Ring resonator based bio sensors using micro-cantilever

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Abstract - *In this paper we propose and analyze an optical MEMS vibration sensor which exploits the photoelastic property of integrated optical microring resonator due to vibration of microcantilever beam. Rapid advances in biochemistry and genetics lead to expansion of the various medical instruments for detection and prevention tasks. On the other hand, food safety is an important concern which relates to the public health.. One of the most reliable tools to detect bioparticles (i.e., DNA molecules and proteins) and determining the authenticity of food products is the optical ring resonators. The performance of these resonators is studied from sensing point of view. Simulation results, using finite difference time domain paradigm, revealed that the existence of a nanogap in the ring configuration achieves higher amount of sensitivity; thus, this structure is more suitable for bio sensing applications*

Key Words: **Ring resonator**, **Wave guide**, **Micro cantilever**, **Bio-sensor**, **Photo–elastic effect,**

1. INTRODUCTION

An optical ring resonator is a set of waveguides in which at least one is a closed loop coupled to some sort of light input and output. (These can be, but are not limited to being, waveguides.) The concepts behind optical ring resonators are the same as those behind whispering galleries except that they use light and obey the properties behind constructive interference and total internal reflection. When light of the resonant wavelength is passed through the loop from input waveguide, it builds up in intensity over multiple round-trips due to constructive interference and is output to the output bus waveguide which serves as a detector waveguide. Because only a select few wavelengths will be at resonance within the loop, the optical ring resonator functions as a filter.

1.1 BLOCK DIAGRAM

The block diagram consists of Microcantilver, Fundamental mechanical parameters of an AFM cantilever are its spring constant and resonant frequency. The optimal values of these parameters depend on the mode of the operations, namely contact mode, non-contact mode, and intermittent contact mode:

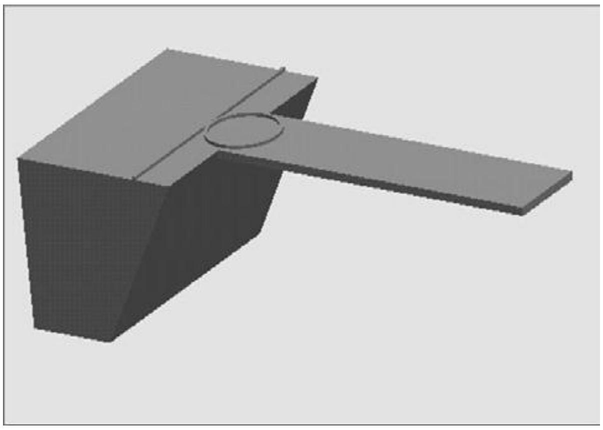

Fig -1 : Schematic diagram of the cantilever integrated with the micro ring resonator. *l, t* and *w* represent the length, thickness and width of the cantilever, respectively.

1.2 Cantilever Design

GaAs has a large photo-elastic constant which makes it a suitable material for fabrication of integrated optical devices and cantilever. Other materials such as Si3N4 and Si can also be used with varying sensitivities. Our design is based on rectangular cantilevers which are compatible with well established micromechanical fabrication technology. For a rectangular cantilever, spring constant is written as.

$$K = \frac{EWt^3}{4l^3} \quad (1)$$

2. Finite Element Method Stress Analysis of the Cantilever

In any cantilever design, the measurement of the displacement of the cantilever with high sensitivity is the essential task. The design of the cantilever and the type of the integrated sensor plays a fundamental role to increase the sensitivity. Bending the cantilever generates stress which is the necessary physical quantity used to characterize the displacement of the cantilever. Photo-elastic effect is used for the sensing mechanism; stress generated on the cantilever changes the refractive index of the waveguide where the optical sensor is loaded. Furthermore, sensing the generated stress using integrated optical devices requires materials suitable for such devices with large stress optic coefficients. A good candidate is GaAs. Applying mechanical stress to GaAs results in variation of local index due to photo-elastic effect, therefore we will use GaAs as a cantilever material. Since the displacement of the tip causes mechanical stress along the cantilever, maximizing the stress on the sensing element will maximize the performance. Obtaining the generated stress is the essential task. The stress distribution on the rectangular cantilever can be written analytically. As the cantilever bends, stress reaches its maximum value at the supporting point and decreases linearly along the cantilever. Therefore, the sensing element is placed at the supporting point where

$$\sigma_{max} = \frac{3Et}{2l^2} z \qquad (2)$$

in which, E is the Young's Modulus, t is the thickness, l is the length and z is the displacement of the cantilever. To obtain more accurate results for complicated geometries Finite Element Method (FEM) analysis is employed

2.1 How Ring used in bio sensing application

In the past few years, optical ring resonators have received a lot of attention as one of the most promising biological sensors. The optical ring resonator measures the target molecules through assessing the deviations in light behavior, which is caused by interaction between electromagnetic wave and biological molecules such as proteins, bacteria, cells, or DNA samples. This change in the behavior of the light is because of interaction between evanescent field of the resonating light inside the resonator and bio particle that exist in the ambient. Existence of bio particles in the medium changes the effective refractive index of surrounded medium, which results in deviation of resonance conditions of the resonator. Consequence of such an interaction is resonance wavelength deviation of the resonator that is related to the number for bio particles in the medium. A sensing mechanism is depicted schematically To enable the periphery of the resonator to absorb bio particles, an active polymer layer can be deposited on the boundary of the resonator.

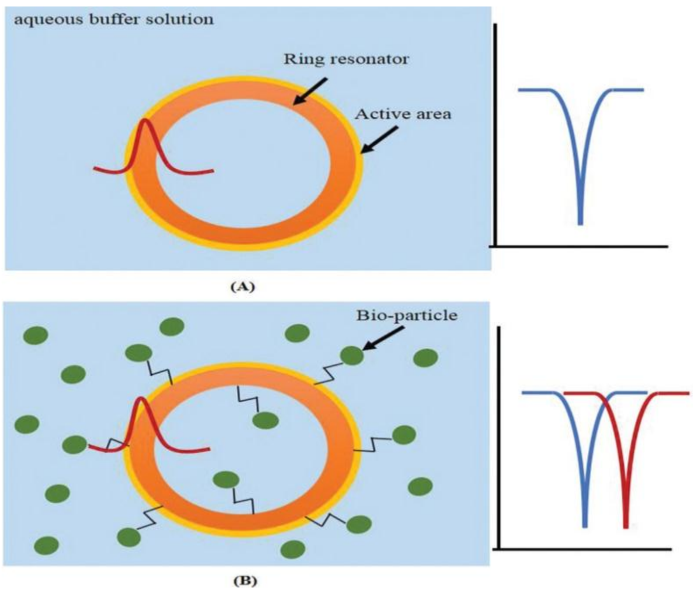

Fig -2: Optical ring resonator as a biological sensing platform; (a) ring resonator is placed in an aqueous buffer solution. (a) There are no bioparticles in the buffer solution. (b) There are bio particles in the medium. The bioparticles captured by the active

2.2 Micro-Ring Resonators

we use a micro-ring resonator integrated on a cantilever as a displacement sensor. This sensor is based on the photo-elastic effect. The atomic forces make the cantilever deflect from equilibrium and this deflection produces stress on the cantilever surface . Index change on the ring due to the stress cause a shift in the resonant wavelength .Fig. 3

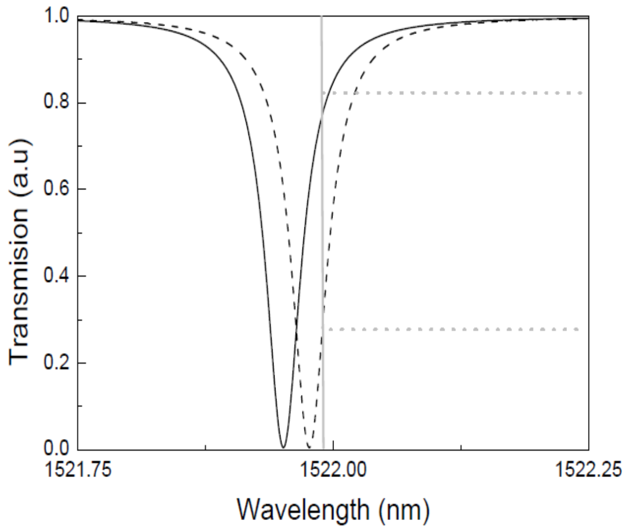

Fig -3: Sensor concept based on a ring resonator. The optical power modulation takes place as position of resonance dip shifts. Inset shows the variation of the output intensity

shows the transmission spectrum of optical waveguide coupled ring resonator and the modulation concept. Stress on the ring causes shift in the resonance wavelength. The stress reaches its maximum value at the supporting point of the cantilever and it decreases linearly along the cantilever.

2.2 specific Q and FSR

Quality factor or Q factor is mainly used to describe the frequency response of are resonator. It is the Figure of merit of a resonator expressed as a ratio between average energy stored in a resonator and energy dissipated per cycle. For a biosensing application in general we need an high-Q resonator, but Sumetsky [100] suggests experimental parameters are equally important in determining selectivity and sensitivity of a sensor. A simplest expression for Q can be written as

$$Q = \frac{\lambda_{res}}{\Delta\lambda} \qquad (3)$$

$$FSR = \frac{\lambda}{N_g L} \qquad (4)$$

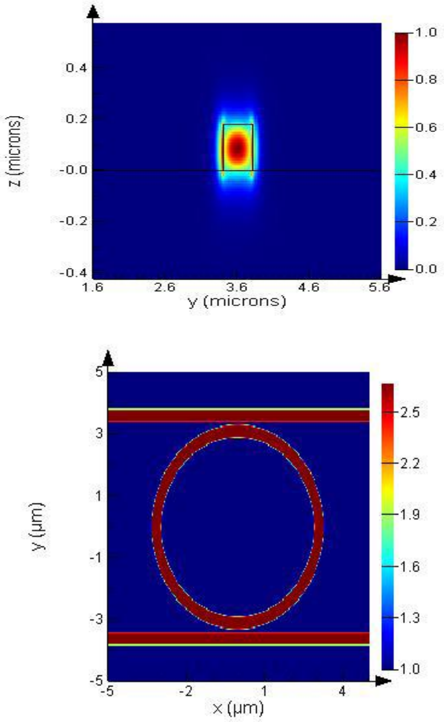

Fig -4 (a) Mode profile of quasi-TE0 (b) Effective index of Micro ring Resonator

3. CONCLUSIONS

In the last few decades several research groups started working on Bio-Photonics, Micro and Nano- opto mechanical systems and towards lab-on-chip applications .After experimental demonstration of fiber based biosensors, significant number of researchers ventured into integrated optic domain

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