Abstract:

We demonstrate optofluidic control and analysis of polystyrene microspheres on a photonic chip integrated with microfluidic channels. Evanescent field optical trapping of the spheres is used for micron scale transport and positioning of the spheres for analysis. Whispering gallery mode resonances are excited in the spheres and measured using the same integrated waveguide used for trapping. This optofluidic system represents a new integrated platform to utilize microspheres for biosensing in lab-on-chip applications.

Summary of Research:

There is a great need for label-free ultra-sensitive biosensors that can be miniaturized and integrated on a planar substrate. The use of whispering gallery modes (WGM) in microspheres have successfully been used with sensitivities capable of detecting single biomolecules [1]. The detection mechanism of these devices takes advantage of the resonant circulation of light around the circumference of these spheres in order to achieve such high sensitivities. Coupling light into these devices is typically done by using a tapered optical fiber [2] or through a prism and therefore a complete system cannot be manufactured using standard photolithography techniques. In this work we demonstrate a device that can take advantage of the WGM resonances of these microspheres in a platform that is completely on-chip and integrated with microfluidics.

The device design is shown in Figure 1 and relies on both microfluidics and optical trapping to transport particles for analysis. After centimeter scale transport within the microfluidic channel, the particles are then trapped by the gradient forces generated by the decay of the evanescent field of a channel waveguide. In addition to the lateral gradient force, there is an axial force due to scattering and absorption which propels the particles along the direction of light propagation [3]. The particles are transported and positioned where they can be analyzed.

The optofluidic platform used here is comprised of silicon nitride (Si$_3$N$_4$) waveguides integrated with channels in polydimethylsiloxane (PDMS). The relatively high refractive index of silicon nitride (n = 2.0) compared to that of silicon oxide (n = 1.46) and water (n = 1.33) leads to a highly confined optical mode. This high confinement leads to a strong gradient in the evanescent field enabling the efficient trapping of particles. The devices are fabricated starting with a blank silicon wafer on top of which 5 µm of thermal oxide is grown. A 200 nm device layer of silicon nitride (Si$_3$N$_4$) is deposited using low pressure chemical vapor deposition, patterned using electron beam lithography,
followed by inductively coupled plasma etching. A lift-off process is used to mask a 250 µm channel perpendicular to the waveguide while the rest of the waveguide is clad with 3.5 µm of evaporated silicon oxide. The interface between unclad and oxide clad waveguides provides the physical barrier which holds trapped particles in place. Microfluidic capabilities were integrated with the photonics using standard soft lithography processes.

The experimental setup consists of a high-power broadband super continuum source coupled into a single mode fiber and then into our photonic chip using a tapered lens fiber. The waveguide transmission is collected and analyzed with a spectrometer. Polystyrene spheres of various diameters are prepared in a 10 mM phosphate buffer solution and injected into the microfluidic channel using pressure driven flow.

Figure 2 shows a sequence of microscope images showing a microsphere that is flowing in a microfluidic channel then trapped and transported along the waveguide. The broadband light that traps the polystyrene spheres also excites its WGM resonances. Figure 3 shows the transmission spectrum of the waveguide while trapping a microsphere. The dips in the transmission correspond to the resonant wavelengths that are coupled into the microsphere. The efficient coupling of light into the WGMs demonstrated here provides an integrated platform for these spheres to be used as refractive index sensors by measuring shifts in the resonance wavelength when biomolecules bind to their surface.

References:


Figure 3: Transmission spectrum showing resonances of a 16.8 µm diameter polystyrene sphere.