Fibered nano-optical tweezers for micro- and nano-particle trapping

Optical "tweezers" are a means by which a small particle can be held stably in the electromagnetic field of a light beam. They have been a well established tool for non-invasive manipulation of very small objects in biology, chemistry, and soft-matter physics. In this context we are developing novel tweezers based on two optical-fibre nano-tips. Compared to standard optical tweezers based on focusing of a strong laser beam, our approach is more versatile and, especially, better adapted for trapping of nanoparticles.

The principle of optical tweezers (*fr."pinces optiques"*) can be understood by considering the optical forces affecting a small particle in a light field. The momentum exchange between the propagating light and the particle leads to a repulsive scattering force ("the pressure of light"). But the incoming light also induces an oscillating dipole inside the particle. This dipole feels a force pulling it up the gradient of the beam's intensity towards the maximum. Production of a strong gradient of intensity of the light is thus necessary for stable trapping. In the classical optical tweezers technique, first realized in 1986, a laser beam is focussed by a high numerical aperture microscope objective to obtain this strong light gradient in the axial direction.

Trapping of nanoparticles requires even stronger field gradients since optical forces scale with particle volume and as Brownian movement becomes more significant. Thus, near-field optical tweezers, utilizing a concentrating optical-fibre light source, and more specifically plasmonic tweezers, have been developed. In the case of fibered optical tweezers the light is tightly enough concentrated at the apex of the fibre tip that there is an intensity gradient steep enough to trap dielectric particles. However, as soon as we move even a little way from the fibre tip, scattering dominates and the particle is pushed away. The use of two fibre tips facing each other can overcome this limitation.

Fibre-based traps can work with samples that are inaccessible to the high-power microscope required for conventional optical traps. They can be used anywhere one can fit a mechanical probe. Today's micromanipulators can position the tip of a fibre with sub-nanometre accuracy, over a range of centimetres, combining the benefits of optical trapping with those of mechanical manipulation.

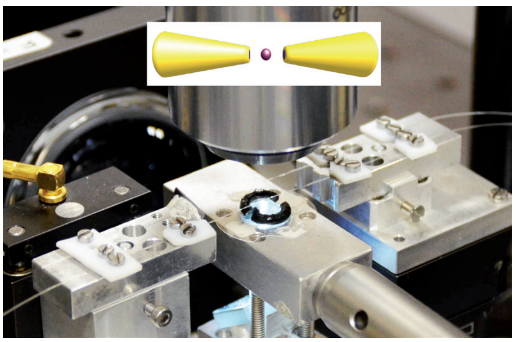

Fig. 1: Photo of our fibre nano-tip optical tweezers apparatus. (Inset drawing : fibre tweezers trapping a microsphere.)

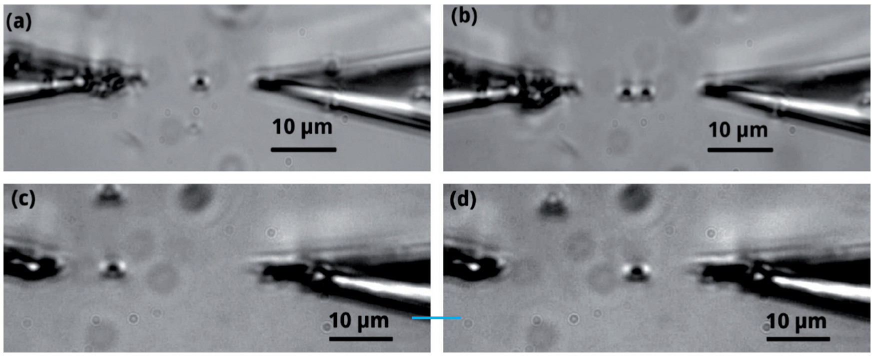

Fig. 2: Trapping of (a) one and (b) two micron-sized dielectric spheres using our dual fibre nano-tip optical tweezers. Images (c) and (d) show control of position of a single particle by modifying the relative light intensities in the two fibre tips.

In this context we are developing a novel approach combining the advantages of fibered optical tweezers and plasmonic tweezers. Our "Fibred Plasmonic Nano-Tweezers" is based on an adjustable plasmonic cavity consisting of two nanometre-sized metalized optical fibre tips. The optical properties of these tweezers can be modified in real-time by controlling the tip-to-tip distance. The objective of this work is to trap and manipulate nanoparticles in order to study light-matter interactions at the nanometre scale.

As an important milestone, we have recently achieved stable and reproducible trapping of micro-particles and nano-particles using two bare (not yet metalized) optical fiber tips with tip-to-tip distances up to 28 µm and optical powers as low as 2.8 mW. The particle position along the optical axis can be controlled by varying the relative optical intensity injected into each fibre tip. Moreover, two or even more particles can be trapped for a few minutes. The effective potential of the optical tweezers can be calculated from trapping videos using three independent theoretical models. This showed that the trapping potential was harmonic with a trapping stiffness up to 35 pN $\mu m^{-1} W^{-1}$, well above the thermal energy of the trapped particles.

The results obtained are promising for projected trapping experiments for dielectric particles below 100 nm size. Metalized fibre tips of the type used in Nearfield Scanning Optical Microscopy (NSOM) can concentrate light into a spot only tens of nanometres across, creating an intensity gradient much higher than that available with a high-NA lens. This should prove very useful for trapping nanoparticles or other strongly scattering objects, and our technique would be perfect for characterizing such systems.

CONTACT

Jochen FICK
jochen.fick@neel.cnrs.fr

Ph.D student
Jean-Baptiste DECOMBE

FURTHER READING

Single and dual fiber nano-tip optical tweezers: trapping and analysis
J.-B. Decombe, S. Huant, J. Fick
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