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Optical binding of particles in the evanescent field of microfiber modes

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Abstract

We investigated the optical binding between dielectric microparticles in the evanescent fields of the first group of higher order microfiber modes. Particle groups consisting of up to five particles were propelled along the fiber and neighboring interactions were experimentally investigated and supported by numerical simulation.

Keywords: tapered optical fibers, higher order modes, optical trapping, optical binding

I Introduction

Optical manipulation has been studied extensively during the last few decades[1]. Following the realization of optical trapping[2], a new phenomenon, termed *optical binding*, was observed when two dielectric particles were trapped and bound transversely in a large beam waist[3]. This was due to the modification of the field caused by the presence of the particles and governed their relative positions[4].

As an alternative to optical tweezers, optical micro- or nanofibers (MNF) can be used for optical manipulation of micron-sized particles. Initial research conducted on the binding effect in a tapered fiber system only considered the fundamental fiber-guided mode (FM)[5]. However, recent developments in MNF fabrication[6-8] has enabled us to extend studies to exploit the properties of higher order fiber-guided modes (HOMs)[9,10]. In this work, we use combinations of the transverse electric (TE_{01}), magnetic (TM_{01}) and the coupled hybrid electric (HE_{21}) modes of a fiber to form the first order linear approximated mode (LP_{11}) of a standard fiber.

The optical binding effect between two, three, four and five particles for HOM and FM was examined. By comparing the group speed of particles, the chain stability of bound particles was also analyzed.

II Results and Discussion

1. Numerical analysis

We used a finite element method (FEM) simulation to calculate the optical force and the corresponding binding potentials with respect to various inter-particle distances. Large demands placed on computational memory limited the simulation to the two-particle case.

As Fig. 1 shows, there are several potential minima where particles tend to accumulate. We assume that particles are inclined to stay in the first potential minimum that occurs at ~16 μm for the FM (upper plot) and ~11 μm for the HOMs (lower plot). One should note that, although the potential well is deeper for the HOMs, the trap is relatively wide. This indicates a relatively weak binding effect between particles under the influence of HOM propagation.

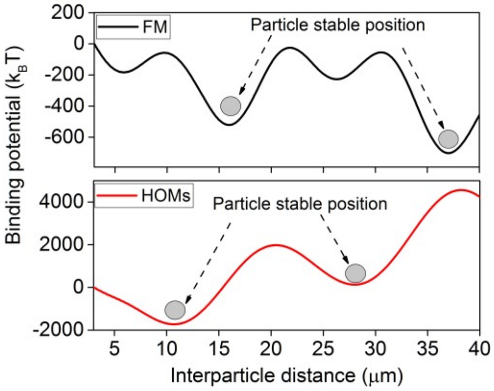

Figure 1. Binding potentials calculated from the optical forces. Figure is adapted from [10].

2. Experimental procedure

The experimental setup for particle propulsion is shown in Fig. 2. A 1064 nm, linearly polarized Gaussian beam (ND:YAG, Laser Quantum 1064) was incident on a spatial light modulator (SLM, BNS1064) mapped with a vortex phase singularity. The reflected pattern was a

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donut-shaped beam, corresponding to the LG_{01} mode. When coupled into the MNF, a coupling efficiency of 45% to the HOMs was achieved. The SLM can also switch between the HOMs and the FM by simply changing the phase mask.

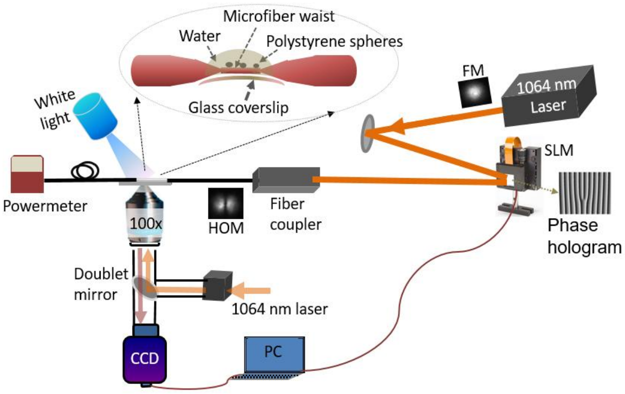

Figure 2. Experimental setup for optical manipulation.

A 2 µm diameter tapered fiber with 80% transmission for the HOMs was prepared using a hydrogen-oxygen pulling rig[11] and mounted at the focal plane of an optical tweezers system. A diluted polystyrene particle solution (particle size of 3 µm) was prepared and dropped on the cover glass, also located at the focal plane of the optical tweezers. The tweezers enabled us to trap any desired number of polystyrene particles and transfer them close to the MNF. When the particles were propelled along the fiber, a CCD camera was used to record the particles' path.

We studied the inter-particle distance for the two particles located farthest from the light source. In both the FM and HOM cases, the interparticle distance was largest for two particles and decreased as the group-size increased. This is due to the redistribution of the light field with the addition of more particles; this could change the interparticle spacing.

The experimental results were in good agreement with the numerical predictions. For the FM, the interparticle distance appeared to be larger compared to the HOM for all cases. These observations indicate the different binding effects under the two different modes.

III Conclusion and Outlook

We investigated a binding phenomenon between particles driven by the evanescent field of the HOMs and FM separately. The observed particle speed and the interparticle distances indicate a weaker binding effect for the HOMs. This may be useful for some systems where independent control of particles is desired. Currently, we are developing this study to investigate angular momentum transfer from the fiber-guided light to the particles.

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