waves [8]. The transducer is a two mask level MEMS device with micro disk seated on the micro stem. When a laser pulse incident on the center of the microdisk, a resonant flapping motion is activated because of the thermomechanical interaction between absorbing and nonabsorbing parts of the disc, coupling a narrow band longitudinal bulk wave propagating along the axis op stem into sample. Laser based ultrasonic techniques have been received much attention because ultrasonic inspection has advantages over traditional ultrasound generation and detection that are based on contact techniques. To increase the amplitude of laser generated ultrasound, different techniques developed successfully. One technique is to deposit a layer of material, which is higher optical absorption coefficient onto surface of sample.

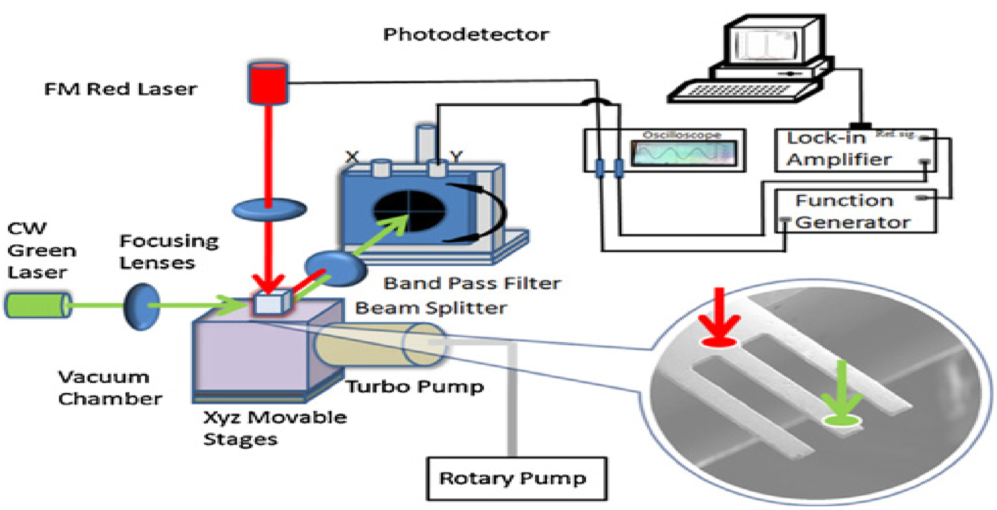

Figure-1. Experimental setup for optical actuation. Inset: Application of optical actuation scheme on TCC device.

2. EXPERIMENTAL SETUP

The devices were mounted in a measurement chamber with base vacuum of 1×10^{-6} mbar. The excitations are carried by a frequency-modulated red laser, and were detected using a green laser and a four quadrant photodiode (4QPC) in the optical lever configuration. The latter technique has been used to detect cantilever oscillation amplitudes below 1nm and therefore is particularly suitable to detect small variation in low amplitude oscillators, as in our case. A band pass filter with optical density (OD) is used to remove the driver laser signal from optical liver path. The frequency response of each cantilever is recorded using XY-stage manual micropositioning system, by moving the whole chip to the optical path and second stage is used to move 4QPC to maximize the signal. The experimental setup is shown in Figure-1. Cantilevers $100x20x2mm^3$ in size and 8ng in mass with Au electrodes on either side of the three cantilevers have been fabricated by standard microfabrication techniques (a representative device is shown in Figure-2) for dielectric force actuation.

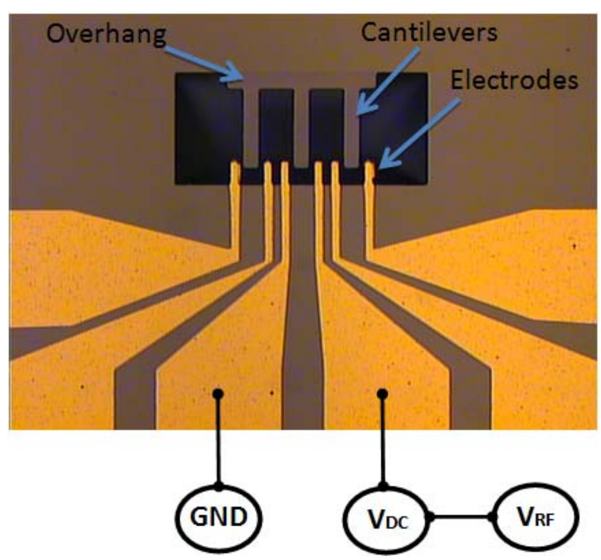

Figure-2. Application of dielectric gradient force actuation scheme on TCC device.

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The TCC device was mounted in a chamber with base vacuum of 1x10-6 mbar. The static voltage signal and the modulation signal have been taken from the DC generator and signal generator respectively. The vibration amplitudes of the cantilevers have been detected by an optical lever system consisting of a green laser and a four quadrant photodiode (4QP). In optical actuation scheme, we have given a frequency pulsed laser on the overhang of the Silicon nitride

TCC and the frequency response have been monitored with standard optical lever deflection method as shown in Figure-2.

3. RESULTS

The results of pulsed actuation and dielectric gradient force actuation are shown in Figures 3 and 4. We successfully actuated the TCC by optical technique and imposing a RF voltage on the lateral cantilever. The oscillation amplitude increases linearly with the RF voltage. Moreover we observed that if a static voltage (Vdc) is applied on the same cantilever on which the RF voltage is applied, the oscillation amplitude is increased by a factor 1+Vdc/Vrf. We investigated also the resonance shapes for the three fundamental oscillation mode, for each cantilever, in the same device. We found that, for each mode, the dielectric actuation imposes equal amplitude on all the three cantilevers Figure-3, while the optical actuation produces differences in amplitude Figure-4, as expected by the amplitude distribution is TCC [6]. Moreover, the width of the second resonance is much larger in the dielectric actuation indicating that a different dissipation mechanism takes place.

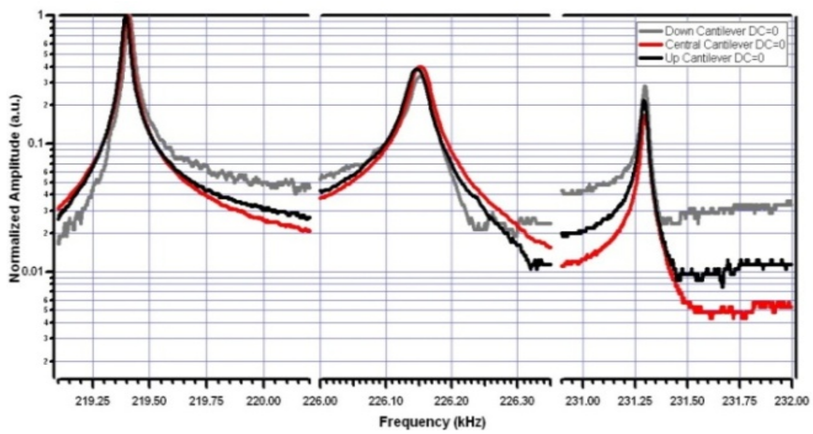

Figure-3. Dielectric force gradient scheme results.

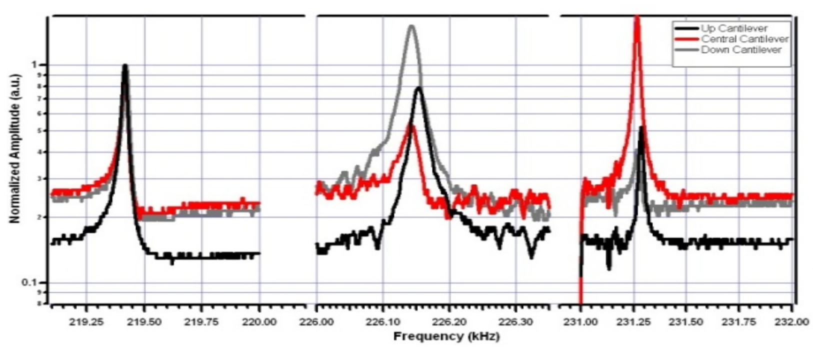

Figure-4. Optical actuation scheme results.

CONCLUSIONS

The Triple coupled cantilever micro sensor is actuated with optical and dielectric force gradient schemes for different eigen mode frequencies. In optical actuation technique the resonant frequencies are varied with respect to optical power applied to central cantilever. Similarly, in dielectric force gradient actuation scheme the eigen frequencies are also varied by varying Vdcand Vrf. So this sensor can further extended to use as Biosensors to detect biomolecules like glucose, fructose, bacteria's and virus.

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