Investigating Planar Integrated Glass Cantilevers Utilizing Bragg Gratings and Mechanical Resonance in a Vacuum

Lewis G. Carpenter, Christopher Holmes, Helen L. Rogers, James C. Gates and Peter G.R. Smith
Optoelectronic Research Centre
University of Southampton
Southampton, UK
lc906@orc.soton.ac.uk

Abstract—**Glass-micro-cantilever Bragg grating devices incorporate both micro-machining and direct UV writing. This novel combination of fabrication techniques reduce construction times on photolithography and allow rapid prototyping. It utilizes the cantilevers mechanical resonance to allow it to be used to detect the change in the air's damping coefficient with pressure.**

Keywords-component; Cantilevers; Planar Integrated Optics; Bragg Gratings;

I. Introduction

We demonstrate a glass cantilever based on a unique micromachining and etching approach, combined with UV writing. Here we explore the changes in the resonant mechanical flexure modes with pressure. Cantilevers are ubiquitous ultra sensitive force sensors used in applications such as Atomic Force Microscopy (AFM), mass sensing, and acoustic transducers. Conventionally cantilevers are fabricated by photolithography; however in this paper we demonstrate a new approach based on micromachining silica-on-silicon substrates. Furthermore this approach is compatible with Direct UV writing of optical waveguide channels and Bragg gratings [1]. The Bragg gratings provide a method of interrogating the deformation of the cantilever.

II. Glass Cantilever Fabrication

A. Fabrication

The planar substrates consist of three layers of matched refractive index silica on silicon substrate. The middle core silica layer is doped with germanium promoting photosensitivity and allowing the ability to UV write waveguides. Definition of the cantilever is achieved by micromachining, grooves into the silica layer with a precision dicing saw. This allows the length and width of the cantilever to be predefined. After micromachining waveguides and Bragg reflectors are direct UV written into the photosensitive layer. Finally the silicon substrate is etched with heated KOH to liberate the silica cantilever from the substrate.

B. Micromachining Advantages

There are several advantages of micromachining over standard etching with masks, these include:

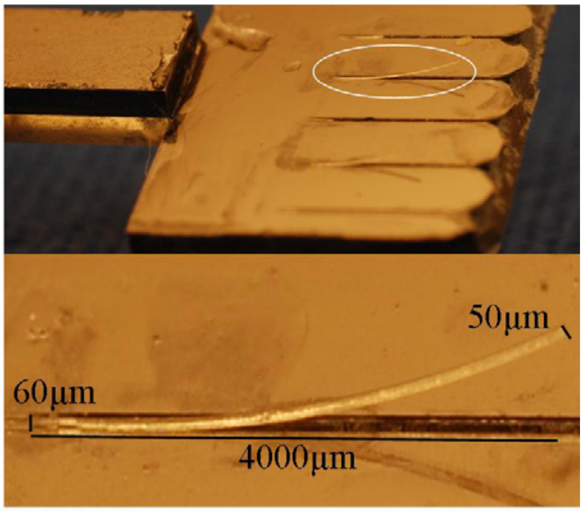

Figure 1. The top image shows the 20mm by 10mm substrate with the pigtail, the cantilever is circled. The bottom image shows a close up of the cantilever with approximate measurements.

- Well defined vertical side walls, rather than sloping ones caused by etching along crystal boundaries
- Overall roughness (R_a) of ~10nm.
- Freedom from mask expense and time investment, thus allowing rapid prototyping

The combination of micromachining, UV writing and the planar geometry allows for smaller devices with many cantilevers and more than one Bragg grating on each cantilever. Simple fiber coupling allows these devices to be multiplexed and distributed over a large area.

III. Glass Cantilever Operation

A. Cantilever Selection

The experiment was undertaken using a 20mm by 10mm substrate, with 9 cantilevers, each having 9 Bragg gratings along its length with central wavelengths each 5nm apart from 1525nm to 1560nm.

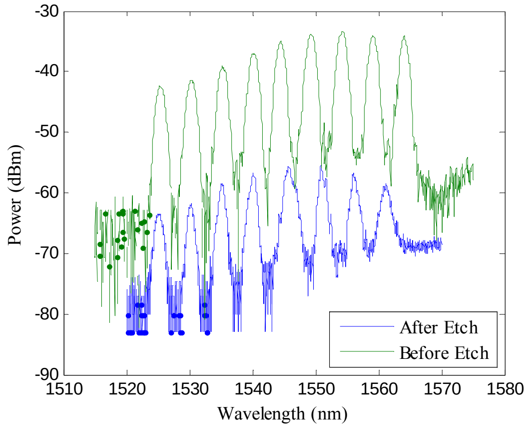

Figure 2. Shows the reflected spectra from the Bragg gratings of cantilever, the final grating at 1565nm was damaged during etching.

B. *Finding the Mechanical Resonace*

The reflection spectra were collected from a cantilever using a broadband source and an optical spectrum analyzer, as shown in figure 2. The 6th grating was chosen to be interrogated because it had the biggest central Bragg wavelength shift from pre and post etching thus it was assumed to be the most sensitive to further stress induced shifts. A tunable laser was used to match the point of highest gradient of reflection of grating 6, which was on the grating's shoulder at 1550.9nm. A piezoelectric transducer was then attached to the substrate and an acoustic signal was sent through the transducer and swept in frequency from 0 to 100 kHz. The reflected optical signal was measured with a photodiode and phase sensitive technique. The largest mechanical resonance was found to be at 25.7 kHz.

IV. Investigating the Cantilever's Mechanical Resonance with Pressure

A. *Mechanical Resonance at vacuum*

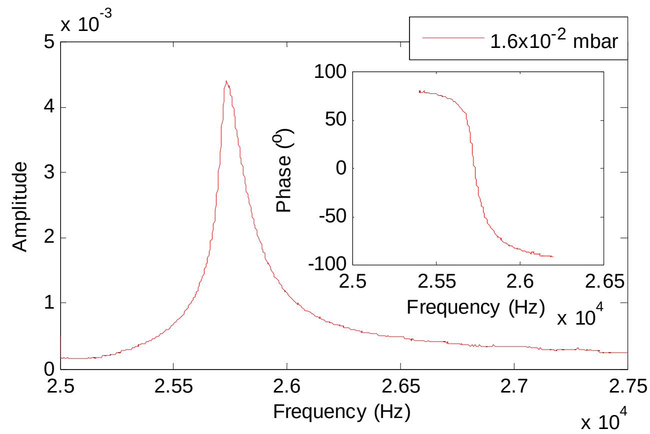

Figure 3. Frequency response showing mechanical resonce of the cantilever. The phase response is shown in the inset and exhibits the expected π phse.

By placing the sample in a vacuum chamber the resonance response of the sample was investigated as a function of pressure. Figure 3 shows the resonance at $1.6\text{x}10^{-2}$ mbar. Resonance curves were taken over a pressure range of $1.6\text{x}10^{-2}$ mbar to atmosphere.

B. *Analytical Data Fit*

A damped driven oscillator model [2] was used to fit the resonance data according to Equation 1:

$$A(\omega) = \frac{\frac{F_o}{m}}{[(\omega_o^2 - \omega^2)^2 + 4\gamma^2\omega^2]^{\frac{1}{2}}}. \qquad (1)$$

Where A is the amplitude, F_o is the maximum applied force, m is the mass, ω is the angular frequency, ω_o is the resonant angular frequency and γ is the damping coefficient.

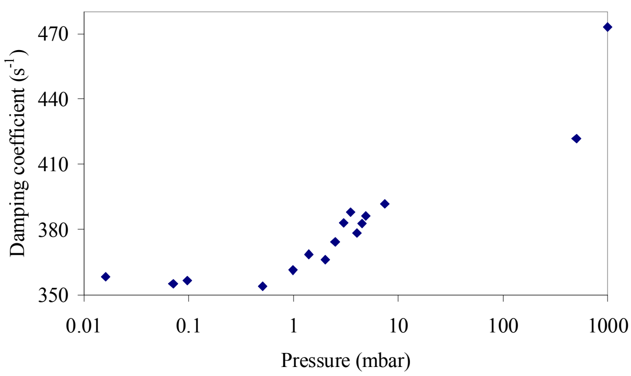

Figure 4. Fitted damping coefficient as a function of pressure.

The damping coefficient is shown in figure 4 and agrees with the trends reported by Kumazaki [3], for a resonant optical fiber. Figure 4 also exhibits the characteristic transition from molecular flow to viscous flow at 1 mbar as the pressure is increased.

Conclusion

Here we have demonstrated an integrated glass cantilever using Bragg gratings to interrogate the resonant mechanical characteristics. We have also shown that placing the glass cantilever in a vacuum changes the characteristics of the resonance curve for its fundamental mechanical flexure mode. Similar results have been shown by Kumazaki. We shall show our latest application of these fabrication techniques.

References

[1] James C. Gates, Christopher Holmes, Benjamin D. Snow, Corin B.E. Gawith and Peter G.R. Smith, "UV written evanescent devices fabricated in micro-structured substrates for optofluidics", Optical sensing and sensors OCIS codes: (280.4788), (130.3120) Integrated optics devices.

[2] G. R. Fowles and G. L. Cassiday, Analytical Mechanics. Fort Worth: Harcourt Brace College, 1986.

[3] H. Kumazki, S. Inaba and K. Hane, "Pressure dependence of resonce characteristics of the microcantilever fabricated form optical fibre," in Vacuum, vol. 47, numbers 6-8, Elsevier Science, 1996, pp. 475–477.