Optofluidic Switching Using SU-8 Microring Resonators

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Abstract:
Here, we discuss the fabrication and characterization of an optically controlled switch to deflect trapped particles through a SU-8 microring resonator architecture. High optical intensities in the evanescent field of the ring generate a gradient force that diverts particles trapped on the bus waveguide to the ring portion of the device. The increase in optical energy translates to a 250% increase in the radiation pressure induced steady-state velocity of particles trapped on the ring. Switch characterization determined that 80% of particles are diverted onto the ring when the device is at an on-resonance state.

Figure 1: Schematic of optofluidic ring resonator switch. Rendered picture of device with PDMS microfluidics.

Introduction:
High optical intensities in planar waveguiding devices are achieved by incorporating a resonant structure, such as a whispering gallery mode (WGM) resonator. These resonators siphon a portion of light from a waveguide and recirculates the optical energy repeatedly along a circular path [1]. Resonance occurs when incoming light is in phase with light in a resonator that has completed a revolution around the structure. This strong coupling correlates with a sharp drop in the bus waveguide output. The large field amplification also applies to the evanescent field of WGM devices.

Here we demonstrate, for the first time, an integrated microring resonator switch for optically trapped microparticles. As seen in Figure 1, our device consists of a microring resonator fabricated in SU-8 epoxy negative photoresist evanescently coupled to a bus waveguide of the same material. The microring resonator device enables a wavelength dependent field amplification in the ring which makes it ideal for an optical particle switch that relies on optical gradient forces.

Fabrication:
The SU-8 ring resonator devices were fabricated using stepper photolithography. Our rings were 200 µm in diameter with a coupling length of 50 nm. The waveguide dimensions were designed to be 2 µm wide and 700 nm tall. The ring gap after fabrication was often reduced by 200-300 nm due to controlled overexposure of the photoresist, creating much smaller gap features than normally possible using photolithography.

The photoresist was spun at 1000 RPM for 40 seconds on a fused silica substrate to achieve a film thickness of 700 nm. Exposure of the wafer was done using an i-line 5x stepper (GCA Autostep) at an exposure time ranging from 0.25-0.3 s.

The variability in exposure time is to ensure the correct amount of controlled overexposure to achieve the sub-resolution gap between the bus waveguide and ring structure. The waveguide devices were then diced and cleaved using a backside cleaving technique, leaving an edge width of 75-100 µm.

Poly-dimethylsiloxane (PDMS) microchannels were patterned 500 µm wide with a height of 25 µm and were...
bonded to the ring-resonator chip, leaving the input and output regions of the chip clad in air. Light is coupled into the waveguides using a tapered lens fiber. Polarization of the light entering the waveguides was determined using a polarization filter and controller. All the experiments conducted here were done using transverse electric (TE) polarized waves.

Results and Discussion:

In Figure 2, we show a series of images that illustrate the active trapping and switching of 3 µm polystyrene microparticles by changing the wavelength of coupled light. By switching the input wavelength 1 nm from \( \lambda_r = 1552.225 \) nm, the resonant wavelength which exhibits the strongest drop in power at the end of the bus waveguide, to non-resonant wavelength, \( \lambda_n = 1553.225 \) nm, we can controllably divert particles from the waveguide onto the ring. We observe that particles that have been trapped on the ring while on-resonance will remain trapped and still be propelled when the ring is switched to an off-resonance state.

Figure 3(a) shows the measured steady-state velocity of 3 µm polystyrene beads on the ring portion of the resonator device as a function of optical wavelength and detected power at the output of the waveguide. We observe that as the optical wavelength approaches the resonant wavelength of the ring resonator, the propulsion velocity of trapped particles increases. The velocity enhancement was 250% of the steady-state velocity at the non-resonant wavelengths. As a control, we can compare the velocity increase for particles trapped on the ring to the velocity of particles trapped on the bus waveguide before the ring as a function of wavelength. The difference between the highest and lowest velocities measured on the bus waveguide was 36%. We can also directly evaluate the likelihood of a particle either being deflected onto the ring or remaining on the bus waveguide. In Figure 3(b), we determine the fraction of particles diverted onto the ring from the bus waveguide. We find that we can achieve an 80% sorting efficiency at the resonant wavelength, and an 80% retention rate when the ring is excited at a non-resonant wavelength.

Conclusions:

Here, we discuss the design and demonstration of an optically controlled switch for trapped particles using a ring resonator structure. The key result is in the method for using optical resonance excited in the ring resonator to pull particles from the bus waveguide. We have quantified the increase in propulsion velocity on the ring due to resonance and the switching efficiency of the ring resonator.

References: