Rolled-up Optical Resonators for Optofluidic Microsystems

Vladimir Bolanos Q.
Institute for Integrative Nanosciences, IFW Dresden, Helmholtzstr. 20, D-01069 Dresden Germany

Novel methodological advances in the fields of optics and microfluidics have led to the rise of optofluidics, in which optical and microfluidic components are combined to provide enhanced functionalities as compact microsystems [1]. Optofluidic applications such as bio/chemical sensors and/or microfluidic lasers have been reported with optical resonators in the form of microdisks, microspheres or microrings [2-5]. Practical lab-on-a-chip devices based on such microstructures are, however, limited since the integration of these microresonators with microfluidic channels is not straightforward due to their dimensions or architectures [2,4,5]. Some optical resonators are additionally limited because their optical resonances are activated by extremely fragile tapered waveguides [2,3]. A rolled-up microtube presents a promising integrable resonator that can be optically activated without the aid of tapered waveguides [6,7]. Moreover, rolled-up resonators offer a clear advantage over other optical resonators because of its inherent built-in microfluidic channel, which facilitate optofluidic applications in lab-on-a-chip devices.

This presentation will report on optimized approaches to functionalize rolled-up optical resonators as a liquid sensor for lab-on-a-chip applications [8-10]. The final developed chip sensing device shows sensitivity values comparable to state-of-the-art liquid sensors based on optofluidic mechanisms. In a rolled-up microtube, whispering gallery modes (WGM) arise due to total internal reflection of the resonant light along the curved tube wall [6,7]. Due to the sub-wavelength thickness of the tube wall, the WGM extends out hundreds of nanometers and hence is very sensitive to the changes in the surrounding media [11]. For instance, a liquid pumped into the tube channel influences the resonant wavelengths of WGM depending on the refractive index of such a liquid. Substitution of liquids can be spectrally monitored establishing a liquid sensing mechanism, which will be discussed in the talk.

More specifically, this talk will include an introduction into optical resonators and various optofluidic applications of these microstructures. Afterward, the fabrication of rolled-up microtubes and the optical characterization of these microresonators will be discussed. Here, the origin of the WGM and the flexibility to control the spectral peak positions of WGM will be explained. Finally, detailed investigations demonstrating three different approaches for an optofluidic sensing device, based on rolled-up resonators, will be presented. This section will combine discussions on liquid sensing by using rolled-up tubes which confines WGM in two and three dimensions [8,9]. Moreover, liquid sensing capabilities of rolled-up tubes integrated in a compact microfluidic chip device will be presented. To conclude the talk, possible further applications of such rolled-up optical resonators will be shown, such as their use as on-chip integrated microfluidic laser or bio/chemical sensing devices where the resonator itself acts as the microfluidic channel.

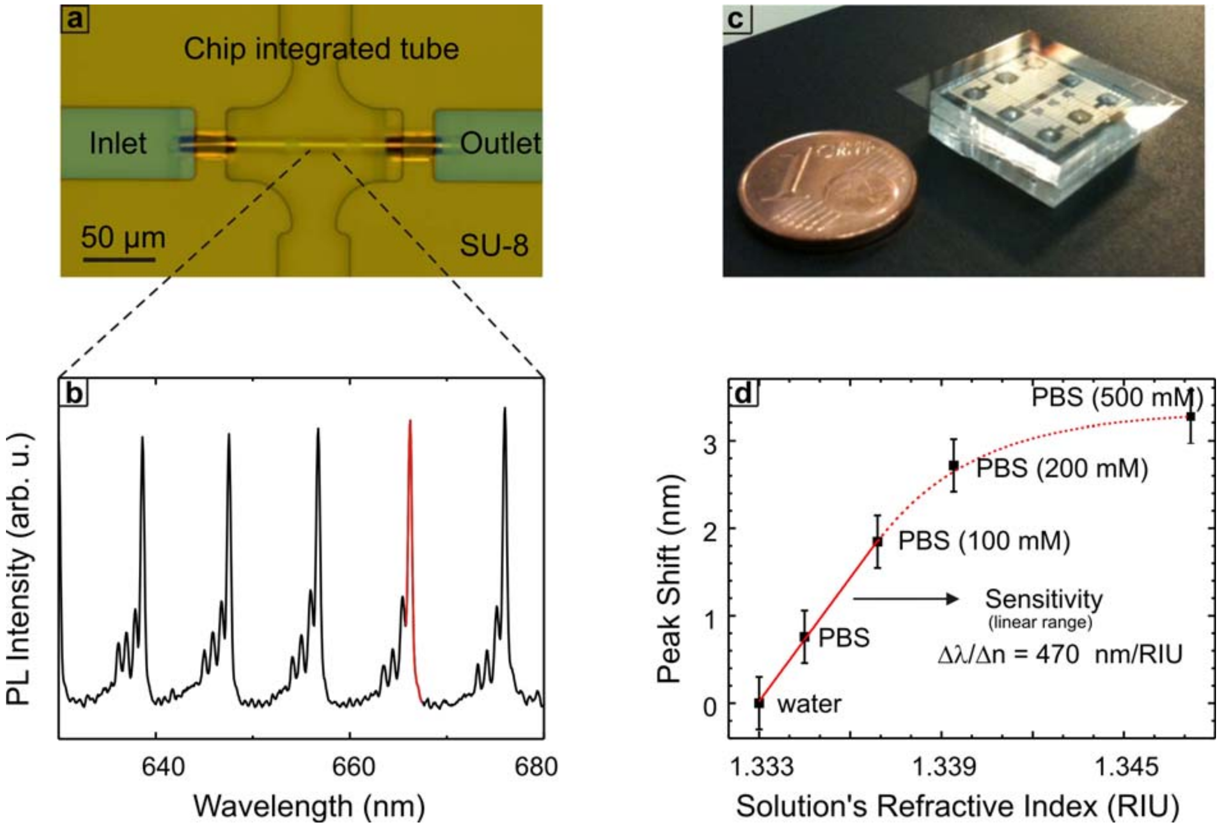

Figure 1. a) Optical image of a rolled-up microtube integrated with microfluidic channels. b) Photoluminescence (PL) spectra from the middle part of the tube in a) where three dimensionally confined WGM are established. c) Photograph of the chip containing the rolled-up optofluidic sensor. d) Evolution of the peak selected in b) respect to the refractive index of the solution inside the tube (here, Refractive Index Units (RUI)). The refractive index of PBS solution is slightly varied by adding glucose (in mM=milimolar). The sensor saturates after 100 mM of glucose. In the linear range, a sensitivity of 470 nm/RIU can be extracted.

[1] C. Monat, P. Domachek, and B. J. Eggleton, *Nat. Photonics* 1, 106 (2007)
[2] Vollmer F., and Arnold S., *Nat. Methods* 5, 591 (2008)
[3] A. M. Armani, R. P. Kulkarni, S. E. Fraser, R. C. Flagan, and K. J. Vahala, *Science* 317, 783 (2007)
[4] N. M. Hanumegowda, C. J. Stica, B. C. Patel, I. M. White, and X. Fan, *Appl. Phys. Lett.* 87, 201107 (2005)
[5] W. Lee, H. Li, J. D. Suter, K. Reddy, Y. Sun, and X. Fan, *Appl. Phys. Lett.* 98, 061103 (2011)
[6] T. Kipp, H. Welsch, Ch. Strelow, Ch. Heyn, and D. Heitmann, *Phys. Rev. Lett* 96, 077403 (2006)
[7] R. Songmuang, A. Rastelli, S. Mendach, and O. G. Schmidt, *Appl. Phys. Lett.* 90, 091905 (2007)
[8] G. S. Huang,V. A. Bolaños Quiñones, F. Ding, S. Kiravittaya, Y. F. Mei and O. G. Schmidt, *ACS Nano* 4, 3123 (2010)
[9] V. A. Bolaños Quiñones, L. Ma, Y. Mei, S. Kiravittaya, and O. G. Schmidt. *in preparation* (2011)
[10] S. M. Harazim, V. Bolaños, S. Kiravittaya, S. Sanchez, O. G. Schmidt. *in preparation* (2011)
[11] V. A. Bolaños Quiñones, G. Huang, J. D. Plumhof, S. Kiravittaya, A. Rastelli, Y. Mei and O. G. Schmidt, *Opt. Lett.* 34, 2345 (2009)