Multipath Trapping Dynamics of Nanoparticles towards an Integrated Silicon Slot Waveguide

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Optical trapping of micro- and nano-particles has attracted much interest in recent years. It has found wide applications in biophotonics, chemical sensing, and microscopy. More recently, facilitated by integrated photonics, the applicability of optical trapping and manipulation of nanoparticles have been greatly extended, which enhances the capability of lab-on-chip technologies. Many nano-photonic structures have been proposed to realize particle transport, trapping, sorting and storage, such as waveguides, resonators, photonic crystals and so on. Different from conventional optical trapping approaches, nanophotonic devices with a high index contrast provide strong optical field confinement and large optical gradient force. A high-index-contrast structure can be designed to support unique modal field distribution, which forms novel optical trapping potential wells. However, the optical trapping design and analysis are typically performed in a static case, where a particle is assumed to be already trapped and the optical force is calculated accordingly. Then, the optical force and trapping stiffness are often used to evaluate device performance. There has been little reported on nanoparticle trapping dynamics, which tracks trajectories of particles in the optical field and flowing fluid. This would give us more insight into the optical manipulation and comprehensive performance evaluation of the device for practical applications.

In this talk, we present the trapping dynamics of a nanoparticle near a silicon slot waveguide. It is shown for the first time that a nanoparticle can go along different paths before it becomes trapped, strongly depending on its initial position relative to the integrated waveguide. Due to a high index contrast between the core and cladding of the silicon waveguide, optical field enhancement produces complex optical force distribution, creating multiple traps on both top surface and sidewalls of a waveguide. We find that, intriguingly, the optical forces originating from different parts of an optical mode compete with each other during particle transport, forming a complicated particle trajectory and particularly a critical area where particle transport becomes unstable. Brownian motion is simulated for 50-nm and 100-nm nanoparticles, and the induced instability is analyzed. Rich dynamic phenomena of nanoparticle transport are revealed in the cases with water flow along and perpendicular to the waveguide. Not only providing physical insight into nanoparticle trapping, such dynamics analysis is also shown to be important for design of optofluidic devices.