## NOTES

*BRIEF contributions in any field of instrumentation or technique within the scope of the journal should be submitted for this section. Contributions should in general not exceed 500 words.*

# Application of carbon nanotubes to topographical resolution enhancement of tapered fiber scanning near field optical microscopy probes

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Scanning near field optical microscopy (SNOM) probes are typically tapered optical fibers with metallic coatings. The tip diameters are generally in excess of 300 nm and thus provide poor topographical resolution. Here we report on the attachment multiwalled carbon nanotubes to the probes in order to substantially enhance the topographical resolution, without adversely affecting the optical resolution. © *2003 American Institute of Physics.* [DOI: 10.1063/1.1564275]

## I. INTRODUCTION

Probes for scanning near field optical microscopy (SNOM) require the delivery, collection, or excitation of light at a point with dimensions smaller than the wavelength used.[1,2] In order to achieve this, probes are typically fabricated a number of ways.[3–7] The most common method, and the focus of this article, is to taper optical fibers down to a few hundred nanometers and coat the sides with a thin layer of metal, leaving a subwavelength aperture at the fiber end face.[3] The taper itself can be achieved either via drawing, or chemical etching techniques.[8] Straight probes of this type are used in systems equipped with shear force distance control (e.g., tuning fork), whereas bent probes are used in systems equipped with optical deflection distance control (contact, noncontact, intermittent contact).

Tapered fiber probes are used extensively due to their relatively high collecting abilities and the simplicity with which the fiber can be connected to sources and detectors. Optically, tapered fiber probes can achieve a resolution better than 50 nm. The size of the probe ($\sim$300 nm), however, prevents these tips from achieving topographical resolution commensurate with typical atomic force microscopy (AFM) tips. On occasion, as is the case with AFM tips, small protrusions on the end of the probe can allow resolution substantially better than that predicted for the tip size to be achieved, although this is not the norm and occurs only for specific samples.

This article deals with the creation of a specific protrusion on the SNOM tip end facilitated by connection of a multiwalled carbon nanotube. Carbon nanotubes are already being used extensively in scanning probe microscopy (SPM) in general to achieve high resolution and high aspect ratio images where pyramidal based tips are inadequate.[9,10]

## II. EXPERIMENTAL METHODS

Multiwalled carbon nanotubes were attached to commercially fabricated SNOM probes (Nanonics Inc.) in a specially designed field emission scanning electron microscope (FESEM), which permits some control over both the length and direction of the nanotube. The carbon nanotubes, which are prepared by a conventional arc discharge method,[11] are aligned on a knife edge using an alternating current electrophoresis technique.[12] Attachment of a tube to the tip is done using two specially designed independent translation stages

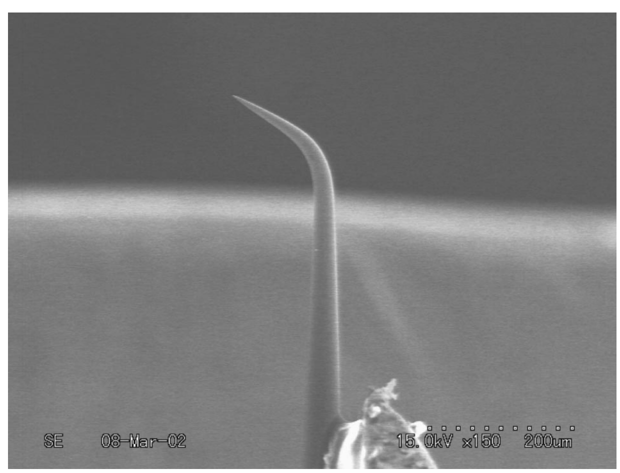


FIG. 1. Low resolution FESEM image of a standard bent tapered fiber SNOM probe.

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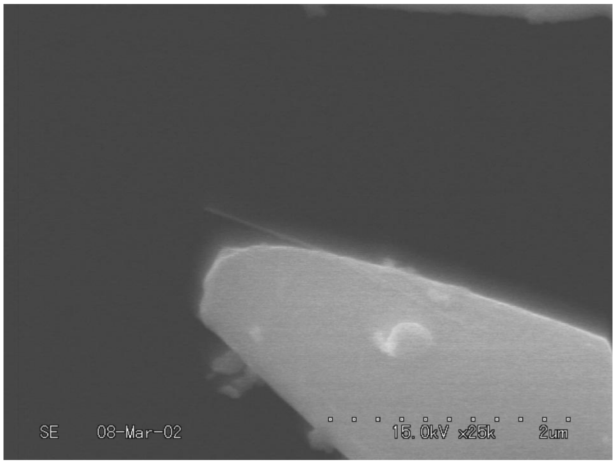


FIG. 2. FESEM image of a SNOM probe tip with a carbon nanotube attached.

for the knife edge and the SNOM probe. With the nanotube and SNOM probe in contact, amorphous contaminants within the FESEM are deposited, using the focused electron beam, to immobilize the nanotube on the tip. To modify the direction of the tube, the tube is aligned with the knife edge and amorphous carbon deposited at the base.

Scanning near field optical microscopy probe measurements were made using a modified commercial AFM (Veeco Instruments, Dimension 3100). For the majority of these specific measurements optical information was not collected as the resolution of the SNOM probes used has been well established, and only the topographical resolution was being investigated. A single optical measurement on a complex photonic device, namely a ridge waveguide, was collected to demonstrate that the optical performance of the modified probes were unaffected. The system was operated in intermittent contact mode during all experiments.

## III. RESULTS

The resolution of the tips, both with and without a carbon nanotube attached, was examined by imaging a piece of silicon that had been scratched and exposed to the environment for several days. The scratches facilitated rapid location of the area of interest, and the accumulated dust and dirt due to exposure met our requirements for the relatively soft and highly detailed sample.

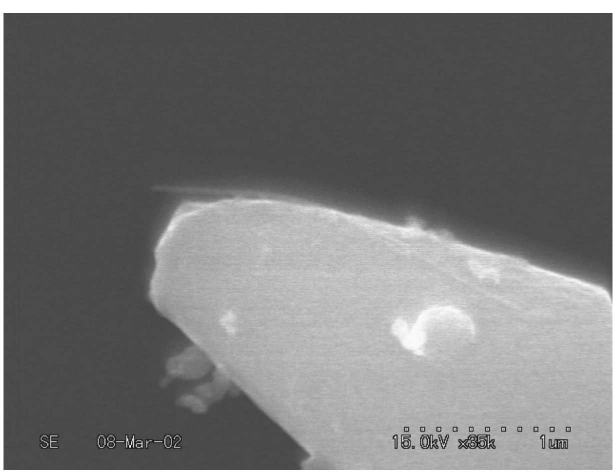


FIG. 3. FESEM image of a SNOM probe tip with an attached carbon nanotube. In this case the nanotube has been bent and fixed so as to be closer to the optical imaging point.

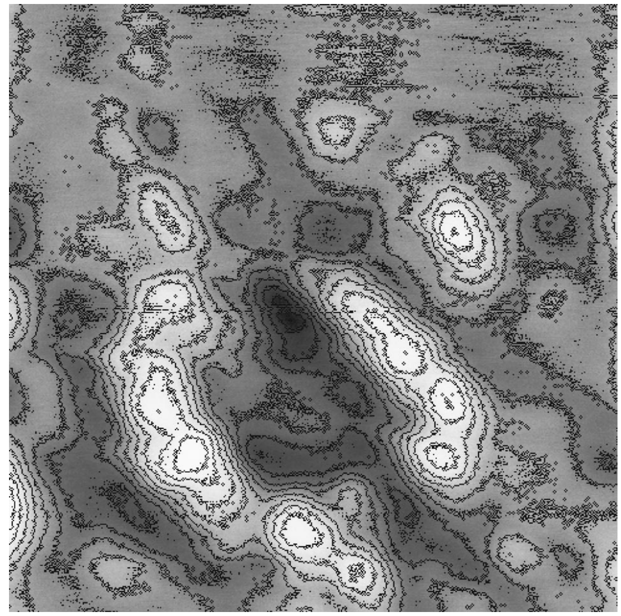

FIG. 4. Intermittent contact mode image of the test sample using a standard SNOM probe: scan size = 1 $\mu$m.

Figure 1 shows a low resolution SEM image of a fiber SNOM probe. The probe in this case is bent for cantilevered operation and is connect at the back end to a ''puck'' to facilitate easy incorporation into commercial AFM tip holders. Figure 2 shows the tip of the SNOM probe with the carbon nanotube attached (CN-SNOM probe). The tube has been positioned so that it only extends slightly beyond the end of the SNOM probe. In Fig. 3 the carbon nanotube has been bent slightly to bring the end of the tube as close as

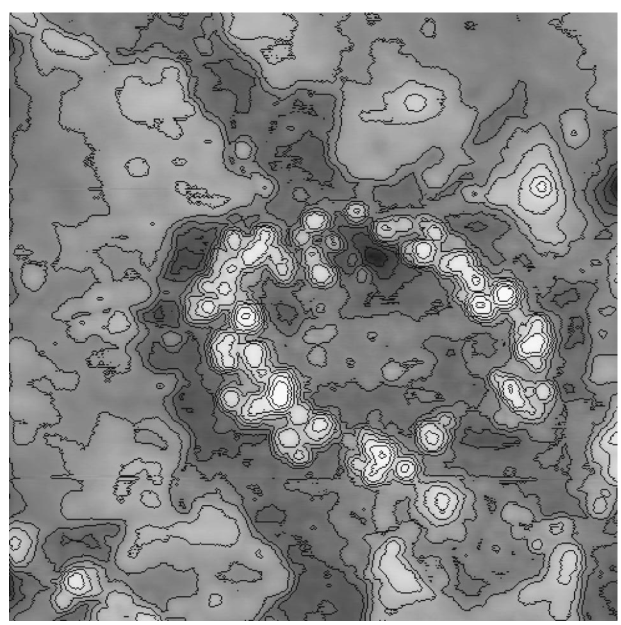

FIG. 5. Intermittent contact mode image of the test sample using a CN-SNOM probe: scan size = 1 $\mu$m.

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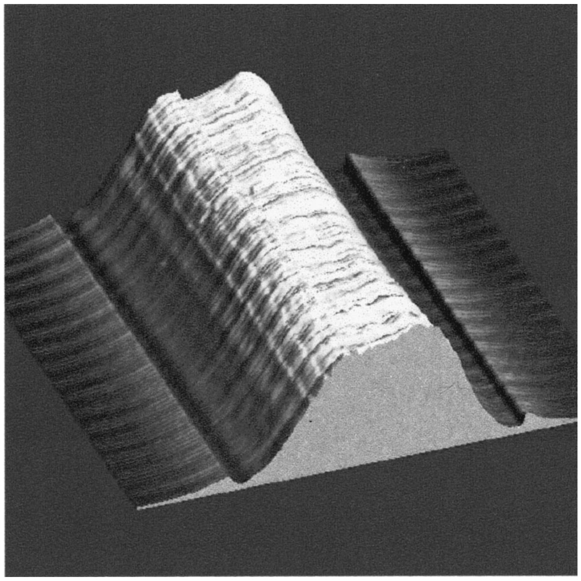

FIG. 6. 3D surface plot of CN-SNOM probe optical image above a ridge waveguide: scan size=30 $\mu$m.

possible to the SNOM imaging aperture. This image clearly indicates the change in tip size that results from the addition of the carbon nanotube.

The test sample was scanned on a 1 $\mu$m range with two SNOM probes. The first probe had a standard tip. The image obtained using this tip is shown in Fig. 4. The second probe had the carbon nanotube attached. The corresponding CN-SNOM probe image is shown in Fig. 5.

It is immediately clear upon inspection, that there is a substantial resolution increase as a result of the connection of the carbon nanotube. If we consider the left hand half of the ring structure, there appears to be three major lobes in the low resolution image, and $>15$ in the high resolution image. The image quality in general has also improved in the CN-SNOM image. The smallest object clearly resolved in this image by the CN-SNOM probe is $\sim 15$ nm in width, with objects $\sim 20$ nm apart being clearly resolved. For the standard SNOM probe the smallest object in the image is $\sim 140$ nm wide, and the minimum object separation is $\sim 100$ nm.

Figure 6 shows a 3D map of the evanescent field measured above a ridge waveguide of the type reported by Poweleit *et al.*[13] The field structure is in excellent agreement with the expected cosine squared field expected above the ridge and the exponentially decaying field away from the ridge (laterally).

## IV. DISCUSSION

The modification of scanning near field optical microscopy probes by attachment of multiwalled carbon nanotubes results in a substantial improvement in the topographical resolution obtained. The CN-SNOM probe in this case has provided images with resolution an order of magnitude better than an unmodified SNOM probe. In both cases the AFM was optimized for image quality and the same tip speed was used, $\sim 2$ $\mu$m/s. The carbon nanotube is carefully located on the side of the tip so as not to obstruct the optical aperture of the probe.

It should be noted that a number of SNOM probes are available on the market that utilize standard AFM tips with holes through the apex of the imaging tip. These tips offer comparable topographical resolution to the CN-SNOM probes but do not have the advantages of being fiber coupled. Minimization of the number of optical components required in SNOM systems is important for low loss systems, even though the aperture itself is the most significant contributor to loss.

Carbon nanotubes are robust and readily fabricated. Attachment to SNOM probes requires specific FESEM equipment but is quick and repeatable. The CN-SNOM probe offers the advantages of both fiber coupled apertures and high topographical resolution.


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