TriPleX^{TM}-based Micro Ring Resonators for Food Safety Applications

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Abstract: Micro Ring Resonators (MRRs) have become the workhorse in photonics, both for data/telecom as well as bio-chemical sensing applications. In this contribution the use of MRRs as sensors for food-safety applications will be discussed.
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1. Introduction

The need for a reliable means to monitor food quality and ensure its safety has become extremely important over the last decades. The use of chemical agents (such as pesticides) and natural toxins and microorganisms, are forming a serious threat for public health. Current methods for monitoring food safety are based on complicated analytical tools. Due to their complexity, long time-to-result and high associated costs, these cannot guarantee a safe and stable food supply. Therefore, a great need exists for screening tools that are simple, fast, low-cost and yet simple to use and reliable.

Micro Ring Resonators (MRRs) have proven to be a reliable optical platform for both optical switching, as for sensitive detector technology[1]. Within the EU-FP7 project BIOFOS, a biosensor platform based on MRRs is being developed for the detection of hazardous species in food samples. The advantages of interferometric biosensors as compared to competing techniques include: high on-line sensitivity, label-free operation, high integration potential, and insensitivity to EM-interference. Here, we present results on the design and first measurements of the sensor platform.

2. System description

The sensor elements are made up of multiple micro-ring resonators (MRRs) as the optical interference elements. The MRRs are monolithically integrated on a photonic chip, based on the TriPleX^{TM} integration technology, which employs silicon-nitride and silicon-oxide layers[2]. The required fabrication equipment is CMOS compatible.

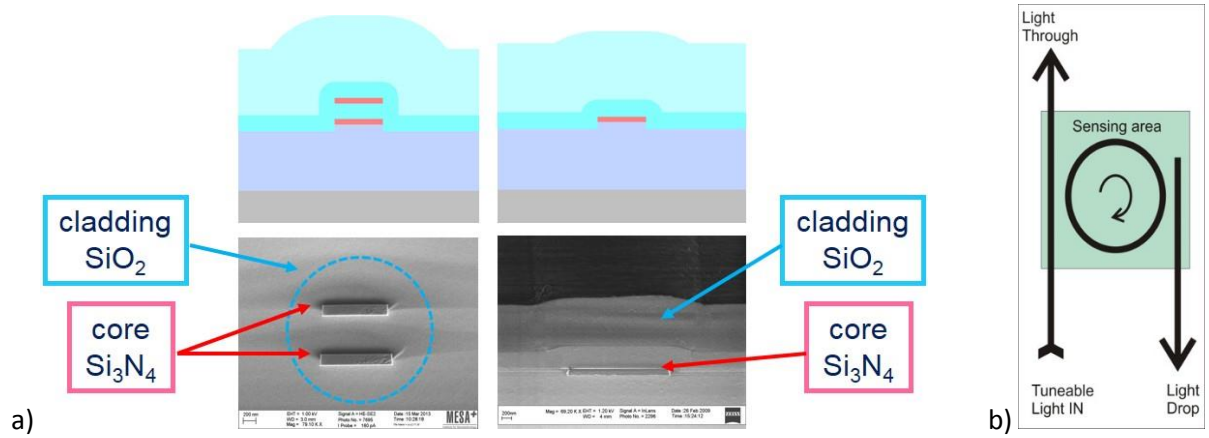

Figure 1: a) Cross-sections of the TriPlex^{TM} planar waveguide technology in the double stripe (DS) layout (left) and the single stripe (SS) layout (right). b) Schematic of an MRR. Depending on the properties at the sensing area, the ratio of light output at the Through port to the Drop port varies.

In Figure 1a) the layer cross-section is shown for Single Stripe (SS) and Double Stripe (DS) structures. The sensors exploit the high quality (Q-factor) of the MRRs as optical cavities, and the ultra-low propagation loss of the TriPleX^{TM} platform (<0.01 dB/cm). It was chosen to operate the system at 850 nm, where low cost, high quality light

sources (e.g. VCSEL's)are available and the absorption by aqueous samples is low[3]. In Figure1b) the schematic operation of the MRR is shown. Light is entering at the In-port. Depending on the interference conditions at the sensing area, part of the light comes out at the Drop-port or at the Through-port. If the properties in the sensing area change, the ratio between the two will also vary, effectively yielding a measurement signal.
The sensitivity of the MRR sensor depends strongly upon the waveguide characteristics. Basically, the sensitivity towards bulk refractive index changes is ~100 nm/RIU, while the surface sensitivity is ~230 pm/nm (see also ref 2). In order to make the MRR selective for specific species, the upper cladding layer of SiO_2 is removed at the position of the ring structure, exposing the Si_3N_4 core layer. Next, a sensing layer is attached to this exposed core, which selectively binds to the species to be detected. Via the evanescent tail of the light in the MRR, any changes in the sensing layer can be detected as an effective change of the refractive index in the waveguide. This principle is shown in Figure 2.

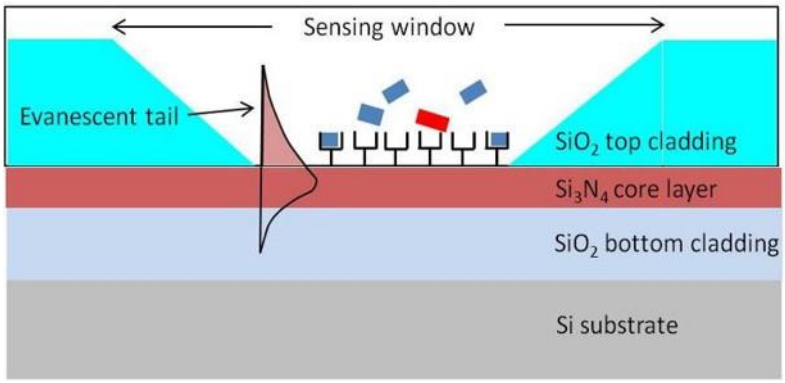

Figure 2: Operating principle of the MRR as a chemical sensor element. At the position of the ring structure, a sensing window is opened, which is subsequently functionalised. Via the evanescent field any change in this layer can be detected.

The sensing layer will be made up of special aptamers, specially designed for selective binding to different analytes in the samples, such as mycotoxins, insecticides, and antibiotics. Using special functionalization techniques, the aptamers selectively attach to the exposed Si_3N_4 layer, thus yielding only binding sites at the sensing area.

3. Read-out

The final device will have both the source and the detector integrated to the chip by flip-chip bonding. However, in our test setup the coupling to the chip will be done using a fibre array.

As a light source, a Vertical Cavity Surface Emitting Laser (VCSEL) with a nominal wavelength of 850 nm is used. By varying the drive current, the wavelength can be swept over a wavelength range that should be larger than Free Spectral Range of the MRR[2]. In Figure 3 the measurement of the output wavelength of the VCSEL as a function of the drive current is shown.

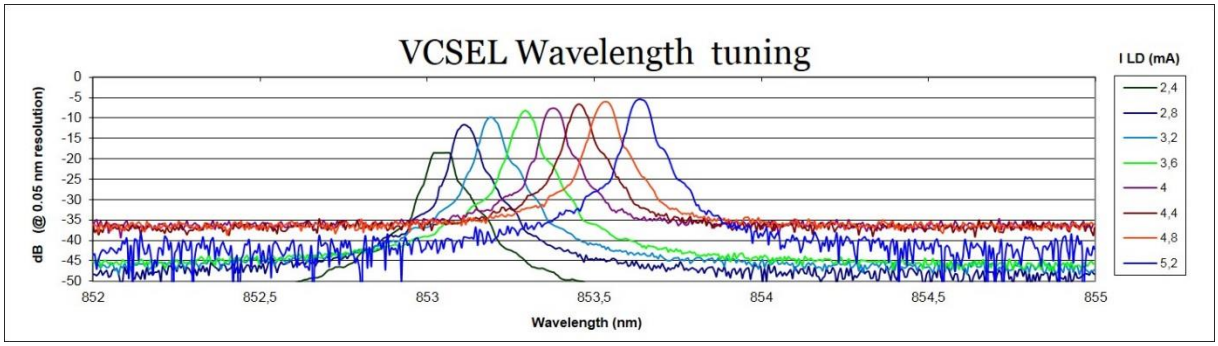

Figure 3: Variation of the VCSEL output wavelength as a function of the drive current.

As detectors, photodiodes will be employed. For each MRR, two photodiodes are needed, one for the Through signal, and one for the Drop signal (see Figure 1b). The ratio of the two signals will be used as measurement output. This not only increases the sensitivity; it also compensates for the increased output of the VCSEL due to the increase in drive current.

An important aspect of the setup is the temperature drift. Any change in temperature will change the resonance frequency of the MRR, interfering with the shift due to the chemical changes to be measured. In the final device, temperature effects can be compensated using a (non-functionalised) reference MRR on the same chip. In our test setup we make use of temperature stabilisation on a temperature controlled stage. In practice, the measurement system allows for a peak detection accuracy of 0.01 pm and measurement resolution of 0.1 pm, while the signal drift is ~1pm/hour. The experimental bulk refractive index resolution is ~$1*10^{-6}$ RIU.

4. Measurements

First measurements to test the MRR and measurement setup have been performed. For this purpose the sensing area of the MRR was exposed to bulk solutions of ethanol in pure water. In Figure 4, the shift of the resonance wavelength is shown during subsequent exchange between pure water and 2wt%, 4wt% and 6wt% of ethanol in pure water. The linearity of the response is clearly visible. On the right of the Figure, the response of the sensor to a 0.005wt% solution of ethanol in water is shown. Because the response is still very clear, this gives an indication of the sensitivity of the sensor.

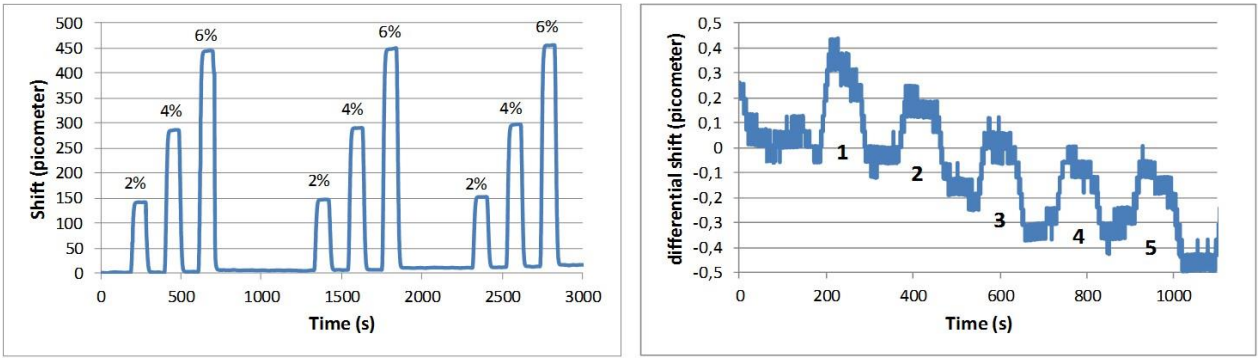

Figure 4: Response of the test MRR to sequential exchange between pure water and ethanol solutions. On the left: varying concentrations of respectively 2, 4 and 6 wt.%. On the right: sequential solution of 0.005 wt.% of ethanol.

5. Conclusions

A sensor platform for detection of potential dangerous contaminants in food has been presented. The sensor is based on ultra-sensitive Micro Ring Resonators that are functionalised by special aptamers that selectively bind to the species to be detected. First measurements with a test setup have been presented and show a very high sensitivity. These measurements underline the suitability of the platform for the proposed purpose. In the near future measurements on chips functionalised with the various aptamers will be performed to test their sensitivity and selectivity. Also, the integration of the VCSEL and photodiodes with the sensor chip will be further developed.

6. Acknowledgements

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7. References

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