All-polymer whispering gallery mode sensor in the low-Q regime

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Whispering gallery mode sensors have been extensively investigated, leading to increasing quality factors. Instead of using a single glass resonator, we use an all polymer resonator array as sensing element. Due to the fabrication, the Q-factor of polymer sensors will be smaller than that of silica sensors, but using low-cost polymer components makes the sensor easy to manufacture.

1 Introduction

Microcavities, such as spheres, rings or toroids, show sharp optical resonances at specific wavelengths, called whispering gallery modes (WGMs). They correspond to light waves circling around the cavity, relying on continuous total internal reflection at the cavity surface. After one roundtrip, the light waves return to the same point with the same phase, hence interfere constructively with themselves and travelling waves arise. So the resonance wavelengths of such micro-resonators depend on the radius and the refractive index of the sphere as well as the surrounding refractive index [1]. All physical quantities which change one of these parameters can be well detected and quantified with such resonators, because they cause a resonance wavelength shift [2]. Besides the possibility to determine quantities like temperature, pressure or the use of the WGMs as biosensors [3], they can also be employed for high resolution wavelength measurement [4]. The most frequently applied techniques to determine the wavelength use interferometric principles, for example Michelson- or Fabry-Perot-interferometers, which are often large and very expensive. Instead of using interferometers, the wavelength could also be determined by recording the shift of the resonance frequency of a single resonator. The WGM resonator can be described by the free spectral range (FSR) $c/(2\pi nR)$ between two neighboring modes, the wavelength shift $\Delta\lambda$ of the resonance wavelength λ as well as the quality factor (Q-factor) [2]. R is the radius and n the refractive index of the resonator. A reduction of the size simplifies the detection of the resonance wavelength shift, because the FSR and the wavelength shift scale with 1/R. Unfortunately reducing the size of the resonator causes a bandwidth broadening of the resonance due to the higher radius curvature of smaller resonators and this leads to a lower Q-factor. Using an array of microspheres with slightly different diameters takes advantage of the fact that every single microsphere has a different resonance behavior. Therefore, using many spheres instead of one relieves the high demands on the resonance quality and thus allows using inexpensive polymer spheres instead of high quality resonators [4, 5]. This opens the perspective of simple and low cost WGM sensing.

2 Experimental Setup

The experimental setup is shown in Fig. 1. A tunable narrow-band laser is coupled under 45° in a PMMA plate. Due to total internal reflection the light is guided in the plate and at the surface of the plate, an evanescent field is present. In this field, commercially available PMMA spheres are placed with random distribution and positions. The light distribution of the spheres is captured by a CMOS camera.

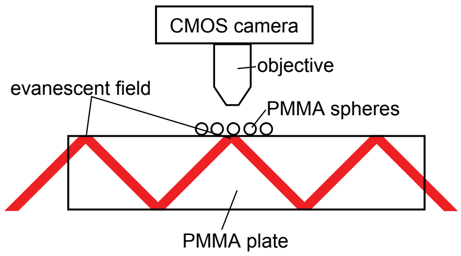

Fig. 1 *Experimental setup: A tunable diode laser is coupled under 45° into a PMMA plate. On the plate PMMA spheres are placed. The intensity profiles of the spheres are captured by a CMOS camera equipped with a microscope objective.*

3 Calibration

Before an array can be used to measure the wavelength of an unknown light source, the array needs to be calibrated once. Therefore the spheres that show the strongest intensity changes are identified and the associated CMOS camera pixel values are integrated over the sphere area leading to intensity profiles of the spheres. The intensity profiles of all

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spheres are stored together in a mode map. Fig. 2 shows the mode map of 18 spheres. The frame number on the y-axis correspond to the incident wavelength, because at each wavelength one image of the array is taken with the cmos camera.

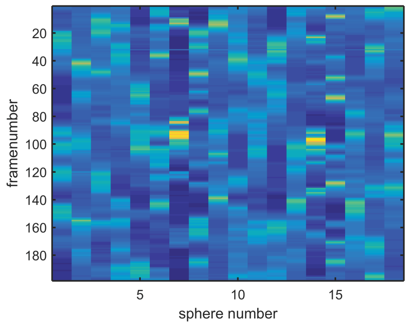

Fig. 2 *Intensities of 18 spheres, stored in the mode map.*

4 Wavelength determination

The modemap generated this way is suitable to determine the wavelength of an unknown laser source. The intensity distribution of the array at the unknown wavelength is captured and compared to the mode map via the correlation function $r(\lambda)$ [4, 5]:

$$r(\lambda) = \sum_{j=1}^{N} |I_j^{DB}(\lambda) - I_j|. \quad (1)$$

I_j^{DB} is the intensity of the j-th sphere in the calibration mode map and I_j the intensity of this sphere at the unknown wavelength. The correlation function has a minimum at the wavelength at which the intensity profile of the unknown wavelength match the intensity profile in the mode map best. So the minimum of the correlation function marks the unknown wavelength (see Fig. 3).

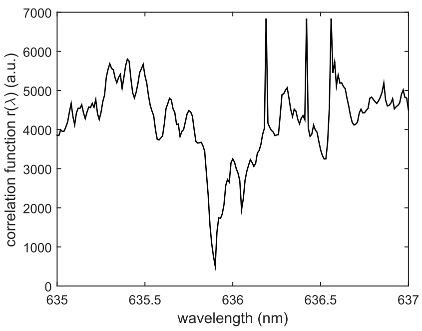

Fig. 3 *Correlation function* $r(\lambda)$ *for 18 spheres. At the true wavelength of* 635.89 nm *the correlation function has a pronounced minimum.*

The accuracy of the wavelength determination depends on the number of spheres used to build the mode map and the sphere size [5, 6, 7].

5 Conclusion

We present a small and completely polymer based spectral measurement device on the basis of the evaluation of optical resonances in micro-spheres. Using PMMA instead of glass, ensures that the device is inexpensive and easy to manufacture. Additionally we found, that the device is well suited for the determination of an unknown wavelength. Currently, the scanning range restricts the possible wavelength region of the unknown source to be measured. Nevertheless, the method is simple and the requirements on the spheres concerning resonator quality are relatively moderate.

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