Optimisation study of micro cantilevers for switching of photonic band gap crystals

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Abstract:

We propose to use electrostatically actuated micro bimorph cantilevers with tips for nanometric perturbations in the evanescent field of various resonators and photonic band gap crystals (PBG) using a self aligning technology. Since in PBG and in other high optical index contrast structures the interaction of evanescent field with mechanical elements start to play a role typically with a distance <400 nanometers, the required cantilever strokes for switching can be accordingly small. This allows for fabrication of relative stiff cantilevers with resonance frequencies in the MHz range. In this contribution we describe the technology for such devices, the optimization studies of the cantilever designs and measurements of mechano-optical interactions using an AFM based cantilever.

Keywords: photonic band gap crystal, MEMS, bimorph

1. Introduction

Out of plane movement of MEMS switches, operating in the MHz region produces variations in waveguiding properties such as propagation constants and losses [1]. To realize these switches, micro bimorph cantilevers are fabricated which can be integrated to PBG crystals by surface micromachining techniques. An analytical model is developed to find the resonance frequency and the pull in voltage for resonances of these switches and is compared with experimental data. Also we have measured the on/off switching by perturbing the near band edge resonance of a waveguide grating with a 20 μm wide silicon nitride AFM cantilever, without using its tip area.

2. Design and Fabrication

The active joint studied here consists of two layers of different materials in which a deformable beam is bent by the bimorph effect as well as by applying an electrostatic force [2]. The upper electrode is a thin layer of Chromium (Cr) which is on the top of a thick layer of dielectric material which is Silicon Rich Nitride (SiRN). For initial design purposes we assume that the bimorph is curved upward by thermal-mismatch induced stresses causing the Cr layer to be in tensile and the SiRN layer to be in compressive stress.

First the microcantilevers are fabricated on p-type silicon wafers, which are wet oxidized for a thickness of 1.5 μm . Following this, is deposited a layer of low stress SiRN by low pressure chemical vapour deposition method for a thickness of 1 μm and the upper Cr layer is sputtered for a varying thickness. The Cr layer is patterned by wet chemical etching followed by a plasma etching of SiRN on both sides of the wafer. Finally the cantilevers are released by sacrificial layer etching of silicon oxide by the Freeze

Drying method [3]. The cantilever length is varied from 20 μm to 100 μm keeping the width fixed at 10 μm in all cases. We propose to use the same technology to fabricate the self-aligned bimorph cantilevers with tips with respect to e.g. the holes in a PBG micro-resonator coupling section.

Fig 1. Fabrication flow (A) for the self aligned bimorph with tips on top of PBG, (B) tipless bimorph on silicon wafer and a fabricated bimorph of length 60 μm on a silicon wafer.

3. Optimisation and Measurements

3.1 Resonance Frequency

If L is the length, W is the width, t is the thickness, EI is the flexural rigidity and ρ is the density of the bimorph, for the first mode of vibration, the frequency is obtained as:

$$f_1 = \frac{1}{2\pi} \left(\frac{1.8751}{L} \right)^2 \sqrt{\frac{EI}{W(t_{Cr}\rho_{Cr} + t_{SiRN}\rho_{SiRN})}} \quad [1]$$

It is observed that the predicted values from the model show a deviation in the resonance frequency for cantilevers of shorter lengths. This is same for both the first and second modes of resonance and is associated with an undercut of 5.4 μm on the anchor point of the cantilever during freeze drying. This causes an increase in effective length in combination with a deviation in effective flexural rigidity from theoretical values which cause a deviation in the resonance frequency. To account for this effect, from equation (1) we have,

$$\frac{\Delta f_1}{f_1} = -2 \left(\frac{\Delta L}{L} \right) + \frac{1}{2} \left(\frac{\Delta EI}{EI} \right) \quad [2]$$

where Δf_1 is the difference between the experimental and predicted resonance frequencies. Ideally equation (2) describes a straight line for $\left(\frac{\Delta f_1}{f_1} \right)$ versus L^{-1} with a slope

– $2\Delta L$ and with a value $\Delta EI/2EI$ as ordinate for $L^{-1}=0$. Using a least square method we find, $\Delta L=1.082\mu\text{m}$ and $\Delta EI/EI$ as 0.0074. Including these corrections in the model give an improved prediction of resonance frequencies as shown in Fig 2.

Fig 2. First resonance mode as a function of L^{-2} for a 200nm thick Cr layer.

3.2. Pull in Voltage

Pull in voltage is one of the points of instability in operating MEMS structures and it is important to understand this instability point in order to properly design and operate the MEMS structures. Following an energy based analysis given in [2] we find the pull in voltage as ;

$$U_{pi} = 2 \left(\frac{d + t_{SiRN} / \epsilon_{SiRN}}{L^2} \right) \sqrt{\frac{2EI V_l}{\epsilon_0 W}} \quad [3]$$

where ϵ_0 and ϵ_{SiRN} are the relative and absolute dielectric constants, d is the gap between the bimorph and the substrate and V_l is the off state deflection of the bimorph.

Fig 3. Measured and predicted pull in voltages as a function of L^{-2} for a 200nm thick Cr layer.

3.3 Mechano Optical Switching

We have observed mechano-optical on/off switching by perturbing near band edge resonance of a waveguide grating with a silicon nitride AFM cantilever, as shown in Fig. 4. When the cantilever is brought to a certain location (A), the 1st near band edge resonance is turned off. This

cantilever location is most likely at the center of the grated section, where the 1st resonance has its maxima [4]. Another cantilever location (B) appears to slightly shift the resonance wavelength, which based on modelling results [5] would be expected when the cantilever is placed slightly above the grating. The observed mechanical perturbation allows 15 dB on/off switching of a specific wavelength and a wavelength tuning of approximately 60 pm.

Fig.4. Measured transmission spectra of a grated silicon waveguide with different cantilever locations.

4. Conclusion

We have proposed a fabrication technology that allows for the manufacture of cantilever mounted tips self-aligned to PBG crystals. Using a simplified process for first testing and characterisation, we have analysed resonance frequency and pull in voltages for micro cantilevers that can be integrated with photonic band gap crystals. It is found that the higher resonance frequencies come at the price of larger switching voltages. Also we have observed the selective wavelength on/off switching and tuning of a waveguide grating, using an AFM cantilever.

5. Acknowledgment

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6. References

- [1] Y. Kanamori, et al, "Photonic crystal switch by inserting nano-crystal defects using MEMS actuator", *Proceedings of the 2003 IEEE/LEOS International Conference on Optical MEMS* Waikoloa, USA, 2003, pp. 107–108.
- [2] Chakkalakal Abdulla, S.M, et al, "Optimised Frequency Range of Active Joints for Nanometre Range Stroke", *MicroMechanics Europe Workshop 2007*, Guimarães, Portugal. pp. 211-214
- [3] R. Legtenberg, et al, "Electrostatically driven vacuum-encapsulated polysilicon resonators Part I. Design and fabrication", *Sensors and Actuators A* 45, 1994, pp. 57- 66
- [4] W.C.L. Hopman, et al, Far-field scattering microscopy applied to analysis of slow light, power enhancement, and delay times in uniform Bragg waveguide gratings, *Opt. Express* 15 (2007) 1851–1870.
- [5] L.J. Kauppinen, et al, "Grated waveguide optical cavity as a compact sensor for sub-nanometre cantilever deflections", *14th European Conference on Integrated Optics 2008*, Eindhoven, The Netherlands.