A SHIELDED CANTILEVER-TIP MICROWAVE PROBE FOR MICRO/NANO SURFACE IMAGING OF CONDUCTIVE PROPERTIES

Y.L. Yang[1], K.J. Lai[2], Q.C. Tang[1], W. Kundhikanjana[2], M. Kelly[2], Z.X. Shen[2] and Xinxin Li[1]
[1]Shanghai Institute of Microsystem and Information Technology, Chinese Academy of Sciences, Shanghai 200050, CHINA; [2]Stanford University, Stanford, CA 94305, USA

ABSTRACT

This paper reports an electromagnetic shielded cantilever-tip microwave-probe for conductive-property imaging at micro/nano surface-area. Equipped with an ultra-sharp tip apex (<50 nm), the probe features small conducting path resistance of R_s<5Ω and conducting path-to ground capacitance of C_{tip}≈1pF. These optimal-designed parameters facilitate satisfactory spatial resolution and microwave-signal intensity during probing test. The fabrication method is low-cost and suitable for batch-fabrication.

INTRODUCTION

Atom force microscopy (AFM) has been extensive used to map the topography of sample. In AFM, a nanometer-scale probe tip is equipped on a microcantilever. The tip is dragged or tapped along a sample surface and deflection of the cantilever is measured. Due to the simple tip structure, only topography property of sample can be tested by AFM. In order to test the conductive-property, microwave impedance microscopy (MIM) has been developed based on AFM technology.

Scanning microwave impedance microscopy is capable of mapping out the local dielectric and conductivity information of thin-film materials [1]. Fig. 1(a) is the schematic of the MIM system setup and Fig. 1(b) illustrate the configuration of the microwave probe. A metal tip is integrated on a microcantilever. By applying microwave signal on the metal probe-tip, the microwave electronics detect the real and imaginary components of the effective tip-to-sample impedance and output as MIM-R and MIM-C signals [2].

Compared to AFM probe, which has simple structure and can be easily fabricated, the microwave probe structure is complicated:

1. The probe tip should be metal and the metal tip should be connected to the wire bond pad to apply microwave signal;
2. The probe tip apex should be sharp enough to ensure a fine spatial resolution, especially for nano materials;
3. A shielded structure is need to make sure that only the probe tip interacts with the sample to depress noise;
4. The conducting path resistance and conduction path-to-ground capacitance should be small enough to get strong microwave signals;

Due to the complex in microwave probe structure, the fabrication of microwave probe is difficult. The most common design of the near-field microwave probe is an etched metal tip, which limits the spatial resolution to be several micrometers [3]. There is another approach to fabricate sharper microwave probe tip by focused-ion beam (FIB) [2]. In this method, silicon nitride microcantilever is fabricated with shield metal traces and then Pt tip is deposited on the cantilever by FIB. Although the FIB tips diameter can reach 200 nm, it still beyond the demand of nano science and nano materials. Furthermore, the process of fabricating FIB deposited tip is expensive and time consuming. This type of probe tip cannot be batch fabricated.

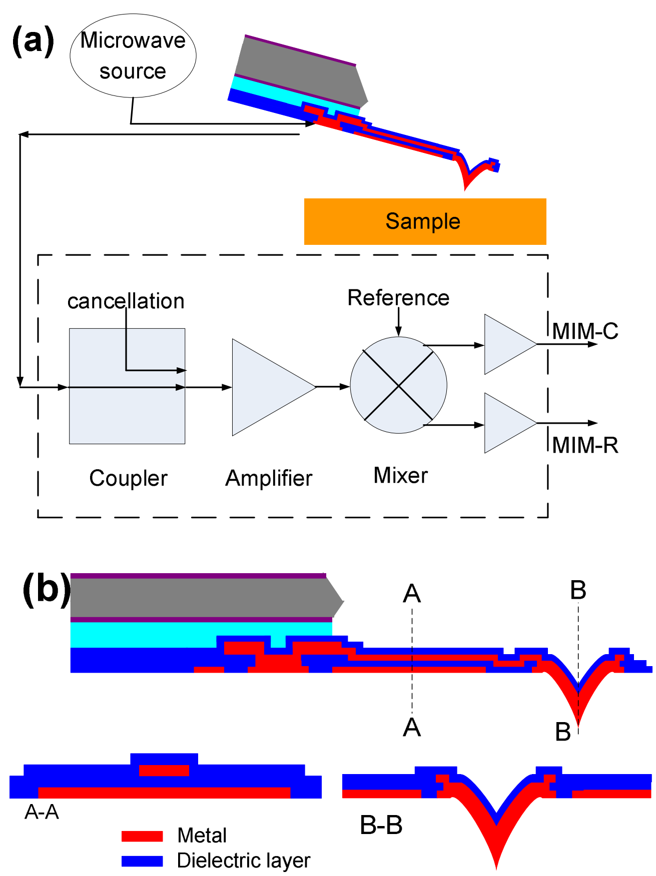


Figure 1: (a) Schematic of the MIM system setup. (b) Schematic of the microwave probe.

To solve there problems, we designed and fabricated a new shielded cantilever-tip microwave probe. Nano-scaled metal tip is integrated on the cantilever. The fabricated probe features small conducting path resistance and conducting path-to ground capacitance. The AFM and MIM testing results show that the tip has fine spatial resolution and strong microwave-signal intensity. The novel process techniques are low-cost and suitable for batch-fabrication.

FABRICATION

Different form conventionally etched tip [4], the metal tip in our design is fabricated by depositing metal into a pre-fabricated tip mold. The tip mold is etched by KOH etching and then sharpened by low temperature thermal oxidation.

Metal layers are deposited and pattern to form the shield metal and conducting path. The SiN layers are deposited and patterned to insulate the conducting path and shield metal and form the main body of the cantilever.

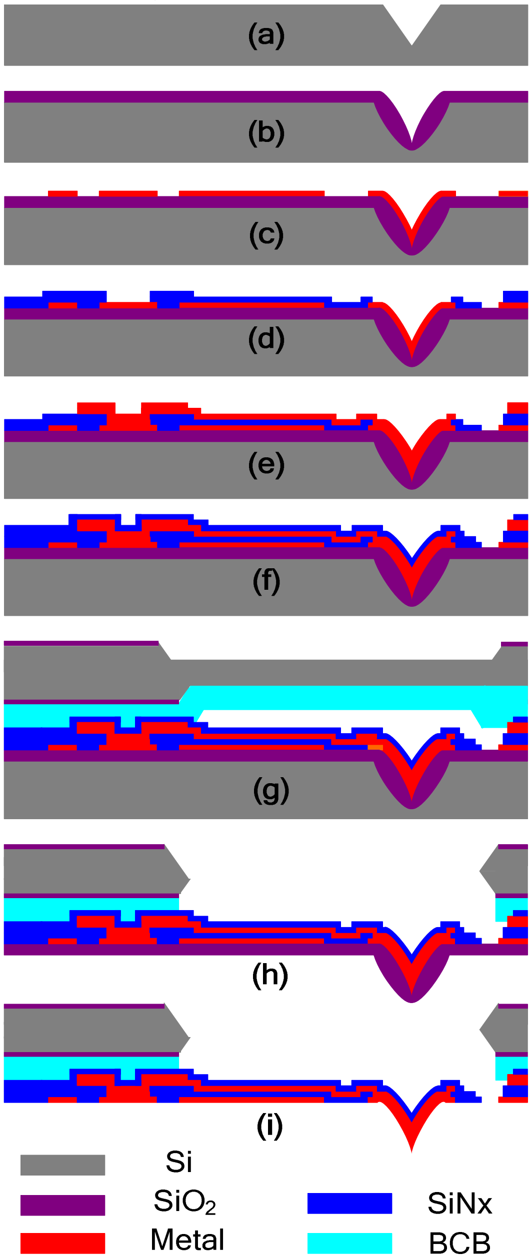


Figure 2: Process flow: (a) KOH etching. (b)Thermal oxidation to sharpen the pit. (c)Deposit and pattern shield metal. (d)Cover the shield metal with top PECVD SiN. (e) Fabricate the metal conducting path. (f) Deposit top PECVD SiN. (g)Bonding. (h) TMAH etching removes the silicon. (i) Release the cantilever.

Fig. 2 shows the fabrication steps in (100) silicon wafers.

(a): By KOH etching, a pyramidal pit is formed as initial tip mold.

(b): 1um-thick SiO_2-film is thermally grown at 950 °C. The oxide thickness at the tip-apex location is thinner than that at other flat regions due to the concentrated compressive-stress, thereby, sharpening the tip-apex.

(c): 500 nm TiW/Au/TiW composite-layers is deposited and patterned to form the microwave-shielding metal-layer. Another metal pattern is independently located in the pit to form the metal-tip.

(d): 800 nm PECVD SiN is deposited and patterned to shape the cantilever and cover the shield-metal. The SiN at the tip si removed to expose the metal-tip.

(e): 900nm TiW/Au/TiW metal conductive path connects the tip and the bonding-pad at cantilever root.

(f) : The cantilever is protected by PECVD SiN for insulation.

(g): The device wafer is bonded with a pre-etched handle wafer.

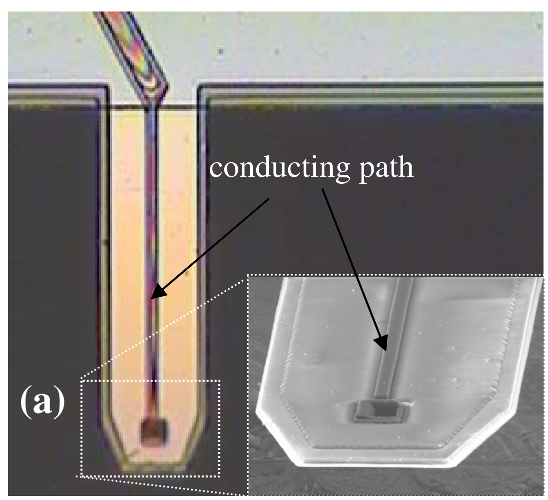
(h): The bonded structure is etched from the both sides in aqueous TMAH until all the silicon surrounding the cantilever is removed to expose the cantilever structure.

(i): With the cantilever front-side protected by photoresist, the cantilever-tip is released from backside by buffered-HF.

It is pointed out that the fabrication doesn't contain expensive and time-consuming one-tip by one-tip trimming process and is suitable for batch-production.

FABRICATED MICROWAVE PROBE

The fabricated probes are illustrated in Fig. 3. In the top view of the cantilever probe [Fig. 3(a)], the metal conducting path connects the metal tip and wire bonding pad. In the bottom view of the cantilever, metal tip is integrated on the cantilever free end with shield metal around. Fig 3(c) gives the close-up view of the metal tip. The length of the pyramidal tip is 7um and the height of the tip is 5um. The tip has ultra-sharp apex with diameter less than 50nm.



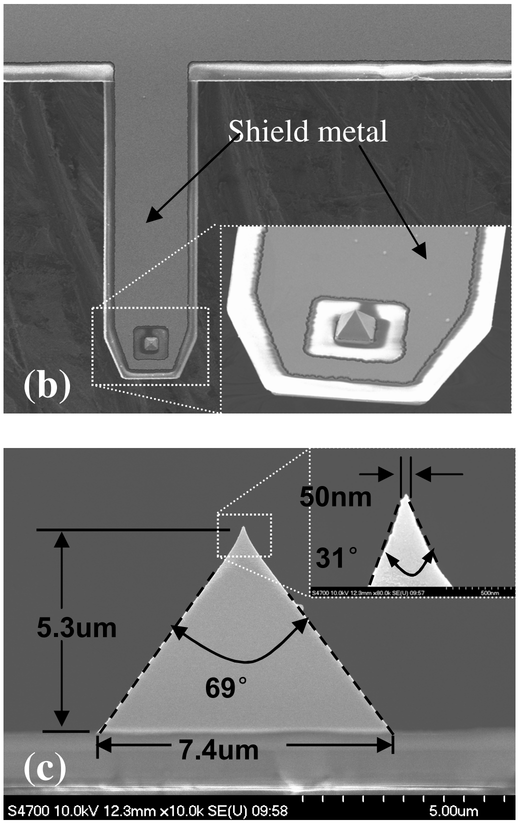


Figure 3: SEM images of the fabricated probes. (a) Top view. (b) Bottom-side view. (c) Close-up view of the sharp metal tip apex. The diameter of the tip apex is smaller than 50nm

TESTING RESULTS

The spring-constant of the cantilever is tested as 0.3 N/m which show good mechanical properties. The series resistance of the metal conduction path is tested as $R_s<5\Omega$ and the conducting path-to-ground capacitance is $C_{tip}\approx 1pF$.

To verify the mechanical and electronically function of the tip, we scanned the standard samples with our fabricated probes and the tested results are shown in Fig. 4. For sample #1 with trenches on SiO_2, the AFM image shows the topography of the sample. The small MIM-C signal reflects the change of capacitance between tip and Si substrate. The MIM-R signal shows that the sample is insulate. For light implanted sample #2, the AMF image show the sample surface is flat and MIM signals give the dielectric properties of the sample. For heavy implanted sample #3, the MIM signal is stronger compare to light implanted sample. The AMF image show that heavy implantation change the topography of the silicon surface. These testing results prove that the probe have good mechanical and electrical performance.

To further test the performance of new batch-fabricated probe, thin grapheme pieces are scanned with our tip and previously FIB fabricated tip and the tested results are shown in Fig. 5. Compared to the images scanned by FIB tip, it is obviously that the new probes in this paper exhibit both finer AFM and MIM images. In the images scanned by our tip, the single-layer and double-layer grapheme location can be clearly identified. The response to step-structure is sharper and the signal-resolution is higher.

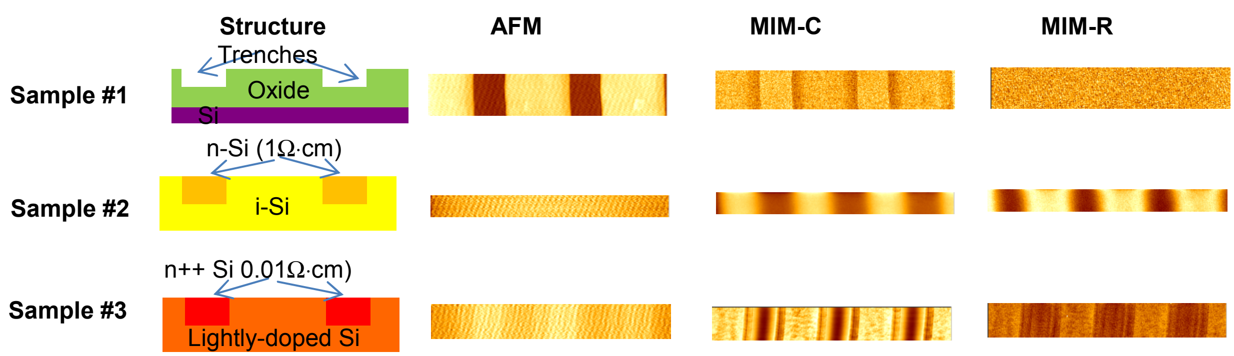


Figure 4: Testing results of localized conductive properties by using the fabricated probes. The surface mechanical functions are verified by AFM topography and electrical functions are identified by MIM scanning signal.

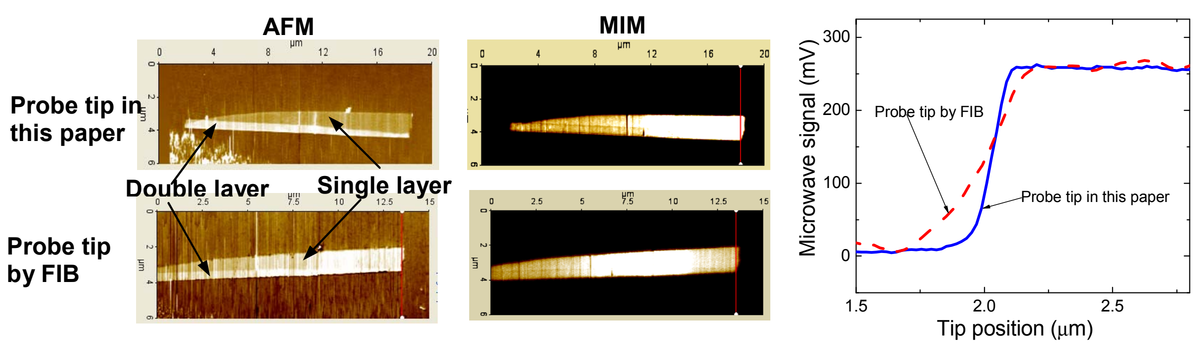


Figure 5: Testing results for thin grapheme pieces by the new batch-fabricated probe compared with the results by previous FIB one-by-one trimmed probe.

CONCLUSION

Electromagnetic shielded cantilever-tip microwave-probes have been design and fabricated. The probe has ultra-sharp metal tip apex with its diameter less than 50 nm. The fabricated probe features small conducting path resistance of $R_s<5\Omega$ and conducting path-to ground capacitance of $C_{tip}\approx 1pF$. The AFM and MIM testing results show that the tip has fine spatial resolution and strong microwave-signal intensity. The fabrication doesn't contain expensive and time-consuming process and is suitable for batch-production.

ACKNOWLEDGMENT

This research is supported by NSFC Project (60725414, 91023046), Chinese 973 Program (2011CB309503) and Korean WCU project (R32-2009-000-20087-0).

REFERENCES

[1] K. Lai, M. Nakamura, W. Kundhikanjana, M. Kawasaki, Y. Tokura, M.A. Kelly, Z.-X. Shen, "Mesoscopic Percolating Resistance Network in a Strained Manganite Thin Film", *Science*, vol. 329, pp. 190-193, 2010.

[2] K. Lai, H. Peng, W. Kundhikanjana, D. T. Schoen, C. Xie, S. Meister, Y. Cui, M. A. Kelly, Z.-X. Shen, "Nanoscale Electronic Inhomogeneity in In_2Se_3 Nanoribbons Revealed by Microwave Impedance Microscopy", *Nano Lett*., vol. 9, pp. 1265-1269, 2009.

[3] T. Wei, X.-D, Xiang, W. G. Wallace – Freedman, P. G. Schultz, "Scanning tip microwave near-field microscope" *Appl. Phys. Lett.*, vol. 68, pp. 3506–3508, 1996.

[4] J. Huang, Xinxin Li, H. Bao, G. Zuo, Y. Wang, F. Feng, Z, Yu, X. Ge, "AFM probes fabricated with masked-maskless combined anisotropic etching and p^+ surface doping", *J. Micromech. Microeng.*, vol. 16, pp. 198, 2006.