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Properties of M-AFM Probe Affected by Nanostructural Metal Coatings

A. Hosoi*, M. Hamada*, A. Fujimoto* and Y. Ju*
* Department of Mechanical Science and Engineering, Nagoya University
Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan

Abstract- **In order to develop a new structure microwave probe, the fabrication of the atomic force microscope (AFM) probe on a GaAs wafer was studied and characteristics of the AFM probe with different nanostructural metal coating were evaluated in order to understand the performance of the probe for the topography of materials and the propagation of microwave signals. The fabricated probe had a tip of 8 μm high and curvature radius approximately 30 nm. The dimensions of the cantilever are 250×30×15 μm. A waveguide was introduced by the sputtering and the electron beam (EB) evaporation technique on the top and bottom surfaces of the GaAs AFM probe with Au or Al film. The open structure of the waveguide at the tip of the probe was introduced by using focused ion beam (FIB) fabrication. AFM topography of a grating sample was measured by using each fabricated probe. It was found that the fabricated probes coated with the Au or Al film have nanometer order resolution. Moreover, using the Au-coating probe formed by the EB evaporation technique, microwave emission was detected successfully at the tip of the probe by approaching an Au film sample.**

I. INTRODUCTION

AFM is a powerful device to obtain information of a material surface in the nanoscale orders. It is used for measuring not only inorganic materials as metals and semiconductors but also organic materials and biomaterials. Also by applying the technology of AFM, the microscopy having new functions is put to practical use, such as a magnetic force microscope (MFM) and a scanning near-field optical microscope (SNOM). Recently, the measurement of electrical properties in local area of materials and devices has become a great need. Although many kinds of scanning probe microscopes have been developed for satisfying the requirement of nanotechnology, a microscope technique which can determine electrical properties in local area is still under developing. On the other hand, microwave microscope has been an interest to many researchers [1-4], due to its potential in the evaluation of electrical properties of materials and devices. The advance of microwave is that the response of materials is directly relative to the electromagnetic properties of materials.

Ju et al. [5-8] have proposed a microwave atomic force microscope (M-AFM) which is expected to be able to realize the evaluation of electrical properties as well as the measurement of topography of materials in nanoscale orders. In the development of M-AFM, it is important to fabricate a M-AFM probe in which microwave signals can propagate well. They fabricated a M-AFM probe having a parallel plate waveguide and succeed to obtain the AFM topography using the fabricated probe [7]. Moreover, they confirmed the emission of the microwave signals from the probe tip by connecting the improved AFM holder to a network analyzer [8]. However, the detection of the microwave signals has not confirmed yet when the improved AFM holder connected to the network analyzer is set up to an AFM main unit. In addition, the influence on the performance of AFM topography with different coating films on the M-AFM probes is not clarified. Also, it is not clear how sensitive the electric characteristics are obtained by introducing different metal films on the probe. To solve these problems, the influence on the mechanical properties and the electric sensitivity of the microwave probe due to the difference of the coating films introduced by different coating methods was investigated in details.

In order to propagate the microwave signal efficiently in the M-AFM probe, metal films were deposited on the top and bottom surfaces of the probe to form a waveguide. The metal film is required to be connected at the end of the beam, and should be absent at the sides of the beam. It is important to form the waveguide with high precision to evaluate the electrical properties of materials because the standoff distance between an AFM probe and a sample is in nanoscale in a practical measurement. However, the microwave probe obtained by the anisotropic etching has a steep slope between the cantilever and the body of the probe, and it is difficult to obtain the uniform film on this part. Frequently the metal film is deposited on the AFM probe by sputtering because the deposition method has an advantage that it is possible to obtain the metal film on an inhomogeneous surface. However, the propagation of microwave signals in the microwave probe may interrupt by the short circuit at the sides of the probe. In this study, the deposition by an EB evaporation technique was used to prevent metal film coating at the sides of the probe. Moreover, Au and Al were used as the coating metal to find better conditions for microwave propagation in the probe.

II. PROBE FABRICATION

A no doped GaAs wafer was used as the substrate of the probe in order to restrain the attenuation of microwave propagating in the probe. Wet etching was used to fabricate the probe because it is possible to obtain the desired structure by causing a side etching under the etching mask in contrast to dry etching. The fabrication method of the probe with GaAs wafer was studied in details by Ju et al. [5, 6] and Iwata et al. [9]. The M-AFM GaAs probe was fabricated by the following process: (i) Forming the

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tip of a probe by wet etching; (ii) Coating metal film on the top surface to form a waveguide; (iii) Forming the cantilever of the probe by wet etching; (iv) Forming the body of the probe by backside etching; (v) Coating metal film on the bottom surface to form a waveguide; (vi) Forming an open structure at the probe tip by FIB fabrication.

In this study, the process for forming the waveguide by coating a metal film on the surfaces of the probe was improved to propagate microwave signals in the probe. The top surface that has a probe tip was deposited with Au or Al by sputtering, respectively, before forming the cantilever of the probe. The bottom surface was deposited with the same metal coated on the top surface by sputtering or EB evaporation technique after forming the body of the probe. Finally, by using FIB fabrication, a slit at the tip of the probe was formed to open the connection of the metal films on the two surfaces of the probe. Consequently, the microwave will be able to propagate along the probe and to be emitted at the tip of the probe.

The fabricated M-AFM probe was observed with scanning electron microscopy (SEM). As shown in Fig. 1, a sharp tip having high aspect ratio of 2.0 was obtained. The tip is the 8 µm high, and the curvature radius of the tip is approximately 30 nm. Figure 2 shows the observation of the cantilever of the probe fabricated by the wet etching. Figure 3 shows the whole appearance of the fabricated probe. As shown in Fig. 4, a microslit was introduced cross the cantilever through the center of the tip by FIB fabrication. The width of the microslit is approximately 100 nm.

III. EXPERIMENTAL RESULTS

A. AFM topography

In order to confirm the resolution of the fabricated M-AFM probe, the AFM topography of a grating sample having 2000 line/mm was measured with the Au-coating and the Al-coating M-AFM probes and a commercial Si AFM probe, respectively. JSPM-5400 AFM was used for measuring of the sample in non-contact mode. The scan area was 2×2 µm and the scan speed was 0.7 µm/sec. The mechanical properties of these AFM

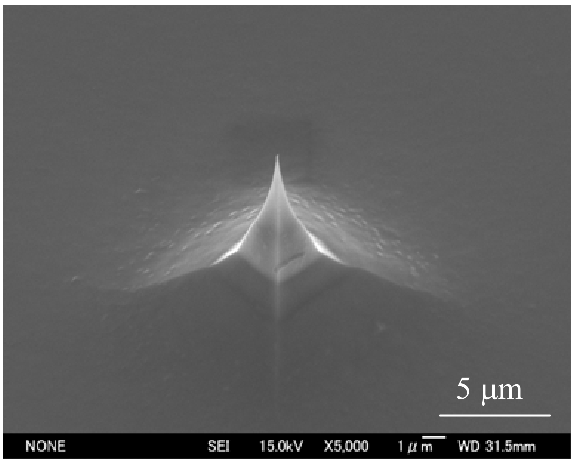


Fig. 1. The tip of the GaAs AFM probe.

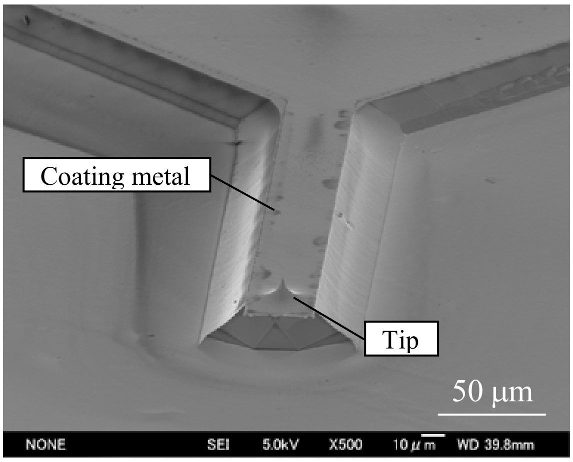


Fig.2. The cantilever of the probe fabricated by the wet etching.

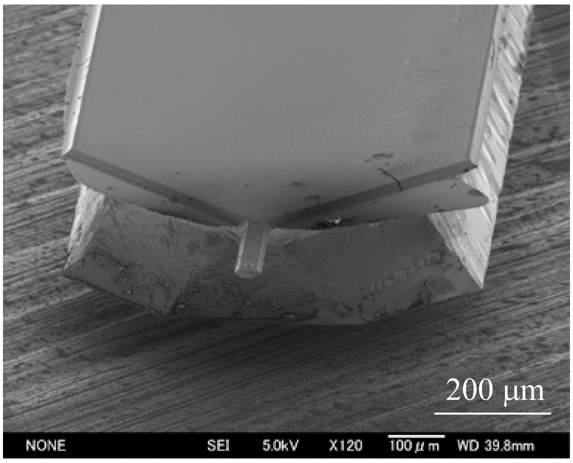


Fig.3. The whole appearance of the fabricated probe.

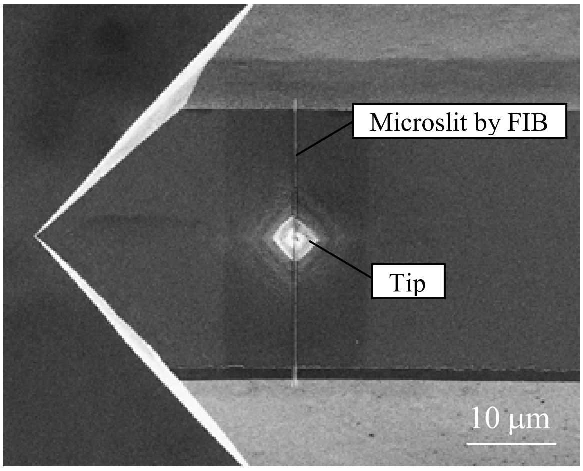


Fig.4. The microslit of the microwave AFM probe introduced by FIB fabrication.

probes were given in Table I. A springconstant was obtained by calculating the cantilever vibration as

$$k = \frac{33m}{144}(2\pi f)^2 . \qquad (1)$$

Where k is the spring constant, m is the mass of a cantilever and f is the resonant frequency. Figures 5 (a)-(c) show the AFM topography of the grating sample obtained with each probe. The pebbly spots in these figures are due to micro-dusts on the sample surface. From the figures, it is observed that the fabricated M-AFM probes have the capability to catch the AFM topography in nanometer orders although the resolution is a little inferior by comparing to the commercial Si AFM probe. The reason why the resolution degraded with the fabricated probes is that the tip of the probes was cut by FIB fabrication.

B. Evaluation of the M-AFM probes with different coating method

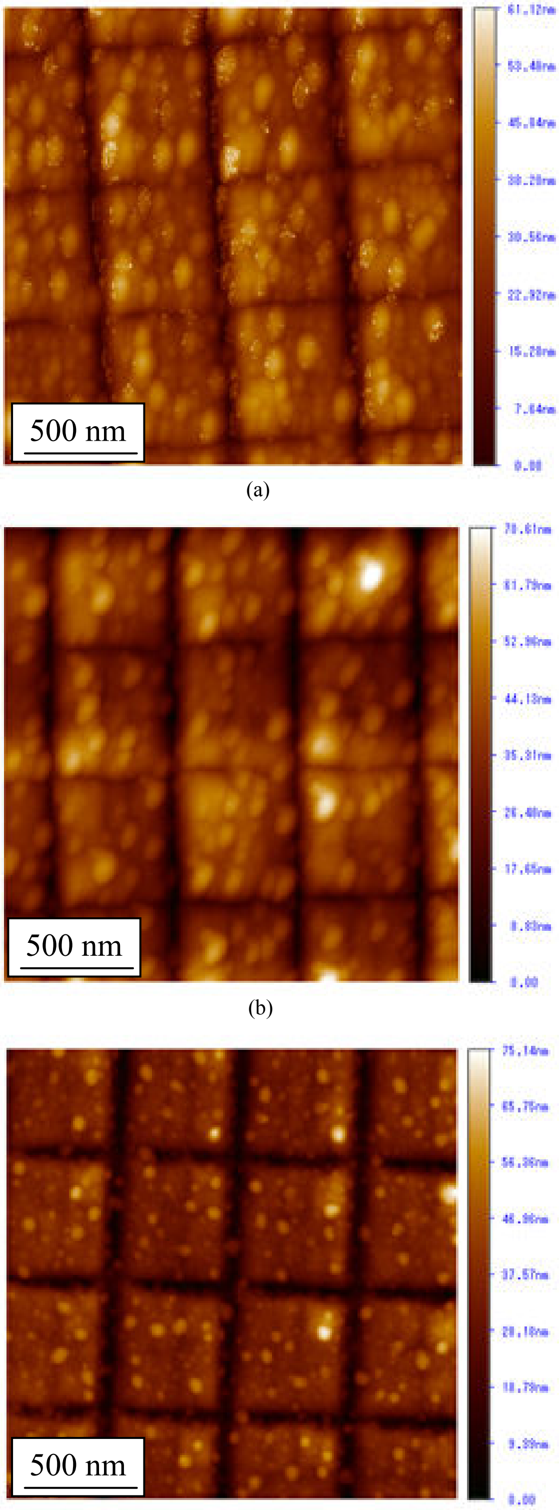
After coating the metal films on the top and bottom surfaces of the probe, the waveguide of the probe should be a short-circuit state because the metal film was also coated on the probe end. To fulfill the function as a parallel plate waveguide, the metal films on the top and bottom surfaces should be an insulated state. To propagate microwave signals along the M-AFM probe and to make it to be emitted from the tip of the probe, an open structure, i.e. an open-circuit state, should be formed at the tip of the probe. It was realized by introducing a microslit with FIB fabrication as shown in Fig. 4. Therefore, the short-circuit or open-circuit state in all M-AFM probes was confirmed by using a digital multimeter. Table II shows the test results before and after FIB fabrication. The short-circuited probe was shown with "S" and the open-circuited probe was shown with "O". From the results, it was found that the EB evaporation technique and Au material are suitable for coating the bottom surface of the probe. It is considered that the Au-coating probe formed by sputtering is in short-circuite state because Au film adhered on the probe sides. On the other hand, the short-circuit state of the Al coating probe was not found because the adherence property of Al for GaAs may be weak by comparing to that of Au.

Table I
Mechanical properties of the fabricated M-AFM probes and the commercial Si AFM probe

	The resonance frequency (kHz)	Q-value	Spring constant (N/m)
Au-coating probe	177	1003	258
Al-coating probe	229	430	376
Commercial Si probe	321	506	115

Table II
The short-circuit or open-circuit state of the probe before and after FIB fabrication at the probe tip

	Before FIB fabrication	After FIB fabrication
Sputtering (Au)	S	S
EB evaporation (Au)	S	O
Sputtering (Al)	O	O
EB evaporation (Al)	O	O



(a)

(b)

(c)

Fig. 5. AFM surface topography of the grating sample having 2000 line/mm: (a) Au-coating M-AFM probe; (b) Al-coating M-AFM probe; (c) commercial Si AFM probe.

C. Propagation and detection of microwave signals

The microwave signal was measured by a network analyzer where the working frequency is 10~70 GHz. A coaxial line was used to connect the M-AFM probe with the network analyzer. In order to realize such connection, the coaxial line having the diameter of 1 mm was fixed on the probe holder which is used to set up an AFM probe for AFM measurement. The outer and inner conductors of the coaxial line are connected to the bottom and top surfaces of the M-AFM probe, respectively. Therefore, microwave transmission line changes form the coaxial line to the parallel plate waveguide in the probe. By using this holder, the M-AFM probe can be set up repeatedly.

Microwave propagation should perform accurately in the fabricated M-AFM probes in order to evaluate electrical property of materials. Using the Au-coating probe and the Al-coating probe formed with EB evaporation technique, microwave propagation was confirmed. The amplitude of the microwave signals was measured with each fabricated M-AFM probe when the probe was approached with non-contact mode to a sample having GaAs substrate and Au-coating film on the surface. To obtain the sensitive response of the microwave signals, the working frequencies of 45.9 GHz and 63.6 GHz were used for the Au-coating probe and Al-coating probe, respectively. The microwave measurement system connected to an AFM is shown in Fig. 6.

Figures 7 and 8 show the results of the amplitude of the reflection coefficient that was measured with Au-coating probe and Al-coating probe, respectively. When the test sample is made to be approached at the tip of the Au-coating probe, as shown in Fig. 7, a change in amplitude is observed clearly. This result indicates that the microwave was emitted at the tip of the probe. On the other hand, the response of microwave signals was not detected with the Al-coating probe. It indicates that the microwave signal was not emitted at the tip of the probe due to in completeness of the coating on the probe surfaces. These results show that the appropriate waveguide of M-AFM probe was formed by coating Au with the EB evaporation technique.

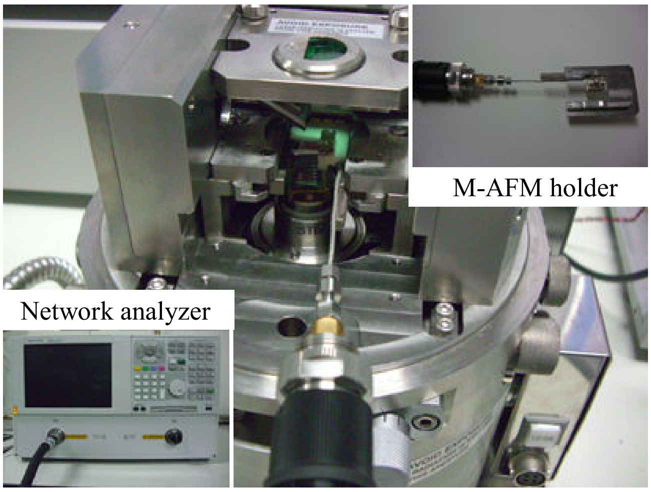


Fig. 6. The microwave measurement system connected to an AFM.

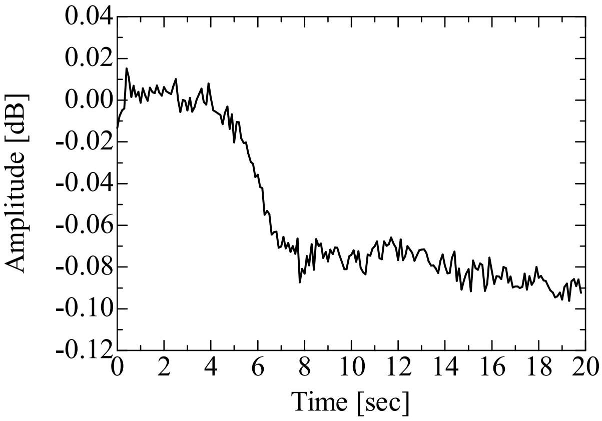


Fig. 7. The amplitude of reflection coefficient measured with the Au-coating M-AFM probe.

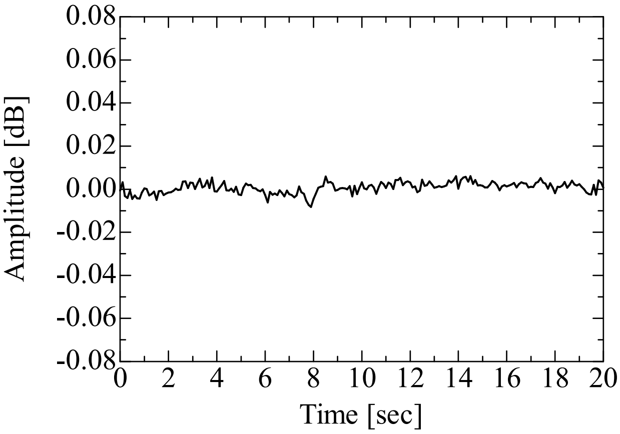


Fig. 8. The amplitude of reflection coefficient measured with the Al-coating M-AFM probe.

IV. CONCLUSION

M-AFM probes were fabricated on the GaAs wafer by using wet etching process. Characteristics of the fabricated M-AFM probe with different nanostructural metal coating were evaluated in order to confirm the performance of the probe for topography of materials and microwave propagation. From the results of AFM measurement, it is observed that both fabricated Au-coating and Al-coating M-AFM probes have the capability to catch the AFM topography in nanometer orders. Moreover, by using Au-coating M-AFM probe formed with the EB evaporation technique, microwave emission was detected at the tip of the probe. These results indicate that the fabricated Au-coating M-AFM probe has the capacity of measuring the electromagnetic properties of materials in nanoscale.

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REFERENCES

[1] Steinhauer, D. E., Vlahacos, C. P. Wellstood, F. C., Anlage, S. M., Canedy, C., Ramesh, R., Stanishevsky, A. and Melngailis, J., "Imaging of microwave permittivity, tenability, and damage recovery in (Ba, Sr) TiO_3 thin films," *Applied Physics Letters*, Vol. 75, No. 20, 1999, pp. 3180-3182.

[2] Duewer, F., Gao, C., Takeuchi, I. and Xiang X.-D., "Tip-sample distance feedback control in a scanning evanescent microwave microscope," *Applied Physics Letters*, Vol. 74, No. 18, 1999, pp. 2696-2698.

[3] Tabib-Azar, M., Akinwande, D., "Real-time imaging of semiconductor space-charge regions using high-spatial resolution evanescent microwave microscope," *Review of Scientific Instruments*, Vol. 71, No. 3, 2000, pp. 1460-1465.

[4] Ju, Y., Saka, M. and Abé, H., "NDI of delamination in IC packages using millimeter-waves," *IEEE Transactions on Instrumentation and Measurement*, Vol. 50, No. 4, 2001, pp. 1019-1023.

[5] Ju, Y., Sato, H., and Soyama, H., "Fabrication of the tip of GaAs microwave probe by wet etching", *Proceeding of interPACK2005* (CD-ROM), 2005, IPACK2005-73140.

[6] Ju, Y., Kobayashi, T., and Soyama, H., "Fabrication of a GaAs microwave probe used for atomic force microscope", *Proceeding of interPACK2007* (CD-ROM), 2007, IPACK2007-33613.

[7] Ju, Y., Kobayashi, T., and Soyama, H., "Development of a nanostructural microwave probe based on GaAs", *Microsystem Technology*, Vol. 14, 2008, pp. 1021-1025.

[8] Ju, Y., Hamada, M., Kobayashi, T. and Soyama, H., "A microwave probe nanostructure for atomic force microscopy", *Microsystem Technology*, Vol. 15, 2009, (in press).

[9] Iwata, N., Wakayama, T., and Yamada, S., "Establishment of basic process to fabricate full GaAs cantilever for scanning probe microscope applications", *Sensors and Actuators A-Physical*, Vol. 111, 2004, pp.26-31.