CHARACTERIZATION OF METAL-COATED FIBER TIP FOR NSOM LITHOGRAPHY BY TIP-TO-TIP SCAN

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1. Introduction

The near-field scanning optical microscope (NSOM) lithography is one of the progressive techniques for preparation of 2D photonic structures. Patterning of photonic structures using this technique is done through a direct writing process which is performed by the optical near-field produced at the apex of a fiber probe [1].

In NSOM, where a sample is placed in the vicinity of a fiber probe with aperture diameter a smaller than the wavelength λ, the spatial resolution limit known from far-field microscopy as diffraction barrier is overcome [2] and it is a function of the aperture diameter a [3]. Dependence of a on the full width at half-maximum (FWHM) of optical field behind the aperture has been previously reported regardless λ [3, 4].

As the aperture diameter a is a crucial parameter for determining the spatial lateral resolution in NSOM, the method for determining characteristics of the metal-coated fiber probe, e.g. the aperture diameter a, by investigation of the near-field intensity profile is presented. The near-field intensity in the vicinity of the fiber tip was taken by tip-to-tip scan, where two fiber probes were used in illumination (source) and collection (detector) mode, respectively. Using the source fiber tip in illumination mode, the non-contact NSOM lithography was performed in order to confirm the spatial lateral resolution of the fiber tip.

2. Experimental

For the optical field characterization, a tip-to-tip scan of two metal-coated fiber tips with circular aperture at the apex was performed. The optical field irradiated from the fiber probe in illumination mode was analyzed by NSOM represented by fiber probe in collection mode.

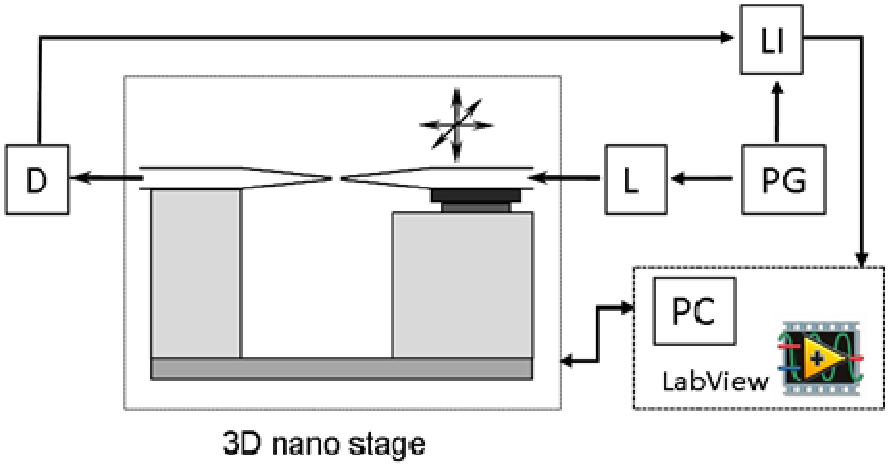


Fig.1: *Experimental setup for tip-to-tip scan, PG – pulse generator, D – detector, L – laser, LI – Lock In.*

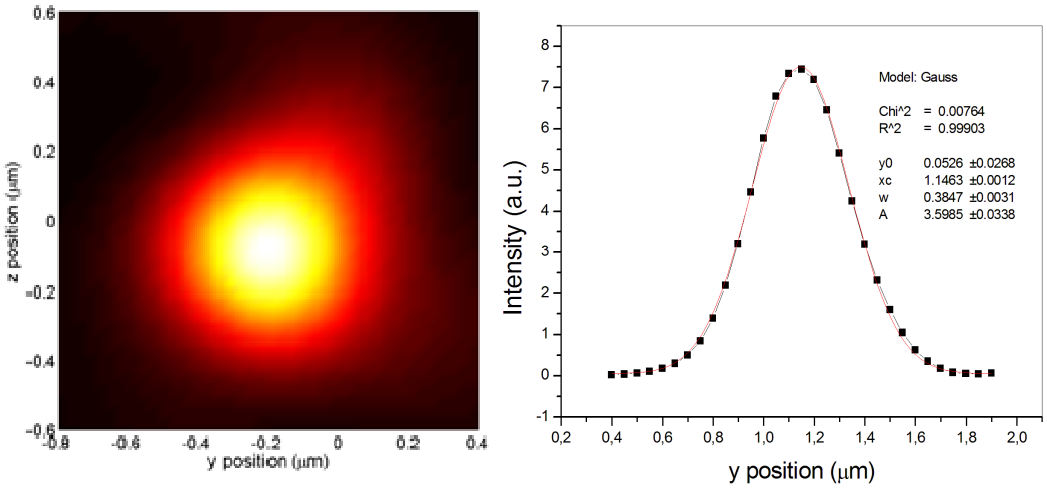
The near-field intensity profile of the source fiber tip in the plane perpendicular to the axis of the tip was taken. Experimental stage requires high resolution 3D motion system controlled by computer (Fig. 1). The source and the detector fiber tip were placed on the moving and static part of the 3D nanoposition system, respectively. As a light source, a modulated 473 nm DPSS laser was used.

After the source fiber tip characterization, the NSOM lithography was performed. In the experimental setup from Fig. 1, the detector fiber tip was replaced by a sample fixed in a vacuum holder. As a sample, a 600 nm positive photoresist AZ 5214E was spin-coated on a GaAs substrate. Exposure was carried out by irradiation of the sample at desired positions through the fiber tip aperture. The sample was developed in AZ 400K developer for 30 s and rinsed in DI water.

3. Results and discussion

For characterization of the near-field intensity profile, a tip-to-tip scan employing one fiber tip as a source and second-one as a detector was performed. The detector was placed in the vicinity of the source (< 200 nm) and performed a scan of the optical field in the plane perpendicular to the axis of the source fiber tip. The scanning range was set to 1.5 µm x 1.5 µm with a step of 50 nm constant in two perpendicular directions. 3D visualization of the exposing near-field intensity profile obtained from the scan is shown in Fig. 2a.

In Fig. 2b, there is shown the cross-section of the near-field intensity profile in the maximum which demonstrates the Gaussian profile of the optical field.



a) *b)*

Fig.2: *a) Intensity profile of the exposing near-field obtained by tip-to-tip scan. b) Cross-section of the near-field intensity profile in the maximum and the Gaussian fit.*

According to previous reports on the dependence of FWHM on the aperture diameter *a* [3, 4], from the intensity profile and the tip-tip distance, the aperture diameter can be determined. Antosiewicz and Szoplik are demonstrating for $a = 40$ nm FWHM of about 50 nm and 60 nm at the distance 5 nm and 25 nm from the tip, respectively; and FWHM of about 90 nm and 105 nm for $a = 80$ nm at the same distances [4]. These calculated FWHMs are independent on the wavelength λ; they are almost constant for all range of visible light.

In our experiment, the tip-tip distance is not exactly known. We suppose it to be lower than 200 nm, thus the aperture diameter can only be estimated with respect to the inaccuracy of distance determination. It is evident from previous, that the aperture diameter of the used metal-coated fiber tip is absolutely less than FWHM of scanned near-field profile. One must take into account that the scanned profile is a combination of near fields of both probes (source and detector) and the real source aperture diameter is even smaller. Gaussian fit function from the Fig. 2b is represented by

$$y \approx e^{-2\frac{(x-x_c)^2}{w^2}}, \tag{1}$$

afterwards FWHM can be explained as

$$FWHM = \sqrt{2\ln 2}\, w. \tag{2}$$

From the Gaussian fit in Fig. 2b regarding the fit accuracy, the parameter w can be obtained: $w \sim 390$ nm. According to Eq. (2), FWHM of the near-field intensity profile is app. equal to 460 nm, which yields the aperture diameter of the source fiber tip.

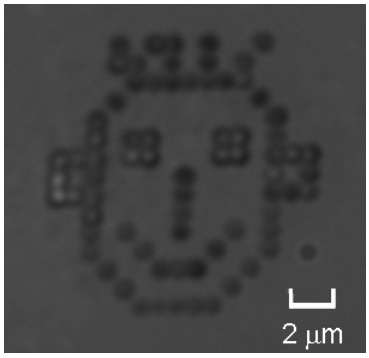


Fig.3: *Optical microscope image of 2D structure designed in the grid with 600 nm period.*

Furthermore, the characterized source fiber tip was employed in NSOM lithography. In Fig. 3, there is shown an example of 2D structure patterned in the photoresist. The structure was designed in the grid with 600 nm period in both perpendicular directions, which proves the fiber tip resolution obtained from previous characterization.

4. Conclusion

A promising tip-to-tip scanning technique for characterization of metal-coated fiber tips with aperture at the apex was presented. Nearly-circular aperture shapes were documented from NSOM measurements with diameter estimated to be less than 460 nm. By knowing the source-detector distance and the FWHM of the near-field intensity profile, the tip-to-tip scan proves an easy and fast method to analyze the fiber tip aperture properties.

The fiber tip resolution was confirmed by preparation of 2D planar structures in thin photoresist layer, where the NSOM lithography uses the metal-coated fiber tip characterized in previous section.

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