CNTs-Insulator-Semiconductor System for Chemical and Biological Sensor Applications

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ABSTRACT

A new Electrolyte-CNTs-Insulator-Semiconductor capacitor is proposed to achieve the compatibility with the CMOS technology. Wafer bonding technique is adopted to attach the AAO template with CNTs to semiconductor surface (the CNTs array grown in AAO template to SiO_2/Si wafer). The CNTs are expected to enhance the sensitivity of the conventional EIS system and to offer the many chemical or biological active sites. The platinum reference electrode and 3.3M KCl solution are proved to act well as the functional liquid gate. From the capacitance-voltage measurements of the fabricated samples, the modulation of the semiconductor surface has been found to show the feasibility of the new structures for use in the high sensitive chemical and biological sensors.

Keywords: carbon nanotubes, biological and chemical sensor, CMOS technology, advanced EIS structure

1 INTRODUCTION

Carbon nanotubes have been a topic of many recent researches for novel sensors in the chemical or biological application. [1]- [4] Many kinds of carbon nanotubes based structures have been proposed as potential sensors. In most cases, the carbon nanotubes are used as electrodes for detecting molecules in solutions [4] In the former case, the higher sensitivity of vertically aligned carbon nanotube arrays over commonly used electrodes is an advantage.[2] In the later case, drastic modulations of electrical properties of the single-walled carbon nanotubes (SWNT) responding to the change in the chemical or biological environments are promising characteristics for sensor application.[4] However, the SWNTs are not reliable channel in the field effect transistors for IC integrations due to its variance in the conductance.

In this paper, an Electrolyte-CNTs-Insulator-Semiconductor capacitor is proposed, where CNTs are used for the electrodes to modulate the surface potential of the under laid MOSFET. We used the anodic aluminum oxide (AAO) technology, which is the most frequently used to fabricate the highly ordered vertical carbon nanotube arrays. Vertically aligned carbon nanotube arrays are used as electrodes to modulate silicon surface potential. The structure works as a conventional EIS (Electrolyte-Insulator-Semiconductor), while the structure can be easily merged with the conventional CMOS technology. The feasibility of the application to the biological or chemical sensors is investigated by measuring the capacitance characteristics of the fabricated system.

2 EXPERIMENTAL PROCESS

Whole device structure is similar to the conventional EIS capacitor system but the interface between electrolyte and insulator is replaced by the multi-walled carbon nanotubes (MWNT) array, which is buried in an Al_2O_3 template, as shown in Figure 1. The Platinum reference electrode is used to set the correct electrolyte potential, which is dipped into the 3.3M KCl solution. To define the surface area and block an unwanted contact between the electrolyte and sensitive surface, we use the photo resist (PMER) to take advantage of the good covering property with easiness in handling. Silicon dioxide layer with the thickness of 25nm was grown by thermal oxidation.

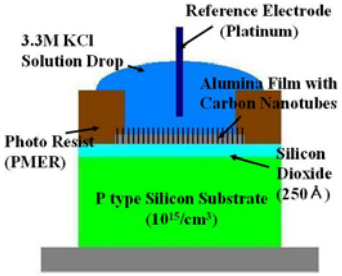

Figure 1 : Device Structure for the C-V measurement of the Electrolyte-CNTs-Insulator-Semiconductor capacitor.

2.1 Carbon Nanotubes Synthesis

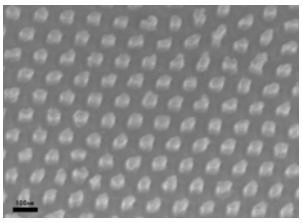

Figure 2 : SEM image of the MWNT array buried in Al_2O_3 template (the diameter is 40nm and the length is 40um)

The Carbon nanotube synthesis using AAO template was used, which is a well known process. The two-step anodization process is employed in our work. After

stripping away the thick aluminum oxide film obtained from the first long anodization, a porous thin alumina film with highly ordered pores is obtained by a subsequent re-anodization. After widening the pores, MWNTs are synthesized by thermal CVD (Chemical Vapor Deposition).

2.2 Bonding Process

To prepare the Electrolyte-CNTs-Insulator-Semiconductor capacitor, we used the wafer bonding technique to combine the MWNT array, which is buried in an Al_2O_3 template, together with SiO_2/Silicon substrate. The bonding process comprises a surface treatment to make the hydrophilic surface and bonding in vacuum under high pressure followed by a post anneal at 250^0C for about 3 hours. The surface roughness and cleanness are the key factors to achieve the good bonding quality. A side view of the bonding surface is shown in Figure 3.

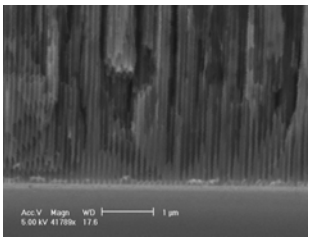

Figure 3 : Side view of the bonded $Al_2O_3/SiO_2/Si$ structure.

3 MEASUREMENT RESULTS

The characterization of the fabricated structures was performed by HP4194A Impedance Analyzer. Two sets of C-V curves of the novel capacitor have been given in Figure 4 and Figure 5. It shows that the modulation in the semiconductor surface occurs for a certain electrode potential (around 0V) which implies that the electrolyte can act as a well functional liquid gate. These excellent device characteristics indicate that it may be a good candidate for bio/chemical sensor applications. In addition, by attaching the molecules or chemicals to the abundant active sites provided by the open-ended CNT tips, the charged particles as the results of the chemical reaction can modulate the surface potential of the semiconductor in a sensitive way. The total capacitor of this system is comprised of the series capacitance of double layer capacitance at reference electrode and silicon dioxide capacitance and capacitance of the depleted region of the semiconductor. The resistances of the electrolyte and semiconductor substrate are negligible. In comparison with the results of Figure 4 and Figure 5, total capacitance is not proportional to its surface area, which may be due to its double layer capacitance of the reference electrode which is rather independent of surface area. The surface modulation proves that this structure can also act as a field effect transistor sensor with a proper post process including the source and drain regions. Usually, the oxide capacitance is thought to be independent of frequency. However, a distinct frequency dependent phenomenon, especially in the data for 1MHz, can be observed from Figure 4 and Figure 5. This may be due to the reduction of the double-layer effect at high frequency.

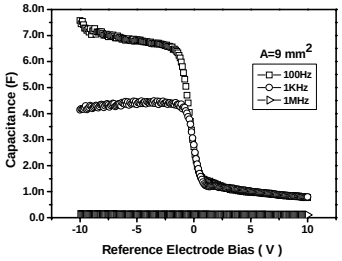

Figure 4 : Capacitance-voltage curve of Electrolyte-CNTs-Insulator-Semiconductor capacitor. Test area is $9mm^2$.

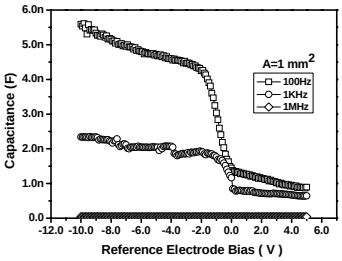

Figure 5: Capacitance-voltage curve of Electrolyte-CNTs-Insulator-Semiconductor capacitor. Test area is $1mm^2$.

4 CONCLUSION

A new EIS system having the MWNTs as the electrode is proposed. It has been shown, from the experiments, that the structure can be used in the chemical and biological sensor application. The possibility of the functionalization of CNTs' open tip and high sensitivity of the nano structure of CNT are the very promising reasons of the proposed structure.

ACKNOWLEDGEMENTS

This work was supported by the Nano Systems Institute–National Core Research Center (NSI-NCRC) program of KOSEF, Korea.

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