Polymer-based Ring Resonators for Sensing

Elke Pichler*, Konrad Bethmann**, Urs Zywietz***, Carsten Reinhardt***, Ulrike Willer*

**Energie-Forschungszentrum Niedersachsen, Technische Universität Clausthal*
***Fraunhofer Heinrich-Hertz-Institut, Goslar*
**** Laserzentrum Hannover e.V.*

mailto:u.willer@pe.tu-clausthal.de

Ring resonators, esp. when processed with well established silicon-nitride wafer technology, are already successfully applied for sensitive detection of gases and fluids. Transfer of this technique into a cost effective material system like a polymer foil is attractive for the realization of sensor networks in a large-scale, complementing other sensors for pressure, strain and temperature.

1 Introduction

Ring resonators are photonic devices comprising of a straight bus waveguide and a closed one in close vicinity. This enables evanescent coupling of light between the two waveguides. The light transmitted through the bus waveguide shows distinct resonances depending on geometrical parameters like the length of the closed waveguide, the length of the coupling zone, and the gap between the two waveguides in the coupling area, but also on the effective refractive index. Thus, these filter elements can be used as sensors for the change of refractive index of the surrounding medium, for example due to change of gas composition.

It has been shown that a change in concentration of the target gas results in a shift of resonance frequency and that quantification is possible due to a linear dependence [1]. However, selectivity is only achieved by functionalization of the surface or by its coating with appropriate receptor molecules to guarantee that only the species of interest is accumulated at the surface and can alter the effective refractive index and all other molecules that might be present and would interfere with this change are kept far enough from the surface to prevent interaction with the evanescent field.

2 Sensor design

The formation of sharp resonances relies on interference of light that travelled through the ring waveguide with that within the straight waveguide. Thus, utilization of single-mode waveguides is essential. Polymeric materials show smaller variations in refractive index which demanded for simulation of the properties of different waveguide geometries to decide on the height and width of the waveguides as well as on the materials to be processed. The waveguides were processed using microscope projection photolithography (MPP). Basically, uv-light is projected with a microscope objective through a mask with the structures to be processed onto a coated substrate foil. Thus, the structures are demagnified and the coating material is selectively polymerized. Excess pre-polymer is subsequently washed away leaving the waveguide on the substrate foil.

In this work Ormosil has been used on PMMA. Simulations showing the waveguide dimensions for single-mode operation are given in figure 1. The refractive index is n=1,52 for Ormosil and n=1,49 for PMMA. Waveguide dimensions for single-mode operation can be identified.

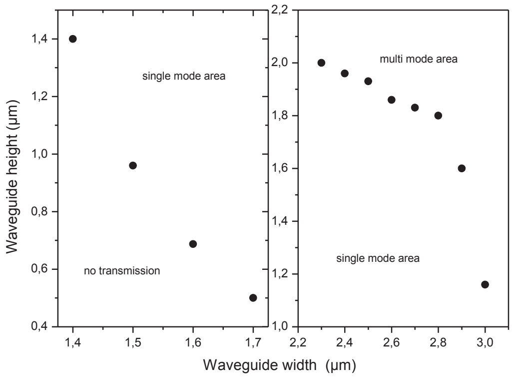

Fig. 1 *Simulated waveguiding properties as a function of structure dimensions.*

3 Results and discussion

Ring resonators were processed with MPP and characterized using a SLED and optical spectrum analyzer. The transmission properties and especially the resonance frequencies also depend on the temperature of the sensor because it influences both, the circumference of the ring and the effective index of refraction. Therefore, the polymer foil with the ring resonators was placed on a temperature controlled mount and the light was coupled in and out of the device using single-mode optical fibers. Figure 2 shows the measured spectra for different temperatures.

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As can be seen, the Finesse is very poor which makes it difficult to precisely locate the dips and their shift.

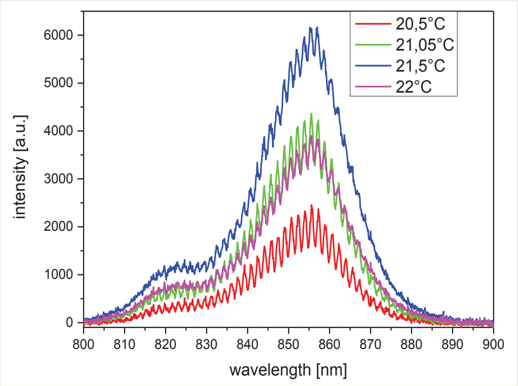

***Fig. 2** Transmission spectra for different temperatures of the sensor device.*

In order to identify the origin of this poor Finesse of about 2, calculations have been performed based on the model discussed in [2]. Governing parameters are the waveguide losses, i.e. the damping while the light travels within the waveguide, losses per coupling event, and the coupling coefficient, i.e. the percentage of light coupled between the two waveguides.

The Finesse was calculated for different parameter fields of waveguide losses and coupling losses as function of the coupling coefficient as shown in figures 3 and 4. For the assumption of a lossless coupling (a=1, figure 3) the Finesse is at least 20, even for significant waveguide losses b. On the other hand, figure 4 shows that values as small as experimentally observed can be reached if losses per coupling event are taken into account.

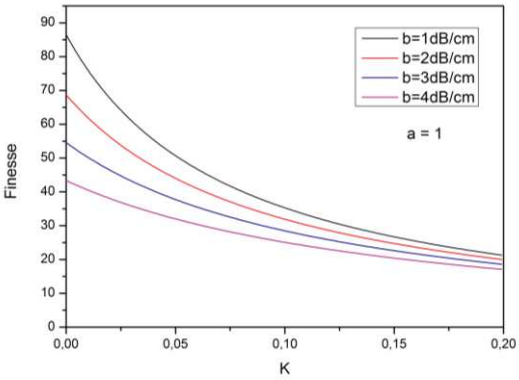

***Fig. 3** Calculated Finesse as a function of the coupling coefficient for different waveguide losses and lossless coupling (a=1).*

The identification of the parameter limiting the Finesse presently is valuable for further improvement of the design of the device and processing with MPP. Work is presently focused on the processing to ensure small coupling losses by improving the quality of the coupling zone.

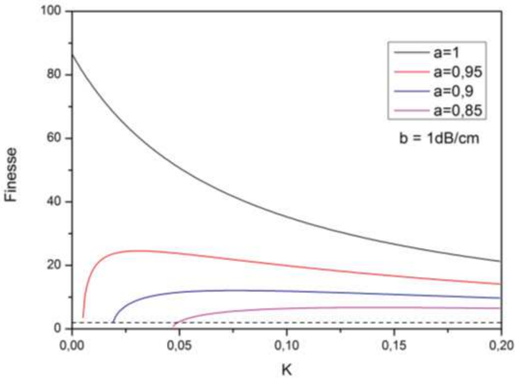

***Fig. 4** Calculated Finesse as a function of the coupling coefficient for different coupling losses and waveguide loss of b=1dB/cm.*

Even though the Finesse is limiting a precise determination of the shift of a single resonance dip, it is possible to determine the shift using the information of all the dips present within the emission profile of the SLED in combination with a background correction.

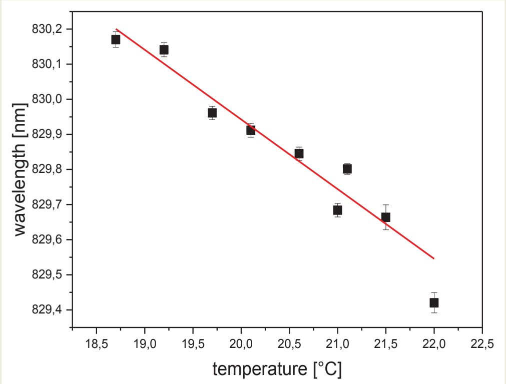

***Fig. 5** Wavelength shift for different temperatures of the sensing device.*

The result of this procedure used on the data shown in figure 2 is presented in figure 5. A linear dependence on the temperature is found.

4 Acknowledgements

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References

[1] R. Orghici et al. ”A Microring Resonator Sensor for Sensitive Detection of 1,3,5-Trinitrotoluene (TNT),” in *Sensors* **10**: 6788-6795 (2010)

[2] W. Bogaerts et al. ”Silicon microring resonators,” in *Laser Photonics Rev.***6**(1): 47-73 (2012)