Deformed microcavities with very high Q-factors and directional farfield emission

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Abstract. We report the design and optimized fabrication of deformed whispering gallery mode resonators in silica with solely ICP-RIE. This allows us to control the morphology of the resonators more freely and results in low surface roughness. The light was coupled into the resonator using a state of the art tapered fiber approach and we determined the Q-factor in the range of $10^5$.

1 Introduction

Optical microcavities are structures that confine light to a defined volume using the mechanisms of reflection and resonance. A special type of modes inside a circular optical microcavity is called whispering gallery mode (wgm) because they are confined by the total internal reflection occurring at the cavity boundary. One main property of a resonator is the Q-factor, which describes the ratio of stored energy inside the resonator to the loss energy per cycle. A high Q-factor, therefore, means long photon lifetime inside the cavity and this increases the light-matter interaction drastically. This is the main reason why high-Q resonators are a research platform for several fundamental investigations and experimental applications [1]. In the recent time high-Q resonators have been used for e.g. quantum electro dynamics [2], telecommunications [3], optomechanics, nonlinear optics [4] and sensing [5].

2 Asymmetric resonant cavities

One intriguing field of study are asymmetric resonant wgm cavities. While circular cavities exhibit a strongly isotropic radiation and propagation pattern, asymmetric resonant cavities show a more complex behavior. Much theoretical work was dedicated to the exploration of optical microcavities which produce a strongly directional farfield and to combine it with the property of high Q factors and therefore low loss [6].

Depending on the refractive indices of microresonators with specific deformations generate a directional far-field while still exhibiting high Q-factors. The limacon is such a morphology for refractive index larger than 3 [7]. Since most of the optical media with very low absorption have a refractive index close to 1.5 investigations showed that a suitable morphology for this regime is the Shortegg, with a shape following the equation2.

$$r(\phi) = R_0(1 + 0.16 \cos(\phi) - 0.022 \cos(2\phi) - 0.05 \cos(3\phi))$$

3 Fabrication

To investigate the behavior and potential applications of deformed cavities establish a fabrication process that allows us to fabricate resonators with very precise control of the deformation. The state of the art fabrication process
for UHQ resonator was shown by [8]. They use buffered HF for the etching of the silica layer and underetch the silica disk with XeF$_2$ vapour. After the structuring they use a reflow process to create a smooth boundary which results in a shrinkage of the resonator. First, we need to etch the 2µm thick silica layer, which is fabricated by thermal oxidation. For this, we use an inductively coupled plasma (ICP)-RIE with CHF$_3$/Ar chemistry. By fine-tuning the etch gases and the ion energy it is even possible to adjust the slope angle of our resonator which allows us to confine mode in the z-direction. The following silicon underetching is achieved by using a cryogenic SF$_6$/O$_2$ ICP RIE which exhibits very high selectivity to silica which is critical for achieving a low surface roughness. We achieved a surface roughness of $R_Q = 2$ nm.

4 Experimental measurement

![Resonance](image)

Figure 3: Fine scan of the resonance compared to a Lorentzian fit with a spectral window of 35 GHz

5 Simulation

To evaluate the experimental measurements we designed a wave optical simulation in comsol. There we computed the eigenmodes of a 100 µm Shortegg to compare them to our measurements. They resulted in a maximum Q-factor of $3 \times 10^6$. However this is the maximum intrinsic Q-factor which could be achieved in the eigenmode evaluations.

6 Conclusion

We demonstrated the fabrication of High-Q using ICP-RIE which resulted in measured Q-factors in the range of $10^5$ in deformed cavities with a diameter of 100 µm.

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