MINFLUX microscopy with all-fiber illumination system

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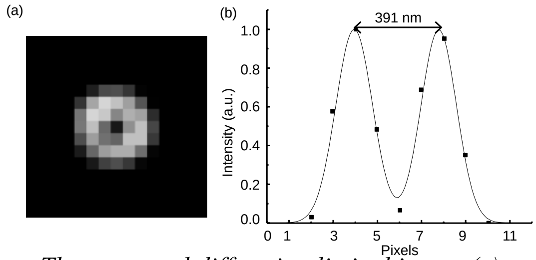

The measured diffraction limited image (a) and the intensity beam profile (b) of doughnut beam generated by the MSC on the camera.

As a new super-resolution localization method, MINFLUX[1] nanoscopy, which employs a doughnut illumination spot as excitation, can attain a resolution of about the size of a molecule, in principle without constraints from wavelength, numerical aperture, or molecular orientation. Currently, free-space beam shaping devices such as vortex phase plate and Q plate for doughnut beam generation at desired wavelengths have been adopted. Such devices require 1) the precise alignment of one or more free-space laser beams, and 2) an additional polarization controlling method to obtain a close-to-zero center intensity of the doughnut beam at the focal plane of a high numerical aperture (NA) objective. An optical-fiber-based implementation of this attractive nanoscopy approach should be able to overcome several engineering challenges, such as low insertion loss (high mode conversion efficiency), high stability of the point spread function (PSF) against environmental perturbations, good alignment tolerances, and more.

Here, we demonstrate the principle of MINFLUX nanoscopy based on the all-fiber mode selective coupler (MSC) integration by a simple modification of a widefield microscopy setup. The MSC used in our setup can support stable cylindrical vector beams (CVB) and arbitrary polarization state doughnut beam generation and propagation at wavelengths typically used in MINFLUX with a conversion efficiency of 94% and insertion loss of <0.5 dB[2]. Other fiber techniques, such as long-period grating (LPG)[3], requires special optical fiber design and fabrication, and polarization-maintaining (PM) fibers[4], need complicated free space beams separation. In contrast, the MSC-based system is more compact, robust, and economical. The MSC-based all-fiber nanoscopy realization may enable endoscopic implementation of such MINFLUX in the long term.

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