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Nanoparticle Trapping and Control in a Hollow Whispering Gallery Resonator

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Abstract

In this work, hollow whispering gallery resonators with thin walls are filled with a water solution containing 500 nm nanoparticles. The quasi-droplet modes of the hollow resonator create an optical scattering force which pushes the particles around with velocities far exceeding 1.2 mm/s. The optical modes are observed to shift up to tens of GHz in the presence of the nanoparticle. By using counter propagating modes, the position and direction of the particles are controlled, this is the first time trapping and control of nanoparticles has been demonstrated in a quasi-droplet micoresonator.

I Introduction

Hollow whispering gallery resonators are optical microcavity resonators where light can travel in modes that are supported within the thin wall of the hollow structure [1,2]. These novel microresonator structures are typically made from a glass capillary can be easily filled with a fluid. The wall of the resonator can be made to thicknesses down to a few hundred nanometers thus allowing the formation of quasi-droplet whispering gallery modes in the case of liquid filled resonators [2]. These features make them interesting devices for optical sensing, optomechanics, lasing, nonlinear optics and for creating hybrid resonator structures [3].

In the last decade there has been some excellent work on improving and optimizing the sensing capabilities of whispering gallery mode microresonators [3]. Indeed, the microsphere, microdisk and microtoroid structures have been used to demonstrate the detection of single nanoparticles with sizes as small as 30 nm [4]. Hollow microcapillary resonators and to some extent microbubble or microbottles have also been used for the detection of biomolecules or refractive index sensing. However, there is no experimental work on the study of single nanoparticles interacting with quasi-droplet whispering gallery mode. As well as detecting nanoparticles it also possible to optically trap and propel nanoparticles in a whispering gallery mode. To date, experimental papers showing the trapping and propulsion of nanoparticles have only been demonstrated on the surface outer surface of the whispering gallery resonator where the evanescent field is small [6-9].

In this paper we make microbubbles or microbottle shaped resonators with wall thickness around 1 μm which are then filled with water containing 500 nm nanoparticles. Whispering gallery modes at 780nm are excited in the wall of the resonators using a tapered optical fiber. Single nanoparticles are detected by the large change in the whispering gallery mode spectrum induced by the presence of the particle. We also observe optical trapping and propulsion of the nanoparticles.

II Experimantal Setup

Hollow microresonators were fabricated from silica capillaries with initial outside diameter of 350 μm and an internal diameter of 250 μm. The capillary was tapered

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down to an OD around 25 µm using the heat and pull method. The capillary was heated by counter propagating CO_2 laser beams focused on the capillary, the pulling was done on one side by a stepper motor translation stage. After tapering, the narrow waist of the capillary was heated again and the air inside the capillary was pressurized. After sufficient heating the wall of the capillary expanded to make a microbottle or microbubble shape. The laser power was adjusted during heating to control the diameter and wall thickness of the microbubble. If required a number of resonators could be made on the same capillary. After fabrication the capillary was glued onto a U-shaped mount. The thickness of the resonator wall was estimated from the dimensions of the capillary and bubble. We aimed to keep the wall thickness at 1 µm or less.

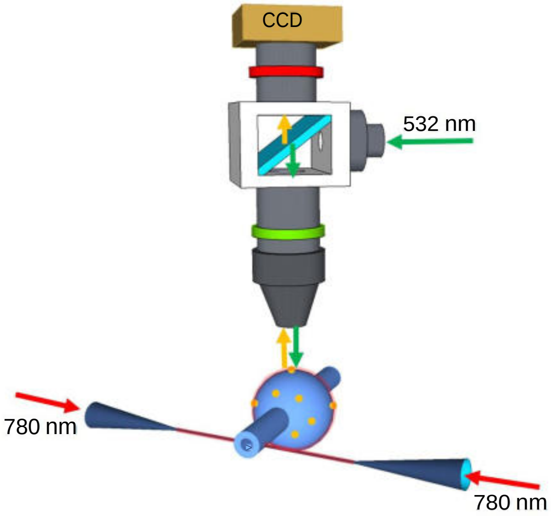

Figure 1. Schematic of experimental setup for nanoparticle trapping and detection in quasi-droplet.

A tapered optical fiber was used to evanescently couple light at 780 nm into the wall of the microresonator. The WGMs were observed by scanning the 780 nm laser over 80 GHz at a rate of 60 Hz and recording the transmitted optical power using a photodiode and data acquisition card. Up to 14 mW of laser power was coupled into the tapered optical fiber. Nanoparticles were injected into the capillary using a syringe pump. The particles used were 500 nm polystyrene spheres doped with a fluorescent dye emitting around 630 nm. The microbubble was imaged using a homemade microscope which also incorporated a dichroic mirror and optical filters. This setup allowed green light at 520 nm to pump the dye doped spheres inside the bubble and collect the fluorescent 630 nm light while blocking the 780 nm probe light. A schematic of the setup is shown in figure 1.

III Results

The frequency position of the whispering gallery modes was monitored, when particles entered the optical field the modes red shifted by more than 10 GHz. For input powers of a few mW we observed particle speeds far in excess of 1.2 mm/s (limited by the camera frame rate), much larger than other optical carousels reported to date [6-9]. Due the strong optical gradient force of the quasi-droplet mode it was also possible pull particles into the optical field even when the fluid is flowing at a high rate.

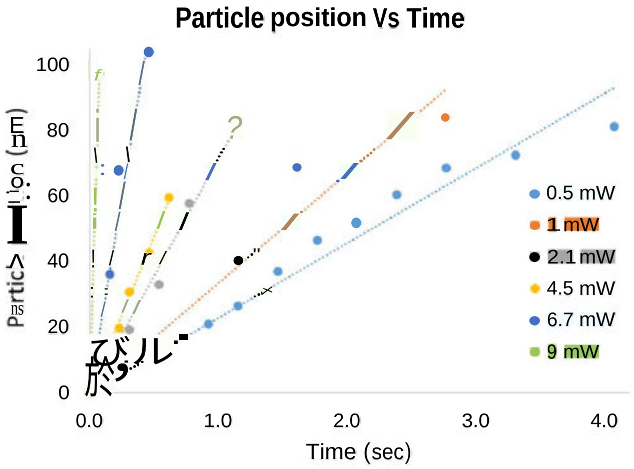

Figure 2. Plot of measured particle position against time for different pump powers. The maximum slope corresponds to a velocity in excess of 1.2 mm/s.

Using an optical circulator, counter propagating whispering gallery modes at 780 nm were excited in the resonator, this made it possible to stop the particle in its orbit, change its direction or position. This is the first time trapping and control of nanoparticles has been demonstrated in a quasi-droplet micoresonator. We have also developed a model to try and interpret our experimental results.

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