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Summary

We propose and demonstrate a procedure to measure the profile of tapered fibers with an accuracy of a few nanometers. It can be implemented on any optical microscope. Only based on a computer analysis of the microscope images, this fast and reliable technique does not require any change on the microscope.

Introduction:

Tapered optical fibers are new choice objects for nonlinear optics [1]. We fabricate these optical nanofibers by stretching, by two translation stages, a standard telecom optical heated by a butane flame [2]. Our experimental rig is shown in Fig. 1. An in-situ microscope allows to capture images of the nanofiber. The two stages are computer controlled, which gives us different parameters to obtain a wide variety of nanofiber profiles.

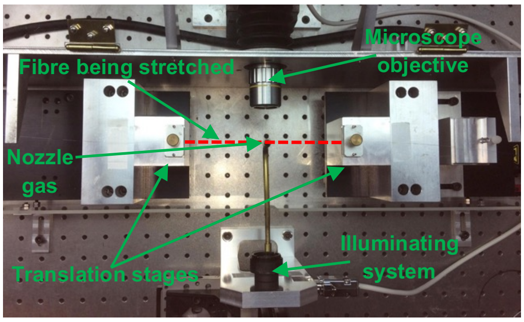

Fig. 1. Puling rig.

The biggest advantage is the confinement of light thanks to their small diameter, which gives very high intensities favorable to nonlinear processes and especially controlling the phase matching by the diameter. These effects are very sensitive to the fiber profile, so to the variation of the diameter along the axis of the fiber. The optimization of non-linear effects may require the knowledge of these diameters to within a few nanometers [1]. The simplicity of optical microscopy would make it ideal for these nondestructive profile measurements as long as the resolution can be increased beyond the conventional diffraction limit. One usual way to beat the diffraction limit is to add additional information to the measurement. In the particular case of tapered fiber measurements, this additional information is the prior knowledge of the object to be measured. We assume that, on the measurement region, the fiber is a perfect silica rod, the only unknown parameter is its diameter. This allows us to simulate the images collected by the microscope for a range of diameters.

Principle:

The microscope system is described in Fig. 2 [3]. The nanofiber is illuminated by a LED at 462 nm which is placed about 20 cm from the nanofiber, so that the light can be assimilated to a plane wave. The microscope (x20 with a numerical aperture $ON = 0.42$) is mounted on a micrometric translation. This allows us to take a series of images at different focuses, along z, upstream and downstream the nanofiber. Each of these images represents the intensity $I_z(x,y)$ diffracted by the nanofiber at a given focus z. A position y_0 is then selected along the nanofiber on which the diameter is to be determined and the corresponding section $I_z(x,y_0)$ is isolated in each of these images. We obtain a series of profiles $I_z(x,y_0)$ of the diffraction diagram for this position y_0 and for a series of z. These profiles are then computer-assembled to obtain a diffraction pattern, $I_{y_0}(x,z)$ for a given y_0 (Fig. 2). To determine the diameter at this position y_0, we have to compare this experimental pattern with all the patterns simulated for different diameters. To do so, we calculate the field at any point between the optical fiber and the objective relying on the formulas given by Van De Hulst [4]. This diffraction field is decomposed into plane waves and all the decomposition is limited to the numerical aperture of the objective. We propagate these plane waves and we simulate the images acquired by the camera for different focuses. We have automated the comparison by calculating the Euclidean distances between the experimental pattern and the bank of patterns calculated for different diameters with a pitch of 2 nm. The diameter corresponding to the minimum distance is the sought diameter. This technique gives a precision of 10 nm on the fiber diameter.

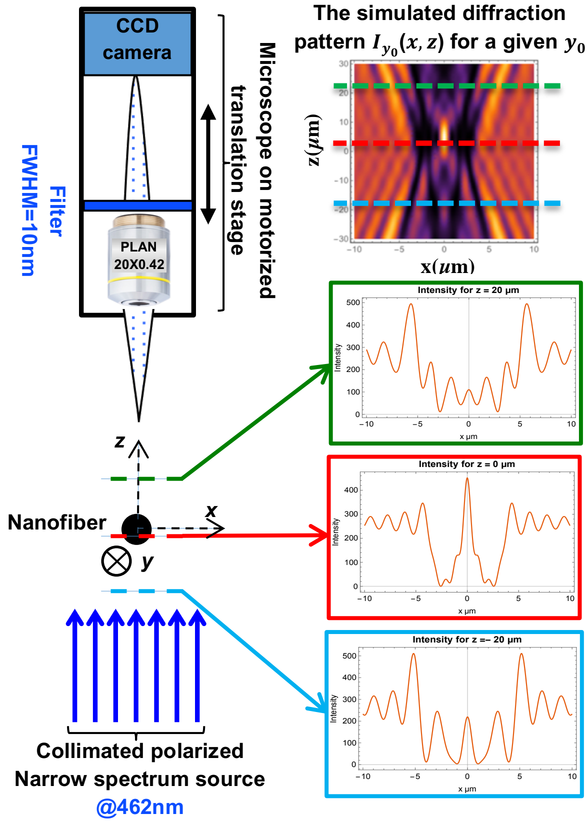

Fig. 2. The microscope with its illuminating system.

Conclusion:

This measurement method can be compared to other non-contact techniques reported in the literature [5-7]. The advantages of our technique are multiple: it is easy to implement with conventional microscopes, it is inexpensive and allows an extended measurement of the diameter at each point along the nanofiber. Currently we determine diameters with better than 10 nm of precision.

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