Optical trapping of dielectric nanoparticles using nanostructured optical fiber tip

Ming Ding,[*1] Olav Gaute Hellesø,[2] Jean-Claude Tinguely,[2] Gilberto Brambilla[1]

[1]*Optoelectronics Research Centre, University of Southampton, Southampton SO17 1BJ, United Kingdom*
[2]*Department of Physics and Technology, University of Tromsø, Tromsø N-9037 Norway*
**md20g09@orc.soton.ac.uk*

Optical trapping has found wide range of applications because it allows for precise control and positioning of micrometre-sized dielectric objects. When the nanoscale objects is small and with a refractive index greater than the surrounding medium, the gradient optical force becomes much weaker, scaling with the third power of its size. In the meanwhile, the thermal motion of the object increases with decreasing object size owing to a reduction in the viscous drag, thereby favouring escape from the trap. So far, the only approach to trap smaller objects is to increase the trapping laser intensity; halving the particle size requires an order of magnitude increase in the local field intensity within the trap. Consequently, trapping very small objects (such as cellular organelles) involves intensities that can exceed their damage threshold. In this work, we consider the possibility of creating an optical trap in which the cell or a part of it has a strong influence on the local electric field and thereby has an active role in the trapping mechanism. This so-called self-induced back-action (SIBA) optical trapping is enhanced by the use of an optical resonance. No resonance is required from the trapped object; the resonance is sustained by the trap itself, which in this case was represented by an optical microfiber tip with a cylindrical hole.

A 3D model of microfiber tip was carried out using 3D Finite Element Method (FEM) to numerically solve Maxwell equations in the frequency domain. The fundamental mode at wavelength λ=980 nm with linear polarization was excited with 1 mW power at the microfiber input. The microfiber tip apex had a 3 μm diameter, was coated with a 100 nm layer of gold and had a hole 550 nm wide and 500 nm deep at its centre. A small (190 nm diameter) spherical object was placed 50 nm away from the gold. The microfiber tip was assumed to be surrounded by water, as it commonly happens in cellular and intracellular environments: this has the effect of avoiding capillary forces and sticking of nanoparticles to the surfaces. When light at 980 nm is launched into the microfiber tip, the spherical object is pulled into and trapped in the hole. This wavelength does not go through the hole and forces exerted on the sphere are thus negative, i.e. towards the interior of the microfiber tip. Simulations show that a strong field is established around the spherical object, which can be stably trapped inside the hole.

The optical microfiber tips were fabricated using the same parameters used in the simulations. The fabrication process can be divided into four main steps: (i) manufacture of optical microfiber tips, (ii) tip flat cut at proper diameter, (iii) gold layer deposition, and (iv) hole opening at the coated microfiber tip apex. Firstly, microfiber tips were manufactured using a commercial micropipette puller, which is a CO_2 laser based pulling machine controlled by a microprocessor. The default configuration of the P-2000 allows the fabrication of microfiber tips with extremely small diameters: typically, fibres can be pulled from 125 μm down to 40 nm diameters and have a taper length of about 1 mm. Since high transmission efficiency is targeted, the taper angle of the optical fiber tips has to be small enough to adiabatically convert the fundamental mode in the fiber core into a fundamental mode in the microfiber. Adiabatic microfiber tips were then cut at 3 μm diameter using focused ion beam (FIB) milling system. A 100 nm thick gold layer was then deposited on the tips using a thermal evaporator. Finally, a hole with 550 nm diameter and 500 nm depth was finally opened at the tip apex by FIB milling. The nanostructured microfiber tip has a pigtail which is then connected to the laser source for trapping experiments.