Adiabatic SNOM Tips for Optical Tweezers

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Abstract: Efficient optical tweezers have been manufactured from optical fibre tapers. Powers in the order of tens of mW have been used to trap micrometric particles in water.

1. Introduction

The possibility to exploit the mechanical action of optical fields to trap and manipulate neutral particles offer an exceptional level of control needed at the frontiers of several branches of science and engineering. Most of the powerful optical manipulation techniques are derived from single-beam optical traps known as optical tweezers [1], developed in the pioneering work of Ashkin and co. at Bell Laboratories [2]. An optical tweezer uses forces exerted by a strongly focused beam of light to trap small objects. Although the theory behind optical tweezers is still being developed, large objects are depicted acting as lenses, refracting the rays of light and redirecting the momentum of their photons. This reaction moves them toward the focus, where the intensity peaks [1]. This approach in free space propagation is limited by diffraction. The minimum focus spot size is typically in the range of a micron. In addition, if a sample is only slightly absorbing, to avoid damages optical trapping is applied just at the surface.

Metallic probes have been proposed to trap small particles [4,5]. Strong field enhancement from light scattering at a metallic tip could generate a trapping potential deep enough to overcome Brownian motion and capture a nanometric particle [4]. Alternatively, a combination of evanescent illumination from the substrate and light scattering at a tungsten probe apex is used to shape the optical field into a localized, 3D optical trap [5]. All these approaches require high powers for the illumination (well above 1W) and present a difficult integration in conventional microscopy instruments like scanning near field microscopes (SNOM).

Lensed optical fibres have been demonstrated to be highly efficient optical traps [6-8] and can be easily integrated with SNOM technology but have the drawback of a large mode field diameter (typically in the range of 10μm).

In this paper we present an easy way to trap particles with low powers (<10mW) using fibre tapers. The use of fibre tapers allows for the ultimate confinement (sub-μm spots) and potentially reduces the trapping power by orders of magnitude.

2. Fibre Taper Fabrication.

During the last fifteen years much work has been carried out to study and optimise fibre taper profiles. Since Birks published his pioneering work on the shape of fibre tapers [9], technology development allowed manufacturing tapers with diameters well below 1μm both from silica [10] and compound glass fibres [11]. Although tapers with submicrometric waist diameters are continuously fabricated to be used as SNOM tips [12], these tapers carry light only in the direction of increasing diameters and losses as high as 99.999% are observed when light is propagating in the direction of decreasing diameters. Huge losses are due to the poor "adiabaticity" of the taper profiles which couple light to lossy unbound modes [13,14]. Using a taper manufacturing rig it is possible to tailor the taper shape to the ideal "adiabatic" profile and achieve losses smaller than 0.05dB (~1%) [10,15]. Tapering a fibre involves heating and stretching it to form a narrow waist. Because of this process taper transitions are connected to untapered fibres at the extremities and can easily be connected to fibre optic components. In this set of experiments we manufactured taper tips using a commercially available pipette puller (model P2000)

Using the criterion proposed in ref. 10 (and assuming the refractive index of air, water and silica at wavelength λ=1.55μm to be 1, 1.33 and 1.44 respectively) we simulated the optimum adiabatic taper profile. We manufactured several samples and checked the profile with a high-magnification optical microscope. Figure 1 compares the profiles of manufactured taper to simulations.

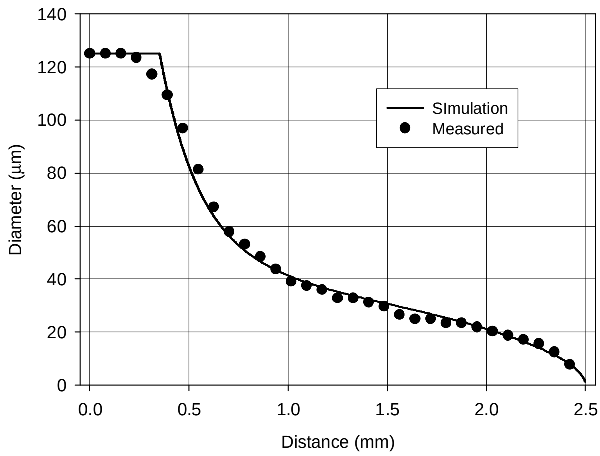

Fig.1. Comparison between the taper profile measured under an optical microscope (dots) and the ideal adiabatic profile evaluated from ref. 10 for λ=880nm.

All the manufactured fibre tapers had a 50cm pigtail to allow prompt link to other optical fibre components.

3. Optical trapping

We connected a fibre taper to an EDFA (Erbium Doped Fibre Amplifier) capable to deliver 23dBm of maximum power at 1.5µm using bare fibre adapters. The fibre taper was immersed in a solution containing silica microspheres with 1µm diameter and analyzed using an optical microscope connected to a PC using a TV card. The EDFA power was increased in steps of 0.1mW and pictures were taken every ~1s. Because of Brownian motion and other environmental factors the microparticles move quickly in water and no trapping was observed at the end of the tip. Whith power in the order of 10mW, a particle has been trapped at the taper tip. Fig. 2 presents four photos taken at ~1s interval where it is clearly visible the particle trapped at the fibre tip while the others move within the liquid. When the power was reduced, the particle was released from the optical trap at the fibre tip. Increasing the power again, we managed to trap another particle which positioned at the fibre tip as far as the power was higher than 10mW.

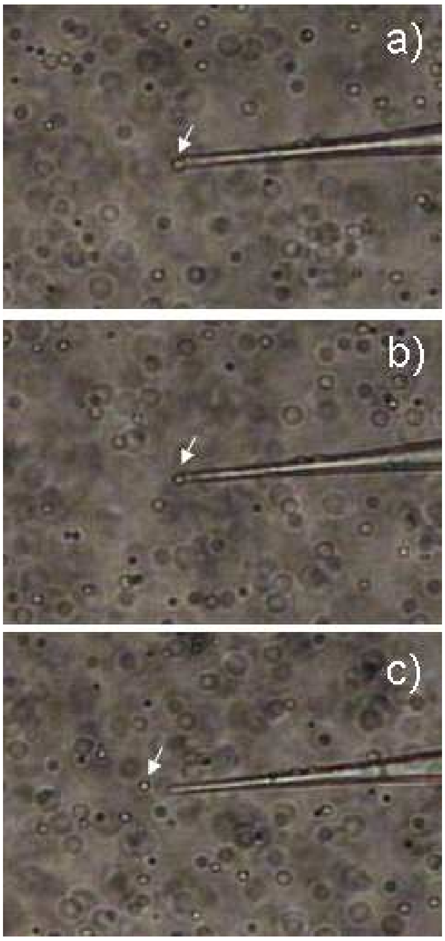

Fig.2. Optical microscope pictures of a fibre taper tip in a solution of silica microspheres (diameter d=1µm). When the laser output is in the order of 10mW (pictures a) and b)) a particle is trapped at the fibre tip. When the laser is switched off, the particle is released (picture c)). The arrow indicates the trapped particle.

4. Conclusions

In this paper we demonstrated that the control of the fibre tip shape allows using a SNOM tip to trap particles with extremely low powers.

5. References

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