Single-Fiber Optical Tweezers for Cellular Micro-Manipulation

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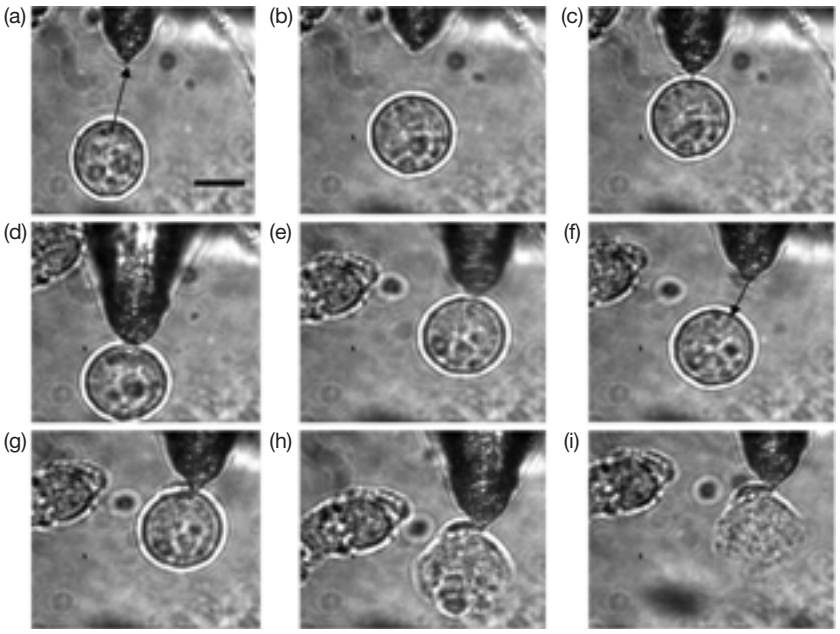
The short working distance of microscope objectives has severely restricted the application of optical tweezers and scissors at large depths. Therefore, researchers are paying more and more attention to the use of optical fiber for this purpose. Recently, in-depth single fiber optic trapping of low- and high-index particles has been demonstrated using micro-axicon-tip fibers.[1,2]

The shape of the cone angle at the axicon's tip enabled fiber-optic trapping in the near-field.[2] Further, we have demonstrated controlled guidance of neuronal growth cones as well as the trapping and stretching of neurons using fiber-optic tweezers.[3] The cells could be stretched[3] by the combined action of two forces—an attractive gradient force due to fiber-optic tweezers at high beam powers pulling the membrane and a scattering force on the membrane as reported in dual-fiber trapping.

We also observed alignment of intracellular dark (high refractive index) material along the direction of laser beam propagation.[3] By mode-locking, the beam of the fiber-optic tweezers was converted to fiber-optic scissors, enabling the dissection of neuronal processes.[3]

This microscopic-controlled nanodissection of neurons followed by a process of resealing and repair could serve as a useful tool for basic and applied studies on neuronal damage, repair and regeneration. When the femtosecond fiber-optic microbeam was at reduced average power, we could microinject impermeable exogenous materials into the trapped cells. At high average powers, we accomplished lysis of a three dimensionally trapped cell.[3]

In the figure, we show optical trapping as well as lysis of biological cells using a single axicon tip fiber. The cell, distant from the fiber tip (marked by arrow in a) is attracted toward the fiber tip (b) at a power of 95 mW and was stably trapped very close to the axicon tip (c). The trapped cell could be transported to a new location (d, e) by maneuvering the fiber tip. Switching the laser beam on and off alternatively allowed the cell to move close (g) or away (f) from the fiber tip, ruling out the possibility of non-optical attraction between the cell and the fiber.



Trapping, transport and lysis of a biological cell using axicon-tip single-fiber tweezers and scissors. All images are in the same magnification. Scale bar: 10 μm.

By mode-locking the near infrared laser beam, we could deliver femtosecond pulses (about 200 fs, 76 MHz), and the same fiber probe could be used for lysis of the trapped cells (h, i) in a timescale of 600±200 ms. This feature is required in many assays to terminate biochemical reactions immediately, thus preventing measurement artifacts.

The non-invasive micro-axicon-tipped optical fiber can also be used in multifunctional mode for in-depth trapping, stretching, rotation, sorting, microinjection and ablation as well as for exciting fluorophores. The depth attainable by optical micromanipulation is enhanced by a single microfabricated fiber device. Moreover, this technology could lead to sophisticated sensing and imaging capabilities that can be applied to live cells.[4]

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