Ultrathin-walled microbubbles for high sensitivity pressure sensing

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1. Introduction

Whispering gallery mode (WGM) microresonators (WGRs) are considered to be excellent candidates for high sensitivity sensing. Here, we report on a relatively new WGM structure, the microbubble, used as a high sensitivity sensor for internal aerostatic pressure [1]. In contrast to conventional WGRs, this structure is hollow and sensing occurs inside the resonator through the evanescent field of the WGMs. Therefore, microbubbles have distinct advantages for optofluidic integration compared to the solid WGRs [2].

In order to achieve higher sensing resolution, we have fabricated microbubbles with an improved Q-factor and submicron wall thickness. The maximum Q obtained was only one order of magnitude lower than the theoretical prediction [1]. As a direct consequence, we achieved high sensitivity and high resolution aerostatic pressure sensing using this microbubble.

2. Experiment

The microbubble was made by melting an internally pressurized silica microcapillary using two counterpropagating CO_2 laser beams. By carefully controlling the laser power and internal pressure, a 170 µm diameter microbubble, with input and output microcapillary stems and a wall thickness of about 550 nm, was fabricated.

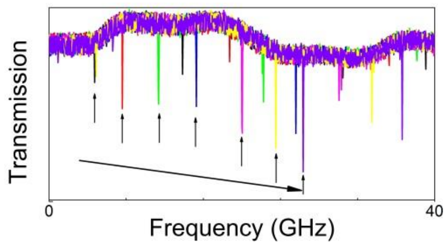

Fig. 1. Frequency shift of a WGM in the microbubble as the pressure is increased.

The microbubble was placed on a 3D nano-positioner in a basic enclosure to reduce environmental effects. The input stem on the microbubble was connected to a pressure source, while the output stem was sealed. A tapered optical fiber was used to couple light from a 780 nm tunable laser to the microbubble for WGM excitation. To measure the sensitivity, the pressure was varied, while monitored by an electrical pressure sensor, and the corresponding transmission spectra through the tapered fiber were recorded.

3. Results

In previous work, it was shown that the ty, dv/dp, is [3]:

$$\frac{dv}{dp} = \frac{c}{\lambda^2}\left(\frac{3C}{n} + \frac{4G+3K}{12GK}\right)\chi \tag{1}$$

where $C, G,$ and K are the elasto-optical coefficients, and the bulk and shear moduli for silica, respectively. $c, \lambda,$ and n are the speed of light, the wavelength, and the refractive index. χ is defined as a geometrical parameter that is related to the diameter and wall thickness of the microbubble [3]. For high sensitivity, the microbubble should be large and thin-walled. The WGM resonant frequency shifts as the internal pressure is changed as shown in Fig. 1. By using a linear fit, the measured sensitivity of the device is 38 GHz/bar.

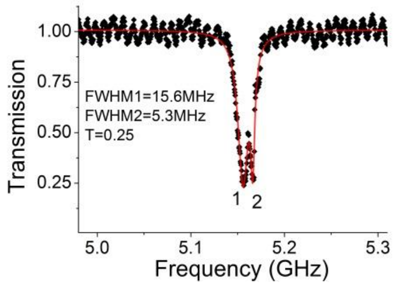

Fig. 2. Transmission dip from which the Q-factor is obtained.

The Q-factor can be measured from the linewidth of a dip in the transmission (see Fig. 2) and a value of 10^8 was obtained. This is only one order of magnitude lower than the maximum obtainable using finite element simulations (2×10^9) [4]. Thus, the minimum detectable pressure is about 0.15 mbar for this microbubble.

4. Conclusions

We have realized an ultrahigh sensitivity aerostatic pressure sensor using a hollow WGR with submicron thin walls. The obtained Q-factor can be as high as that achievable in solid WGRs, which is a crucial improvement for microbubble sensing applications.

Acknowledgements

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