Behrens, Arne; Hentschel, Martina; Sinzinger, Stefan:

Untersuchung deformierter optischer Mikrokavitäten anhand des abgestrahlten Fernfelds

Zuerst erschienen in:	DGaO-Proceedings. - Erlangen-Nürnberg : Dt. Gesellschaft für angewandte Optik. -120 (2019), art. B17, 2 S.
Erstveröffentlichung:	04.09.2019
ISSN:	1614-8436
URN:	urn:nbn:de:0287-2019-B017-3
[*Gesehen:*	24.09.2019]

Untersuchung deformierter optischer Mikrokavitäten anhand des abgestrahlten Fernfelds

Arne Behrens*,Martina Hentschel**,Stefan Sinzinger*

Institut für Mikro- und Nanotechnologien MacroNano® TU Ilmenau
**Fachgebiet Technische Optik*
***Fachgebiet Theoretische Physik II*

mailto:arne.behrens@tu-ilmenau.de

Deformed microcavities generate a higly directional far-field. We want to use the intrinsic loss which gets radiated into the far-field domain to analyze the photon statistics and calculate the Q-Factor without nearfield manipulation. To achieve this goal a stable fabrication platform based on reactive ion etching was developed and characterized

1 Introduction

Optical microcavities are structures which confine light to a defined volume using the mechanisms of reflection and resonance. There are many different structures to achieve this goal. The most known is probably the Fabry-Perot resonator which solely consists of two mirrors. In this article, we will focus on optical microcavities which use total internal reflection to confine the light inside the resonator. This mechanism eliminates the adjustment of different optical elements and as be seen in (1) the resonance condition is similar to a linear resonator. The amount of loss and therefore damping of the light is described by the Q Factor (2) which corresponds to the number of roundtrips after the light intensity is decayed by -3dB.

$$\lambda_0 = \frac{2\pi r n_{eff}}{m} \tag{1}$$

$$Q = \frac{\lambda_0}{\delta\lambda} \tag{2}$$

$$\Delta\lambda = \frac{\lambda_0^2}{\pi r n_{\mathrm{eff}}} \tag{3}$$

2 Whispering Gallery Modes

The term Whispering Gallery Modes was coined from an analogy with acoustic waves. It was found that acoustic waves travel along the walls of a circular gallery like e.g. in the dome of he St Pauls Cathedral and that even very quiet noises could still be heard over a large distance. Electromagnetic Whispering Gallery Modes are solutions of the Maxwell equations, which only exist very close to the boundary and therefore undergo continuous total internal reflection. They feature many of interesting properties like ultra-high Q factors, very low mode volumes and very small resonator sizes. Combined with the possible chip integration they are an excellent research platform for topics like, Quantum cavity electrodynamics [1], nonlinear optics [2], bio chemical sensing [3] or microlasers [4].

3 Asymmetric resonant microcavities

Much theoretical work was dedicated to the description of optical microcavities and to produce a directional far-field. It was found that introducing a small deformation from the ideal circular shape of the cavity according to equation (4) a very directional far-field can be generated [5].

$$r(\phi) = R0(1 + 0.43\cos(\phi)) \tag{4}$$

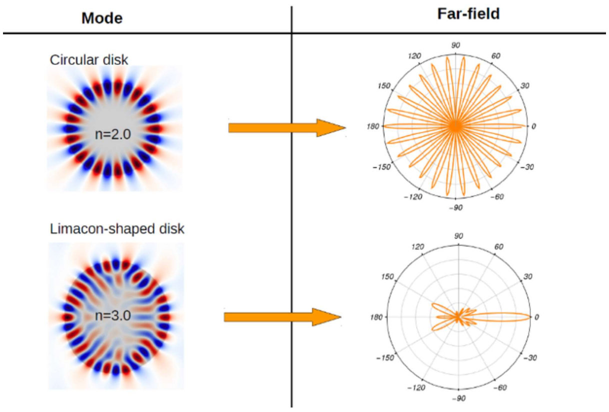

Fig. 1 *Comparison of the internal mode structure and the emitted farfield of a circular and a Limaçon disk*

This far-field can be explained by a combination of wave theory and chaotic ray dynamics which could be seen as a mesoscopic approach. This result is even suitable for microlasers which operated in a multimode regime. So this is an excellent model to describe deformed optical microcavities.

4 Process platform

To study the behaviour of deformed cavities and arrays we need to establish a process platform to produce this kind of on-chip resonators. We decided

DGaO-Proceedings 2019 – http://www.dgao-proceedings.de – ISSN: 1614-8436 – urn:nbn:de:0287-2019-B017-3
submitted: 01.Aug.2019 published: 04.Sep.2019

to use silicon dioxide as material for the Whispering Gallery Mode due to the very low absorption over a relatively broad spectrum and its compatibility to sophisticated plasma etching processes. As a substrate for the resonators, we use silicon.

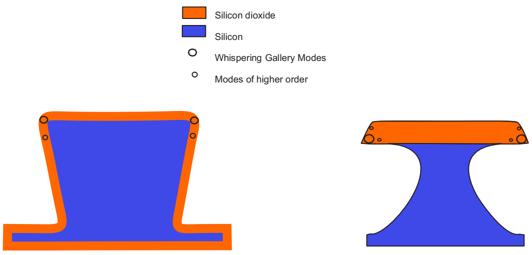

Fig. 2 *schematic of the developed processes*

We developed two different process ways to achieve our goal. For the first process, we structure the resonators in silicon with a cryogenic ICP-RIE based on fluor chemistry with a subsequent oxidation step to produce a 2 µm thick silica shell with very high purity. To smoothen the surface we introduced an additional oxidation step followed by a wetchemical etching with HF to remove the surface roughness. The result is shown in Fig 3.

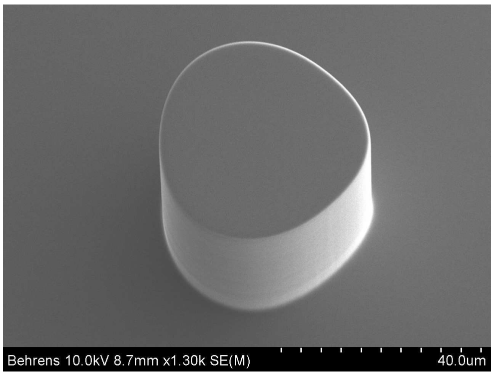

Fig. 3 *SEM image showing a 25 µm Shortegg microresonator*

The second process contains two etching steps and produces angled silica microdisks on top of an under etched silicon pad.

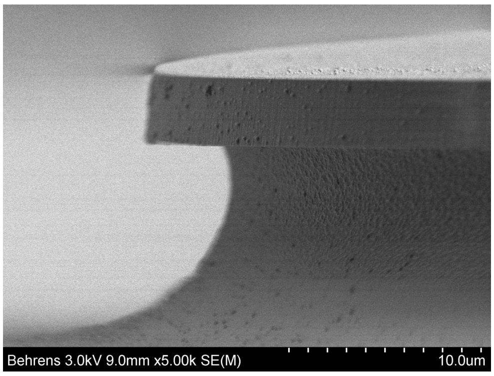

Fig. 4 *SEM image showing a 25 µm silica microdisk on a silicon pad*

The concept is similar to the standard process which was developed by [6] except that we use plasma etching processes which allows one to manipulate the resonator morphology. Furthermore, the control over the thickness of the silica disk and the slope angle allows us to achieve a distance between the cavity slopes of about 400nm while using standard i-line lithography which can achieve a stable minimal feature distance of about 800nm.

5 Measuring the Q-Factor

The characterization of these structures will be realized by a Time-Correlated Single Photon Counting (TCSPC) experiment. For this, we use a single photon camera called LINcam. The emitted directional far-field will be observed by a microscope connected to the camera. Then we will couple pulsed laser light into the resonators by using an evanescent coupling method. The pulse laser is connected to the SPC and will trigger the acquisition. The decay rate of the emitted far-field will correspond to the Q-factor according to equation (5).

$$\tau = \frac{Q}{2\pi f} \qquad (5)$$

6 Conclusion

A versatile and tunable fabrication platform was developed to lay the foundation stone to examine the photon statistics of the emitted far-field of deformed optical microcavity.

References

[1] D. Vernooy, A. Furusawa, N. P. Georgiades, V. Ilchenko, and H. Kimble, "Cavity QED with high-Q whispering gallery modes," Physical Review A **57**(4), R2293 (1998).

[2] T. Kippenberg, S. Spillane, and K. Vahala, "Kerr-nonlinearity optical parametric oscillation in an ultrahigh-Q toroid microcavity," Physical review letters **93**(8), 083,904 (2004).

[3] J. Zhu, S. K. Ozdemir, Y.-F. Xiao, L. Li, L. He, D.-R. Chen, and L. Yang, "On-chip single nanoparticle detection and sizing by mode splitting in an ultrahigh-Q microresonator," Nature photonics **4**(1), 46 (2010).

[4] S. McCall, A. Levi, R. Slusher, S. Pearton, and R. Logan, "Whispering-gallery mode microdisk lasers," Applied physics letters **60**(3), 289–291 (1992).

[5] J. Wiersig and M. Hentschel, "Combining directional light output and ultralow loss in deformed microdisks," Physical review letters **100**(3), 033,901 (2008).

[6] D. Armani, T. Kippenberg, S. Spillane, and K. Vahala, "Ultra-high-Q toroid microcavity on a chip," Nature **421**(6926), 925 (2003).