Ultrasonically induced Effects in Electroless Nickel Plating to Fabricate a Near-Field Optical Fiber Probe

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Ultrasonically induced Effects in Electroless Nickel Plating to Fabricate a Near-Field Optical Fiber Probe

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We have studied the submicron size dependence of electroless nickel plating under ultrasonic irradiation with a frequency of 1 MHz to fabricate a near-field apertured probe. Using a new ultrasonic bath with a small water depth of 80 mm, we found that a nickel film with a hollow structure is coated on the flat clad end of a fiber probe. The diameter of the hollow is 12 μm much smaller than the ultrasonic wavelength in water. [DOI: 10.1143/JJAP.47.4317]

KEYWORDS: nano-optics, near field optics, optical fiber, plating, scanning probe microscopy, ultrasonic

Near-field scanning optical microscopy (NSOM) and combined NSOM with shear-force microscopy or atomic force microscopy has been widely used as a powerful tool for nano-optical spectroscopy, optical processing, and polarization imaging.[1)] To obtain highly resolved NSOM images, one has to fabricate a fiber probe with a metal coat and a nanotip because the spatial resolution is mainly determined by the tip and aperture diameters. To realize the mass production of a fiber probe, we proposed a method based on electroless nickel plating in 1995,[2)] and recently, we have succeeded in obtaining a new type of probe having a decreasing thickness profile toward the tip. This decreasing thickness profile shows that the submicron size dependence effect[3–5)] of nickel deposition is induced by ultrasonic irradiation with a frequency of around 1 MHz. However, other ultrasonic effects and related parameters, for example, the water depth of the ultrasonic bath, have not been known yet. We fabricated two ultasonic water baths with different bath depths of 80 and 230 mm, and performed the electroless nickel plating of a tapered fiber probe under 1 MHz ultrasonic irradiation. In this paper, we describe the profile of a nickel film plated on a tapered fiber and its hollow structure [as shown in Fig. 2(b)] generated in the flat clad end of a fiber probe.

The plating method for fabricating a near-field probe consists of etching, surface activation, and plating as shown in the upper part of Fig. 1. Here, δ is the depth of the water bath. First, a GeO_2-doped fiber with a high index difference of 2% is etched by two buffered HF solutions with volume ratios of 40% NH_4F : 50% HF : H_2O = 1.7 : 1 : 1 and 10 : 1 : 1 for a total time of 75 + 60 min at 25 °C. The obtained fiber probe has a conically tapered core protruding from the flat clad end. The cone angle is 20°, and the apex diameter is less than 10 nm. Next, the probe is coated with a thickness of around 4 nm at argon ion atmosphere by a magnetron sputtering unit. Finally, the plating under ultrasonic irradiation is performed for 10 min. The lower figure shows the top view of the ultrasonic transducers with a frequency of 1 MHz. The plating bath is a 100 mL tallbeaker made of pyrex glass. The diameter of the beaker is 50 mm. The round side and bottom have thicknesses of around 2.0 and 1.9 mm, respectively. The ultrasonic energy is confined above the transducers. An ultrasonic water bath with δ = 80 mm is driven by an amplifier (NF HSA4012) and a signal generator (NF WF1944). The signal voltage and amplifier gain are 4.1 V (peak-to-peak) and 20, respectively. Although the amplifier current is around 2.25 A, we could not observe the

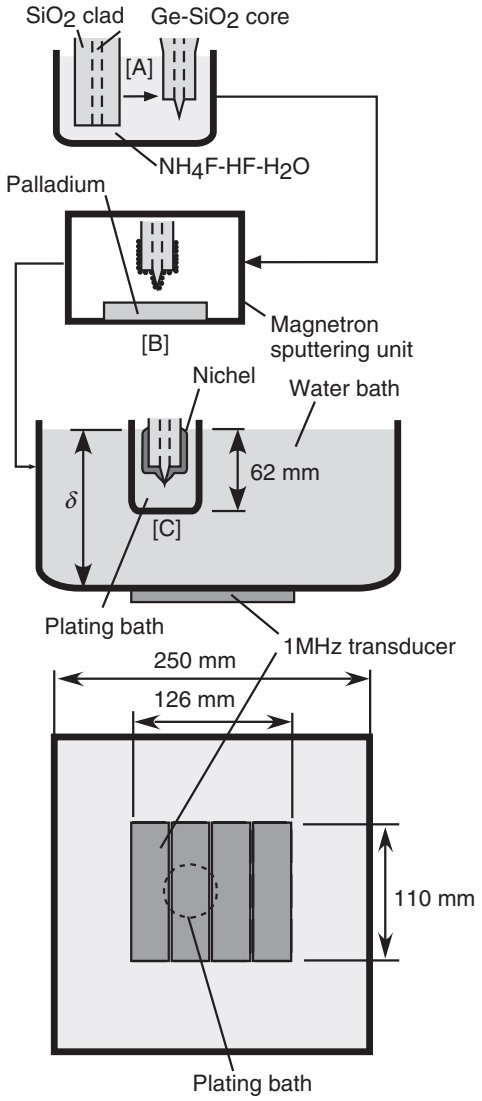

Fig. 1. Schematic image of plating method for fabricating a NSOM probe.

generation of ultrasonic cavitation. The maximum ultrasonic power is roughly estimated to be in the 10 watt order. The plating bath is fixed above the second transducer, and fiber samples are soaked in the plating solution down to a depth of 10 mm at the center of the tallbeaker or second transducer. In another ultrasonic bath with δ = 230 mm (silicon wafer size), electric power can be effectively converted into ultrasonic power by a commercial ultrasonic driver (Honda Electronics W-357HP). The input electric power is fixed to

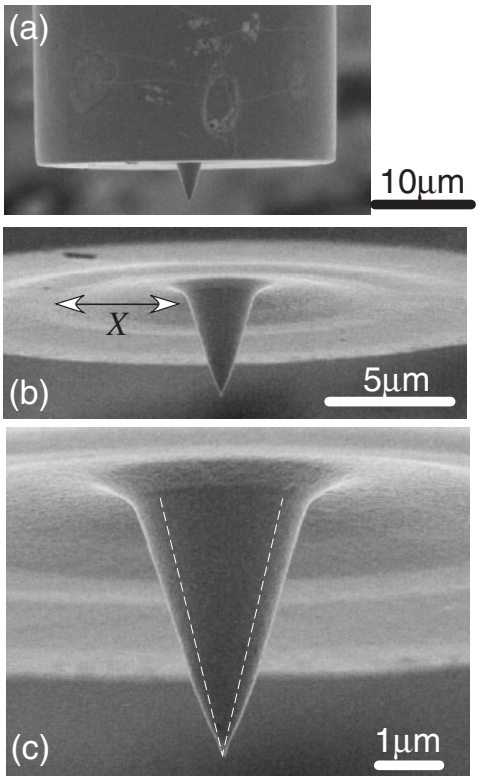

Fig. 2. Scanning electron micrographs of (a) plated probe, (b) flat clad end, and (c) tapered core fabricated at $\delta = 80$ mm.

be 225 W for four transducers. For details of the plating bath, refer to refs. 2 and 3.

The plated probe, as shown in Fig. 2(a), was obtained at $\delta = 80$ mm. Figures 2(b) and 2(c) show the magnified views of the flat clad end and tapered core, respectively. In Fig. 2(c), the cross-sectional profile of the Ge-doped fiber is represented by hatched line. The profile shows that the submicron size dependence is caused by ultrasonic agitation. However, the plated nickel does not take a constant thickness at the entire flat clad end. It has a hollow portion, indicated by an arrow, with a radial width of $X = 5$ μm. The probe could not be used for NSOM owing to optical leakage from the portion. To avoid the generation of such a hollow structure, the water depth of the ultrasonic bath should be increased, though the ultrasonic agitation power is decreased then. The hollow portion size of 12 μm is much smaller than the interference period of an acoustic wave, which is mainly determined by the ultrasonic wavelength in water. Furthermore, the hollow is formed reproducibly, smoothly, and stably. Unfortunately, the formation of a hollow with a diameter of 12 μm cannot be easily explained by the known ultrasonic effects, such as cavitation, rectilinear flow,[6–11] interference by two sources,[12] and the vibration of an optical fiber.[13,14] The formation mechanism has not yet been known. For the amplifier current, increasing to a value more than 2.25 A without overload is difficult. At a value less than 2 A, the submicron size dependence could not be caused.

Figures 3(a) shows the scanning electron microscopy (SEM) photograph of the probe plated at $\delta = 230$ mm. The probe has a flattened clad end and a decreasing thickness profile toward the apex in the tapered portion, as shown in Fig. 3(b). The electroless plating unit with a water depth of $\delta = 230$ mm is found to be much more effective than that with $\delta = 80$ mm in the fabrication of a near-field probe.

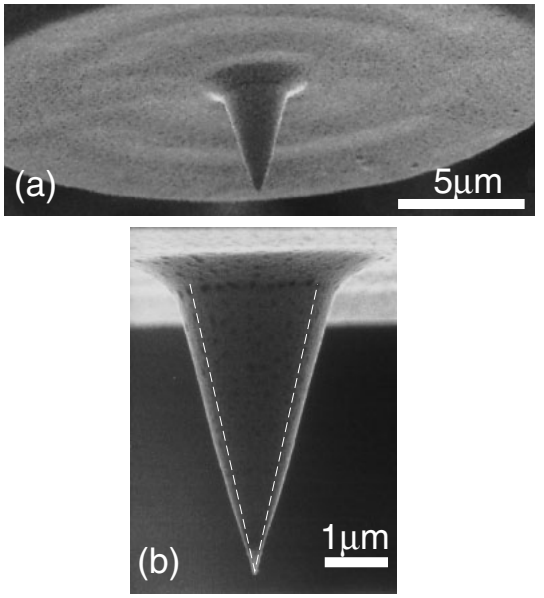

Fig. 3. SEM micrographs of (a) plated probe and (b) tapered core fabricated at $\delta = 230$ mm.

We performed the size dependent nickel plating of a tapered fiber under 1 MHz ultrasonic irradiation using two plating units with different water depths of $\delta = 80$ and 230 mm. The two obtained probes have nickel thickness profiles that gradually decrease from the foot of the tapered core toward the tip. Furthermore, at the smaller depth $\delta = 80$ mm, the plated nickel film on the flat clad end has a hollowed portion with a diameter of 12 μm at the center.

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