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NOTES

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Construction of a near-field spectrum analysis system using bent tapered fiber probes

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We take advantage of a combination of laser heating and pulling and electric arc bending to fabricate bent tapered fiber probes. The bent angles can be varied from 30° to 70° and tip diameters fall within a few tens of nanometers. These bent fiber probes can easily be adapted into any dynamic mode atomic force microscope. By proper manipulation of the bent angles, a spatial resolution of up to 60 nm is achievable. After coating the bent fiber probes with a thin layer of Pt/Pd film by ion sputtering, the transmission efficiency is measured to be around 10^{-5}, which is applicable for near-field spectrum analysis experiment.
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Atomic force microscopy (AFM), a breakthrough measuring method, is one of the most useful and popular tools for measuring the surface characteristics of materials. This technique not only offers the advantage of being virtually nondestructive to the surface of a sample but also is capable of demonstrating spatial variations in the submicron range. Combined with the manufacturing technology of the nanoscale optical fiber probe, called near-field scanning optical microscopy (NSOM), it has also proven to be a powerful tool for near-field optical measurements. The most common configuration used scans a sample located at a distance between 1 and 20 nm right below the optical aperture of the fiber probe, and superior resolution between 10 to 100 nm can be achieved. Straight tapered fiber probes[1] have so far proven favorable for this purpose. As a result, an additional shear force[2,3] or normal force[4] detection unit needs to be implemented to regulate the tip–sample distance. Bent tapered fiber probes[5–8] manufactured by a combination of laser heating/pulling and electric arc bending can be easily placed in an AFM tip holder without any modification of the detection system. Superior image resolution up to 60 nm is within reach with appropriate manipulation of the bent angles. In the application of the NSOM, a resolution of 150 nm is accomplished.

A 125 μm telecommunication single mode fiber was used in this study. During fabrication of the bent tapered fiber probes, we first acquired a number of straight fiber probes of different shape and geometry. The pulling was done by a Sutter Instrument P2000 laser based fiber puller.[9] These probes were subsequently bent by an electric arc heating machine.[10] Two types of straight fiber probe with taper lengths of 1070 and 1700 μm are illustrated in Figs. 1(a) and 1(b), respectively. The tip diameters of both probes were less than 60 nm according to scanning electron microscope measurements. The bent angles of fiber probes depend on the electric arcing time. Figure 1(c) shows a short, thick bent tapered fiber probe with a bend angle of 50°. The diameter at the point of bending was 80 μm and the bent length 600 μm. The bent probe like the one we mentioned whose maximum allowable bend angle was confined within 60°. For a higher bend angle, undesirable swelling could occur at the bending point as a result of excessive heat being generated by a

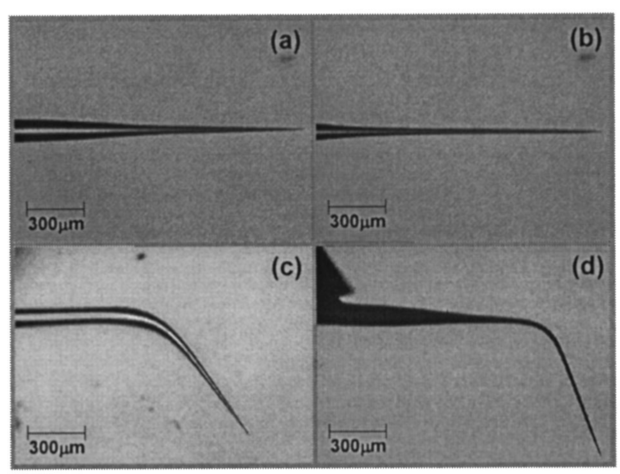

FIG. 1. Photographs of straight fiber probes with taper lengths of (a) 1070 and (b) 1700 μm, and bent fiber probes with bent angles and bent lengths of (c) 50°, 600 μm and (d) 70°, 800 μm, respectively.

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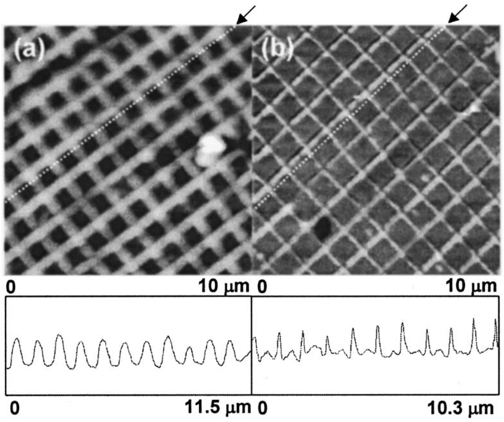

FIG. 2. 10×10 μm^2 tapping mode AFM images on a 1 μm pitch grating acquired by two probes with bent angles of (a) 50° and (b) 70°, respectively. The line plots are topographical variations along the dashed lines indicated by the arrows.

longer electric arcing time. Figure 1(d) shows a long, thin bent tapered fiber probe with a 30 μm diameter at the bending point and bent length of 800 μm. It took only 4 s to achieve a bend angle of 70°. In our experiment, these probes were used in a Nanoscope III Bioscope AFM made by Digital Instruments, Santa Barbara, CA. In Fig. 2, 10×10 μm^2 tapping mode AFM images on a 1 μm pitch grating are shown. Two probes with bend angles of 50° [Fig. 1(c)] and 70° [Fig. 1(d)] were employed for Figs. 2(a) and 2(b), dividually. Topographical variations along the two dashed lines indicated by the arrows are also presented. From Fig. 2, the resolutions measured with the full width at half maximum (FWHM) are found to be around 200 and 60 nm, respectively.

After bending, the probe was coated with a layer of Pt/Pd film around the tip by ion sputtering. A 632.8 nm He–Ne laser with 1 mW output power was fed to a bent tapered fiber probe. The transmitted light of the probe was measured by a 1×1 cm^2 Si photodiode (S100V, UDT Sensors) underneath the tip followed by a current amplifier. And the distance between the tip and photodiode could be controlled at around 20 nm by the feedback system of the AFM. Note that the scan size must be set to zero. Figures 3(a) and 3(b) show the transmission efficiency measured at different sputtering thicknesses of the tip for the probes in Figs. 1(c) and 1(d), respectively. The transmission efficiency of the

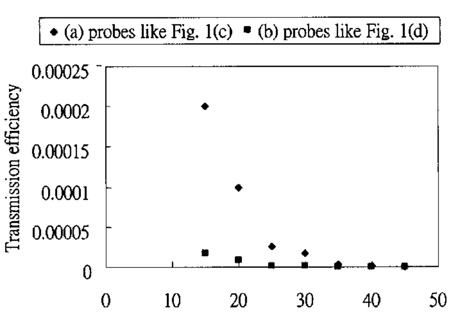

FIG. 3. Relationship of sputtering thickness vs transmission efficiency of scanning probes under different bent angles.

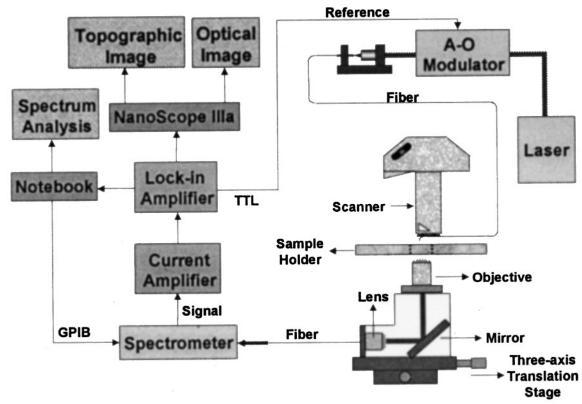

FIG. 4. Schematic diagram of the tapping mode NSOM spectrum system.

probes like those in Fig. 1(c) was better than that of the other type of the probe like that in Fig. 1(d), so we could apply this one to near-field optical measurement. When the sputtering thickness was between 10 and 20 nm, better transmission efficiency was expected because, under such conditions, light was transmitted through the tapered edge around the aperture. As a consequence, the near-field image resolution was restricted to 500 nm. For sputtering thicknesses of about 20–30 nm, the corresponding transmission efficiency was measured as 10^{-5}, and the resolution could be upgraded to 200 nm. It should be noted that, if the sputtering thickness were below 10 nm or above 35 nm, light leakage at the bending point or light obstruction at the pinpoint would occur.

A schematic diagram of the experimental setup is shown as Fig. 4. A probe resembling the one in Fig. 1(c) coated with 25 nm of Pt/Pd film was used in this near-field experiment. The input He–Ne laser light was modulated at 81 kHz by an acousto-optic modulator (N21080 or N23080, NEOS Technologies), and then focused into the fiber coupler by a 20× objective. The transmitted light was collected by a 20× objective, mirror, and lens (350330-B, Thorlabs) underneath the sample into a spectrometer (SpectraPro® 500*i*, Acton Research Corporation) built with a photomultiplier (R928, Hamamatsu, Japan). The signal was processed by a current preamplifier (SR570, Standard Research Systems), lock-in amplifier (SR830, Standard Research Systems) and then recorded by the AFM control unit. The microspectrometer was

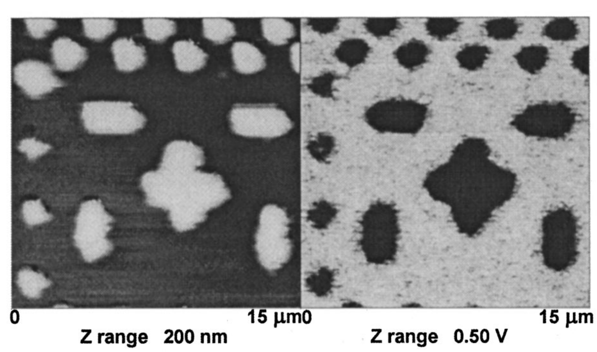

FIG. 5. 15×15 μm^2 tapping mode AFM (left) and transmission mode NSOM (right) images of a special pattern of chromium coating over a photomask obtained simultaneously.

controlled by a general purpose interface bus (GPIB) interface and LabView program. In Fig. 5, simultaneously acquired 15×15 μm^2 images of the AFM and NSOM of a special pattern of chromium coating over a photomask are presented. The wavelength of the spectrometer was set at 632 nm, with a bandwidth of 2 nm. The brightness contrast in the NSOM image signified the distribution of transmission near-field light intensity at this specific wavelength. A near-field signal resolution of around 150 nm was achieved as determined by the 20%–80% intensity distance on the edge. The special pattern in the right-hand image of Fig. 5, picked up by the scanning probe, was almost caused by the near-field effect, because we had adjusted the focus plane of the lens on the sample surface.

In conclusion, we have successfully developed the fabricating technology for bent tapered fiber probes. These bent probes can be easily applied in any dynamic mode AFM and for research in near-field detection. In the future, such a system will be further utilized to conduct studies in near-field fluorescence spectrum analysis. In addition, the spring constant of the bent probes can also be tuned by changing the cantilever length, which is especially useful in investigating the nanomechanical properties of thin films.

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[1] G. A. Valaskovic, M. Holton, and G. H. Morrison, Appl. Opt. **34**, 1215 (1995).
[2] R. L. Williamson and M. J. Miles, J. Vac. Sci. Technol. B **14**, 809 (1996).
[3] K. Karrai and R. D. Grobber, Appl. Phys. Lett. **66**, 1842 (1995).
[4] D. P. Tsai and Y. Y. Lu, Appl. Phys. Lett. **73**, 2724 (1998).
[5] H. Muramatsu, N. Chiba, K. Homma, K. Nakajima, and T. Ataka, Appl. Phys. Lett. **66**, 3245 (1995).
[6] C. E. Talley, G. A. Cooksey, and R. C. Dunn, Appl. Phys. Lett. **69**, 3809 (1996).
[7] D. P. Tsai and W. R. Guo, J. Vac. Sci. Technol. A **15**, 1442 (1997).
[8] R. S. Taylor, K. E. Leopold, M. Wendman, G. Gurley, and V. Elings, Rev. Sci. Instrum. **69**, 2981 (1998).
[9] G. A. Valaskovic, M. Holton, and G. H. Morrison, Appl. Opt. **34**, 1215 (1995).
[10] H.-N. Lin, U. Lewlomphaisarl, S. H. Chen, L. J. Lee, and D. P. Tsai, Rev. Sci. Instrum. **69**, 3843 (1998).