Light-on-a-Chip Group

Electrooptical Engineering

ITMO UNIVERSITY

BGU

Dynamic illumination of spatially restricted or large brain volumes via a single tapered optical fiber

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January 4, 2018

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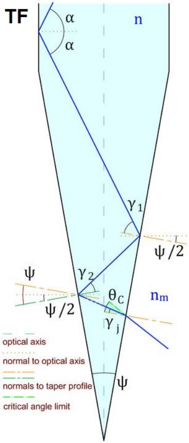
What is the Optogenetics?

- Optogenetics is the integration of optics and genetics to achieve gain of previous loss of function of events within cells of living tissue.
- It is a neuromodulation technique employed in neuroscience that uses a combination of techniques from optics and genetics to control and monitor the activities of individual neurons in living tissue even within freely-moving animals and to precisely measure the effects of those manipulations in real-time

Single tapered fiber (TF), flat-faced fiber (FF)



$$\alpha = \cos^{-1}\left(\frac{1}{n}\cdot \sin\theta_i\right)$$

$$\gamma_1 = \alpha - \frac{\psi}{2}$$

$$\gamma_2 = \gamma_1 - \psi = \left(\alpha - \frac{\psi}{2}\right) - \psi = \alpha - \frac{3}{2}\psi$$

$$\gamma_3 = \gamma_2 - \psi = \left(\alpha - \frac{3}{2}\psi\right) - \psi = \alpha - \frac{5}{2}\psi$$

...

$$\gamma_j = \gamma_{j-1} - \psi = \alpha - \frac{2j-1}{2}$$

until TIR condition $\gamma_j > \theta_C$ is fulfilled

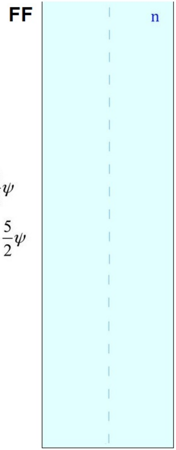


Figure: Simplified model of ray propagation and outcoupling in TF and FF

Design principles of tapered optical fibers

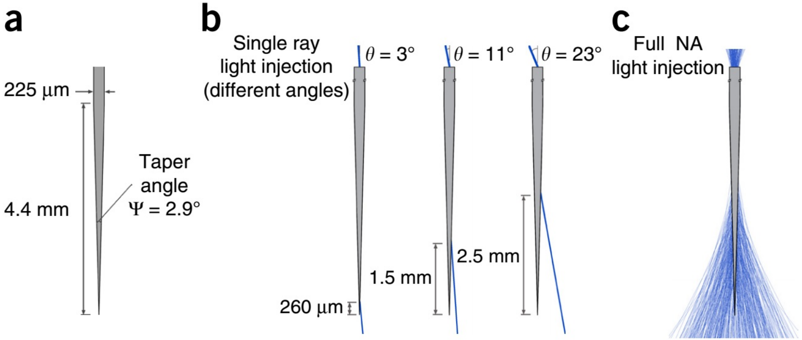


Figure: Emission properties of TFs

Design principles of tapered optical fibers

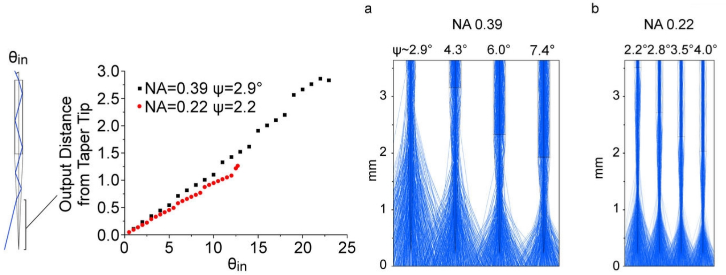


Figure: Dependence of the output distance from taper tip on the input angle (left) and ray-tracing simulation of propagation and outcoupling in TFs of different NA and taper angles (right)

Design principles of tapered optical fibers

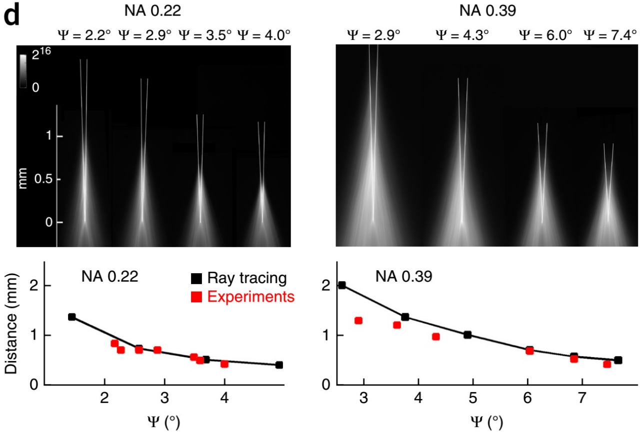
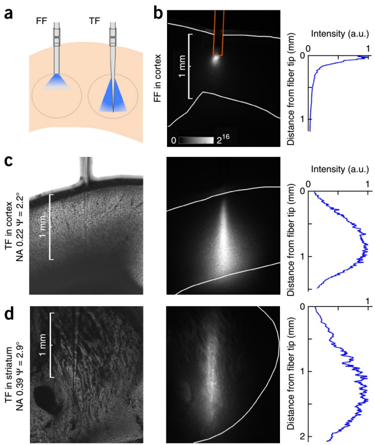


Figure: Emission properties of TFs

Illumination of large brain volumes with TFs



(a) Schematic of light delivery in brain tissue **(b)** Left: light emission from an FF implanted into cortex in a fluorescein-impregnated brain slice. Right: fluorescence intensity profile in the tissue starting from the fiber end face. **(c,d)** Bright-field images (left) identify the positions of the TFs in the fluorescein-impregnated cortical or striatal brain slice used for acquisition of the fluorescence images (middle). Right: normalized profiles of fluorescence intensities beside the taper, starting from the first emission point.

In vivo examination of effective excitation in striatum, a large brain

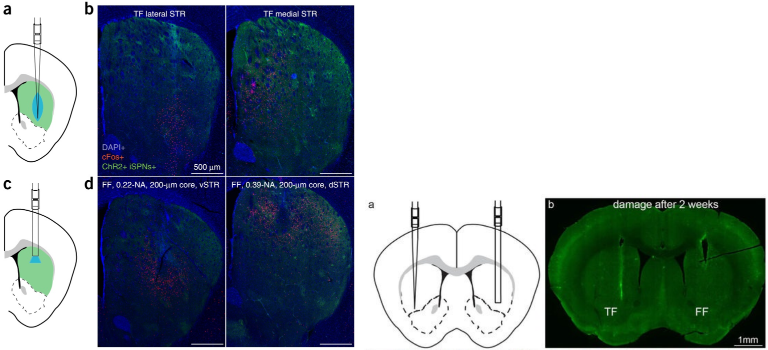


Figure: In vivo examination of effective excitation in striatum

Dynamical selection of illuminated brain regions

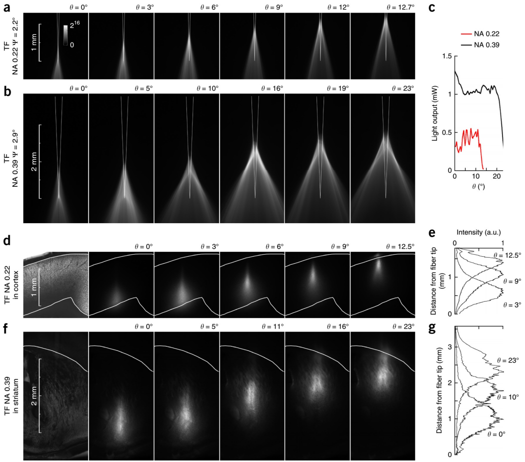


Figure: Site-selective light delivery with TFs.

In vivo multisite stimulation

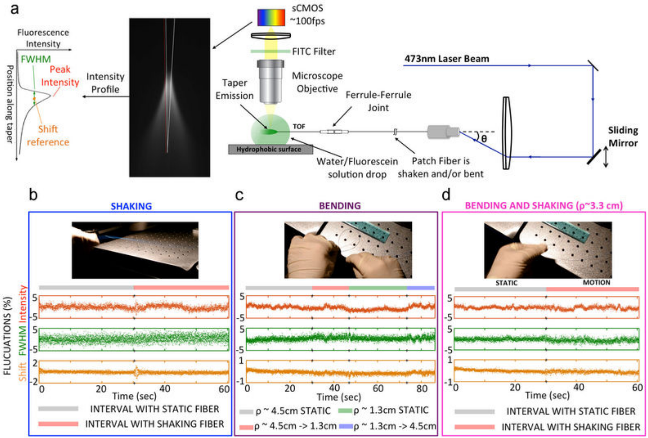
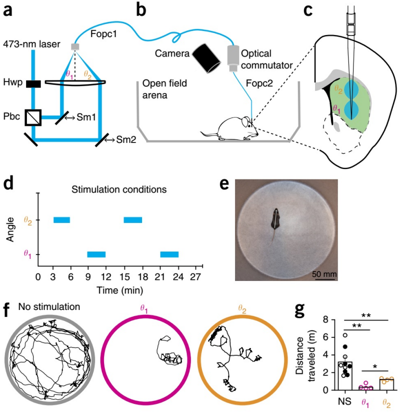


Figure: Approaches used to model and measure light output from the TFs

In vivo multisite stimulation



Stimulation of ventral Θ1 and dorsal Θ2 striatum

Selective light delivery with TFs in the open field.

Illumination of large brain volumes

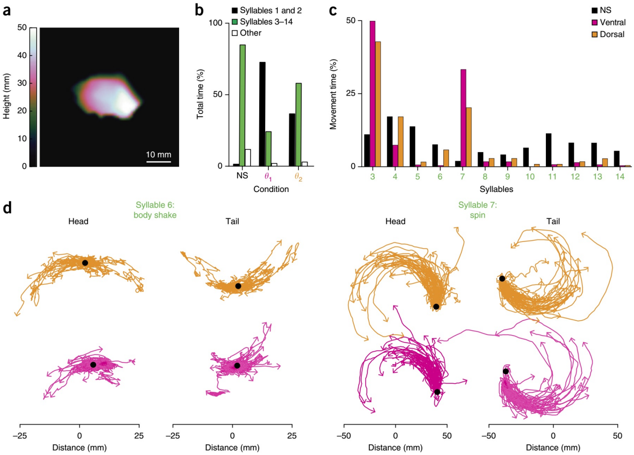


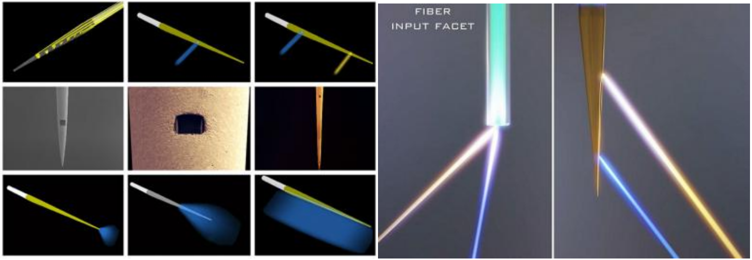
Figure: Mapping subsecond structure of behavior during optogenetic manipulation of ventral or dorsal striatum.

Sum up

- Demonstration that TFs have several advantages for light delivery in the brain that might allow this tool to replace the flat-cleaved optical fibers that are typically used for optogenetic experiments.
- Due to their tapered and smaller average cross section, TFs are minimally invasive and can be implanted directly into the brain region of interest.
- TFs are multipurpose, such that the same device allows either large-volume or site-selective light delivery
- The depth of the excited volume can be tailored by selecting the fiber taper geometry and NA, instead of by increasing the laser power as commonly done in experiments with FFs.
- Tissue absorption and scattering do not determine light distribution along the fiber axis, as in FFs.

Future work

- TFs can be coated with metal, with small openings to restrict light delivery.



http://optogenix.com/tapered-fibers-optogenetics