Functional Nanowire Microscopy Tip

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ABSTRACT

The practical application of nanostructure was achieved to adopt an electrical-conductive nanowire (NW) as a microscopy tip. The nanowire-sitting structure provided excellent topographic images and electrical information from a nanoscale object. Dielectrophoretic method was applied to align the nickel silicide (NiSi) NW on a Si cantilever. The NiSi NW containing solution was firstly prepared and dropped in the electric field applying space between a Si cantilever and a metal coated-Si substrate. This bottom-up assembly using a nanostructure may provide a promising route of assembling the nanostructure-embedding system.

Keywords: Microscopy tip, Nickel silicide, Nanowire, Bottom-up assembly, nanostructure-embedding system

1 INTRODUCTION

Due to advantages of the nanoscale materials, intensive efforts have been fulfilled to achieve nanomaterial-assisting applications, such as nanoscale interconnects[1-3], transistors [4], or filed emitters [5].

Nanotechnology has progressed in some areas and provide a large-scale application of nanomaterial in a circuit line patterning and a transparent heater owing to the excellent electric or thermal conductivity of carbon nanotubes [6,7].

Although the large-scale approach of using nanostructure materials is quite accessible to illustrate the possibility in practical utilizations, the nanoscale manufacturing still has a difficulty in the architecture of nanomaterials. It is an inevitable step to position a nanostructure on the demanded spots for practical utilizations.

The bottom-up approach is an architecture of nanostructure by positioning of the nanoscale material on a designated spot.

Dielectrophoresis (DEP) is the post-assembly approach, which is one of the promising ways to align the nanomaterials with electric field modulation to locate the nanoscale object at a designated spot. The post-assembly may release the burden or limit of the self-assembly approach.

In the conventional nanoscale electric force microscopy (EFM) fabrication method, it requires multiple processing steps including nanoscale machining technique by focused ion beam (FIB). The first step is a coating of chromium (Cr) and gold (Au) on a V-shaped silicon nitride cantilever, which prevents the charging problem during the machining. The sketch step is following with an aperture formation and platinum (Pt) deposition to enable an electrical connection between the pyramid bottom and the cantilever. Then, Pt deposition was performed to make a nanoelectrode at a tip apex [8].

We herein present the fabrication of a functional nanowire microscopy tip, which reads topographic and electric information from a nanoscale object. It also discusses the growth of electric excellent single crystalline nickel silicide (NiSi) nanowire (NW) and the positioning of NiSi NW on a Si cantilever by DEP method.

2 EXPERIMENTAL DETAILS

2.1 Growth of crystalline NiSi NW

Ni as a catalyst was thermally evaporated onto a 500 nm-SiO_2 coated Si substrate at a high vacuum level of 5×10^{-7} Torr before loading in PECVD (plasma-enhanced chemical vapor deposition) system (SNTEK, Korea). Silane (SiH_4,10% balanced in H_2) as a Si source was supplied to react the Ni. The gas flow rate was fixed at 50 sccm (standard cubic centimeter per minute) for 10 min.

The grown NiSi NW was investigated by field emission transmission electron microscope (FETEM, FEI Tecnai F30 Super-Twin) and revealed that the NiSi NW has a single crystalline and Ni_3Si_2 orthorhombic structure as shown in Figure 1.

2.2 Positioning of NiSi NW by DEP

The DEP is a promising approach to align nanostructures at a designated position with high reliability and accessibility. To perform the DEP-assisted nanowire alignment, the NW containing solution was prepared by ultrasonic vibrating from a NW grown Si substrate. The solution was dropped in the ac electric applying system. This process was performed in the assembly of the NiSi NW EFM tip. The DEP factor modulation was achieved by varying the frequency which controls the number of nanowires to be attached on a designated spot.

3 RESULTS ANS DISCUSSION

DEP process was performed to assign a NiSi NW onto a Pt-coated Si cantilever (AppNano ANSCM-PC), which has a resonant frequency of 160 kHz and a spring constant of 5 N/m. The NiSi NW containing solution of 0.5 μl was dropped in a space of the Pt-coated Si cantilever and a 50 nm thick Al-coated Si substrate as shown in Figure 2 (a). An electric field of 2 Vp-p at 5 MHz was applied and positioned a single NiSi NW onto the Si cantilever. The space distance between two metal structures (Pt-coated Si cantilever and Al-coated Si substrate) was set as 1 μm. The NW sitting on a Si cantilever is shown in Figure 2(b).

The fabricated NiSi NW mounting EFM probe was used to obtain polarities of 70 nm thick-PZT film, which has gained interests in memory application [9]. The PZT film surface was polarized by a conventional conductive PtIr5 tip (Nanosensors^{TM} EFM) to have different three patterns. The polarized pattern was firstly formed by a negative 10 V for 8 μm × 8 μm area followed by a positive input for 5 μm × 5 μm area inside of the previously patterned region. The final pattern was polarized by a negative voltage applying for a 2.5 μm × 2.5 μm square of 45-degree slanting as shown in Figure 3(a). The NiSi NW EFM probe was operated by a non-contact mode and EFM images were obtained by a scanning probe microscope (PSIA XE-100). The polarity pattern images obtained by the NiSi NW tip are shown in Figure 3(b). A bright square image was formed by the positive charging region and dark regions were presented by the negative charging regions. These results present that the NiSi NW EFM probe works properly to acquire electric signals.

A schematic of the electric circuit to measure the NiSi NW interconnection was shown in Figure 4 (a). A voltage of 0.5 V was applied in both Pt metal electrodes. Due to the single crystalline structure and good electric conductive property of the NiSi NW, the potential drop across the NW length should be uniform. The voltage of NiSi NW connection was obtained from the NiSi NW EFM tip and the equivalent circuit is given in Figure 4(b).

The potential drop is increased by being located EFM tip far from one voltage source but it closes to the other voltage source at the same time, which means that the voltage reading from the EFM is close to the input voltage if the voltage drop is uniform through the NiSi NW connection. Figure 4(c) is a voltage profile by scanning the NiSi NW FEM tip on through the NiSi NW connection. Figure 4(d) is a plot of voltage readings. It shows the uniform voltage distribution at each point with a little standard deviation value of 0.0143 V. The potential distribution in the NiSi NW interconnect was achieved from the NiSi NW EFM tip showing equipotential distribution through the NiSi NW interconnect and negligible potential drop through the NiSi NW interconnect.

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4 CONCLUSION

The practical use of the nanowire was realized by adopting the electric conducting NiSi NW as a tip to acquire topographic images and electric signals by through a conventional PZT film and even a nanoscale interconnection. The functional microscopy tip was fabricated by electric conductive NiSi NW and gave electric signals from the NiSi NW interconnection. The post-assembly approach of DEP method provides degree of freedom to fabricate an EFM tip and nanoscale interconnects.

Electrical information was obtained by the NiSi EFM tip through the NiSi NW interconnection. It reveals that the potential distribution of NiSi NW interconnection is uniform indicating the high potential of NW interconnection and functional NW utilization as well.

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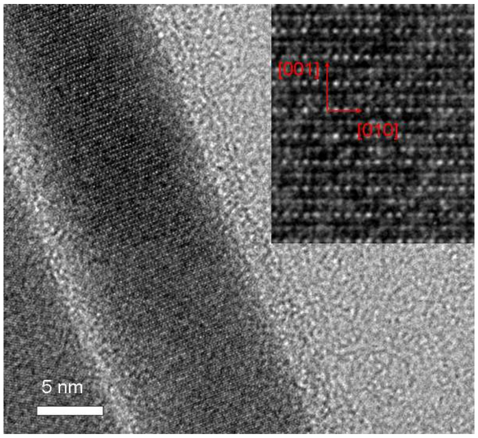
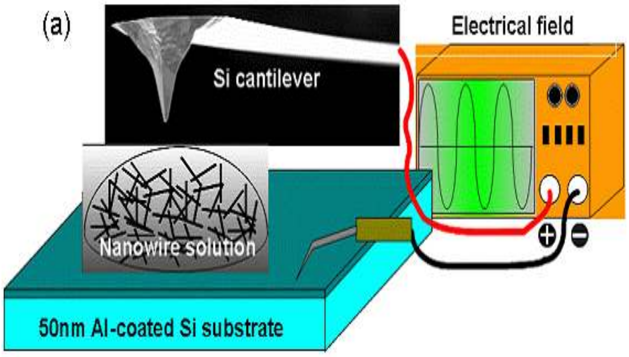


Figure. 1. High resolution TEM micrograph of NiSi nanowire with diameter of 13 nm. The inset shows that the NiSi nanowire has an orthorhombic structure with Ni_3Si_2 composition.



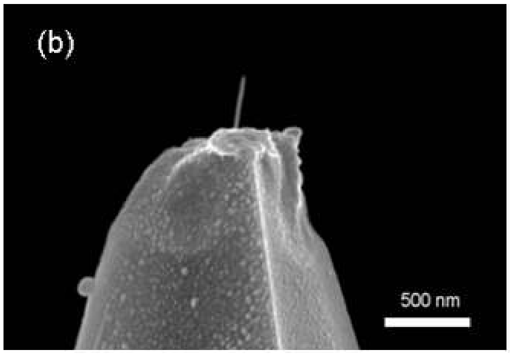


Figure 2. NiSi NW EFM tip. (a) A schematic of DEP-assisted NW tip fabrication. (b) The NiSi NW sitting on a Si cantilever

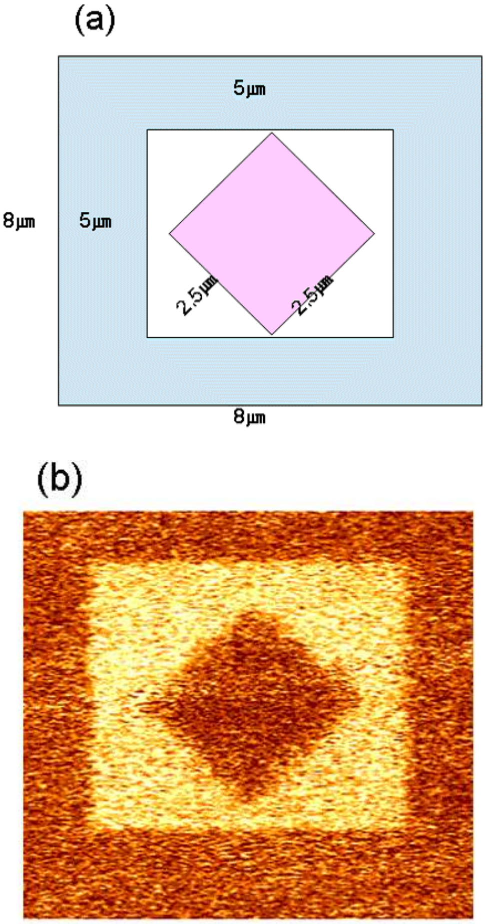


Figure 3. NiSi NW EFM tip probing images of the PZT film (a) A topography. (b) An EFM image.

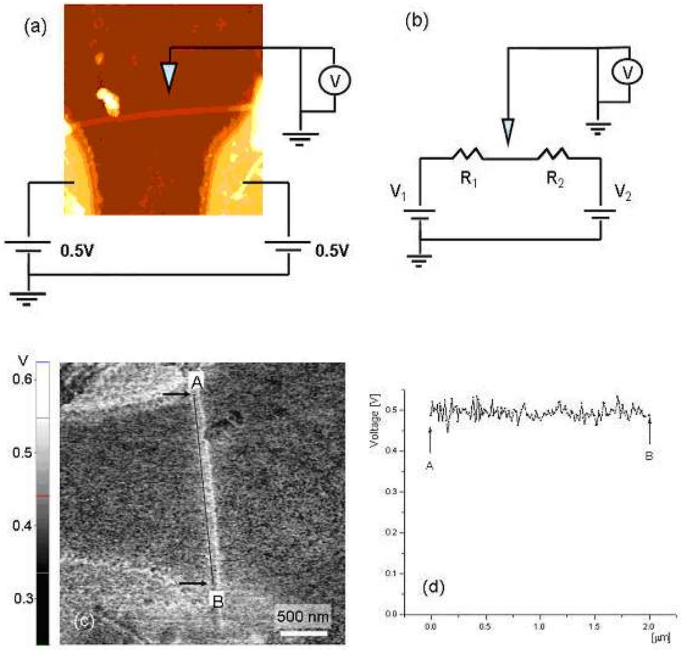


Figure 4. (a) A schematic of polarity patterning on a PZT film. (b) Polarity readings by the NiSi EFM tip from the patterned PZT film.

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