Integration Process of Carbon Nanotube Piezoresistive Elements into Microsensors

Naoki Oda[1], Takahito Ono[1], Masayoshi Esashi[2]
[1]Graduate School of Engineering, Tohoku University, 6-6-01 Aza-Aoba, Aramaki, Aobaku, Sendai 980-8579, Japan
[2]The World Premier International Research Center Initiative for Atom Molecule Materials, Tohoku University, , 6-6-01 Aza-Aoba, Aramaki, Aobaku, Sendai 980-8579, Japan
ono@nme.mech.tohoku.ac.jp

Carbon nanotubes (CNTs) are very attractive materials owing to its large gage factor as a piezoresistive element. Thus, CNTs have high potential abilities as a strain gage for various sensor applications. However, batch-fabrication process for integrating CNTs is generally difficult because CNTs are flexible and easily deformed during microfabrication process, in addition adhesion force to substrate is very weak. In this paper, we report the batch-fabrication process of integration of carbon nanotubes piezoresistive elements into microstructures based on chemical vapour deposition of carbon nanotubes, and deposition of SiO_2 onto the CNTs.

It has been reported that semiconductive CNTs exhibit a gage factor of over 1000 [1,2], also metallic CNTs exhibits a gage factor of ~200 [3]. In generally, a gage factor of silicon piezsoresistor is ~100, depending on its dopant concentration, thus, CNTs are very useful for gaining the sensitivity of piezoresistive microsensors.

In order to demonstrate the integration of CNTs into microstructure, a cantilevered structure shown in Fig. 1 is fabricated in this research. At the support part of the freely-suspended SiO_2 cantilever, the strain gage of CNTs, which are buried into SiO_2, is formed. This CNTs buried into SiO_2 are regarded as a composite of CNTs and SiO_2 (CNTs-SiO_2), where the CNTs are directed into the longitudinal direction of the cantilever. The CNTs-SiO_2 resistive elements as a strain gage are electrically connected by Cr-Au wires. The bending of the cantilevered structure will produce the strain in the longitudinal direction of CNTs and change their resistance.

Figure 2 shows the schematic of the fabrication process. Starting material is Si wafer, and SiO_2 is deposited on the surface by plasma enhanced chemical vapour deposition (PECVD) using TEOS ($Si(OC_2H_5)_4$) as a gas source. CNTs are grown from a 1 nm-thick Fe pattern using PECVD (shown in upper figure of Fig. 3). We employed a CNTs alignment technique in order to form aligned CNTs as reported in Ref. [3]. In this method, the substrate with CNTs is dipped into ethanol and taken out form the solution. The CNTs can be well aligned into in-plane direction on the surface as shown in the lower figure of Fig. 3. Next, the CNTs are buried into SiO_2 using ozone-TEOS CVD, and this process can form the CNTs-SiO_2 composite as shown in Fig. 4. After photolithography, the CNTs-SiO_2 are patterned by reactive ion etching (RIE) using a mixture of SF_6 and Xe gases. Figure 5 shows the SEM image after the patterning. Next, Cr-Au pattern are formed for making electrical wires and pads. Then, cantilever structures are formed by patterning the SiO_2 using RIE. Finally, the cantilevers with a total thickness of 4 μm are released by etching the Si substrate from the backside using resist as a mask.

Figure 6 shows SEM images of the completed microstructures. On the surface of the support part, piezoresistors of CNTs-SiO_2 is formed. We believe that this integration process of the piezoresistive elements of CNTs can applied to various sensor applications.

References:

[1] R. J. Grow et al., Appl. Phys. Lett., **86** (2005) 093104.
[2] C. Stampher et al., Nano Lett., **6** (2006) 1449.
[3] C. Stampfer et al., Nano Lett., **6** (2006) 233.
[4] Y. Hayamizu et al., Nature Nanotechnology, **3** (2008) 289.

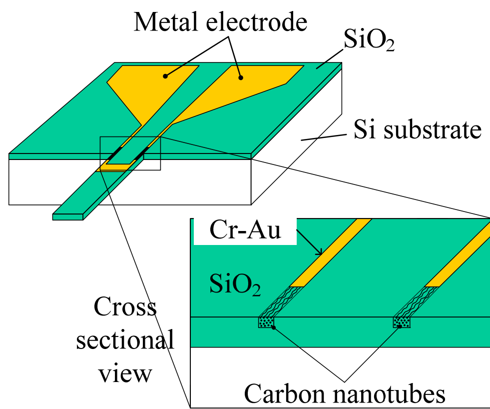

Figure 1. Schematic of fabricated microstructure with carbon nantube piezoresisitve elements as a strain gage.

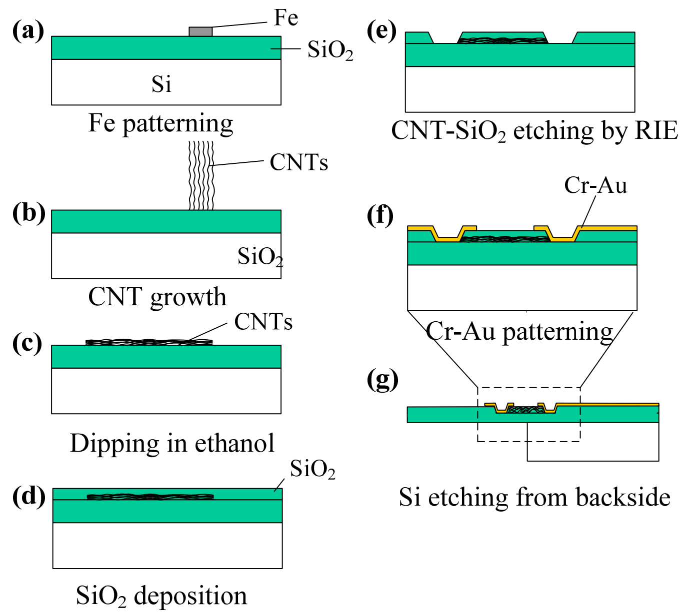

Figure 2. Microfabrication process of the integration of carbon nantube piezoresisitve elements.

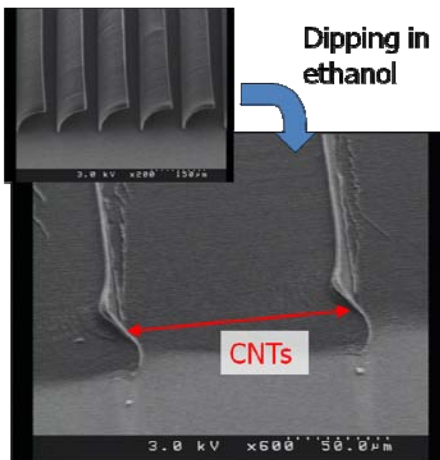

Figure 3. SEM image carbon nanotubes aligned on the SiO$_2$ surface.

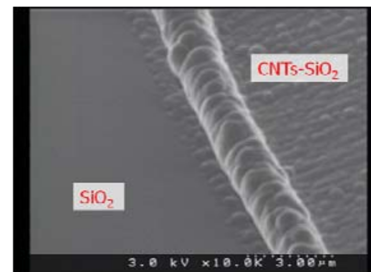

Figure 4. SEM image of CNTs-SiO$_2$. The CNTs aligned on the SiO$_2$ surface are buried into SiO$_2$ using ozone-TEOS CVD.

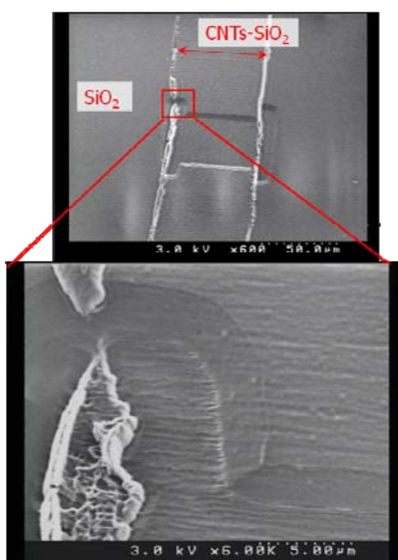

Figure 5. SEM image of the patterned CNTs-SiO$_2$ using reactive ion etching.

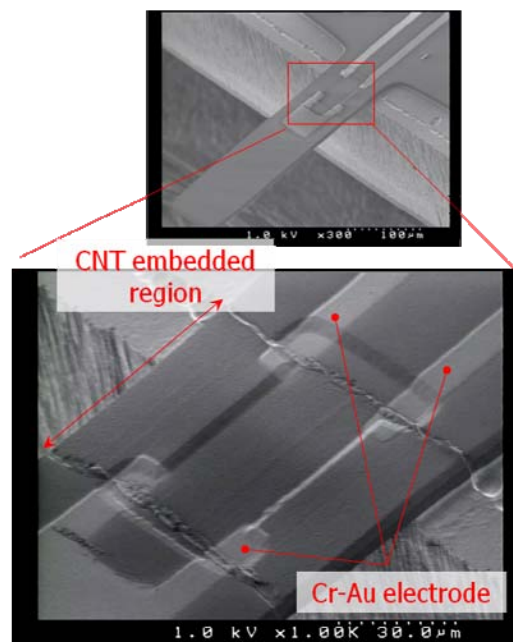

Figure 6. SEM image of completed microcantilever. At the support part, carbon nanotube piezoresistors are formed, and the piezoresistors are electrically connected via Cr-Au electrical wires.