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GHZ ELECTRICAL PROPERTIES OF CARBON NANOTUBES ON SILICON DIOXIDE MICRO BRIDGES

SHENG F. YEN[1], HAROON LAIS[1], ZHEN YU[1], SHENGDONG LI[1], WILLIAM C. TANG[1,2],
AND PETER J. BURKE[1,2]
[1]Electrical Engineering and Computer Science, [2]Biomedical Engineering,
University of California, Irvine, 204 Rockwell Engineering Center
Irvine, CA 92697, United States

We present the concept, design, and preliminary results of an approach to reduce the high-frequency capacitive feedthrough and dielectric leakages of carbon nanotubes grown on silicon dioxide micro bridges suspended over silicon substrates. The microwave reflection coefficients (S_{11}) from carbon naotubes before and after partial removal of silicon in proximity were collected and compared. The S_{11} data show that measured impedances from carbon nanotubes before the removal of silicon are lower than that after the silicon has been removed. Even a partial removal of silicon from adjacent vicinity resulted in an average increase of 5 dB in S_{11}, indicating a significant contribution of feedthrough from silicon substrate.

1 Introduction

Semiconducting single-walled carbon nanotubes (SWCNTs), with its diameter of 1.4 nm, are attracting attentions for their potential use in true nano-scale electronics that promises a significant reduction in size and power compared to CMOS. CNT-based field-effect transistors (FET) [1] and simple logic circuits [2 – 4] have recently been demonstrated.

More intriguing is the fact that SWCNTs are systems approaching one-dimensional (1-D) quantum systems with interacting electrons. Theories and models of the quantum impedance of SWCNTs has been developed [5], in which the high-frequency behaviors of SWCNTs are described with lengthwise distributed quantum capacitance, electrostatic capacitance, and kinetic inductance.

The first experimental results from measuring the microwave reflection coefficient (S_{11}) of SWCNTs on silicon substrate at 4K have been demonstrated [6]. This result was achieved by means of capacitively coupling a SWCNT with metal electrodes to an impedance-matching circuit. In contrast to DC or low-frequency measurements, capacitive couplings between the contact pads and the nanotube terminals have been proven effective at Ultra-High Frequencies (UHF) [6], and thus low-resistance Ohmic contacts are not required. In these experiments, a thermally-grown silicon dioxide film on the silicon substrate served as an insulator between the substrate and the nanotubes under measurement. For the same reason, at GHz frequencies, the contact pads were capacitively coupled to the substrate through this dioxide layer, resulting in capacitive feedthrough and dielectric leakages. This may influence the measurement accuracy for the impedance of the nanotube at high frequencies.

To circumvent the difficulties with capacitive feedthrough and dielectric leakages through the silicon substrate at UHF frequencies, we conceptualized, designed and performed initial tests of a silicon dioxide micro bridge to support individual carbon nanotubes to facilitate GHz electrical measurements with suppressed capacitive feedthrough via the silicon substrate.

2 Modeling and Design

Figure 1 shows the cross-sectional drawing of a CNT on a silicon dioxide layer and the silicon substrate. The electrical equivalent circuit model is shown in Fig. 2. At high frequency, the silicon substrate acts as a parasitic signal path, coupling capacitively through the oxide layer to the contact pads, contributing to the overall effective impedance. We conceived and designed silicon oxide micro bridges to geometrically isolate the CNTs and the contact electrodes from the substrate to significantly suppress feedthrough signals, as shown in Fig. 3.

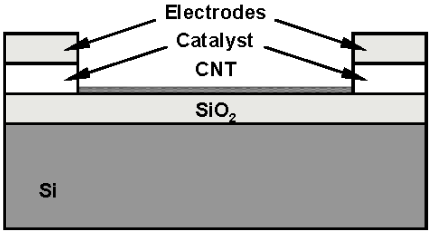

Figure 1. Cross-sectional drawing of the nanotube fabricated on top of silicon substrate with oxide insulation.

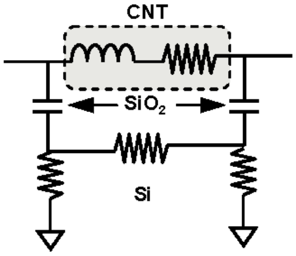

Figure 2. Equivalent circuit of the system depicted in Fig. 1.

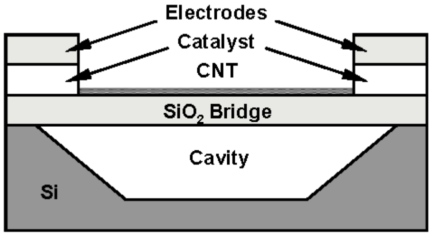

Figure 3. Cross-sectional drawing of the nanotube fabricated on top of a silicon dioxide micro-bridge.

3 Device Fabrication

3.1 *Nanotube Growth and Electrodes Fabrication*

Conventional optical lithography with photoresist were employed to deposit and pattern nanoparticle catalyst from an aqueous suspension. The catalyst receipes and the nanotubes growth procedure were detailed in Ref. [7]. CNTs were grown with chemical-vapor deposition (CVD) on catalyst islands with methane as the feedstock. Electrode patterning and metallization (Pt/Ti/Au) were performed over horizontally-oriented CNTs. Figure 4 is the scanning electron micrograph (SEM) of the electrodes, in which the electrode gap was designed to be 5-µm and the conductors were separated by 50 µm to facilitate RF probing. Figure 5 shows the SEM of a CNT bridging the gap between two electrodes at an oblique angle. The fabricated gap was 4.61 µm, which is slightly narrower than the designed 5 µm.

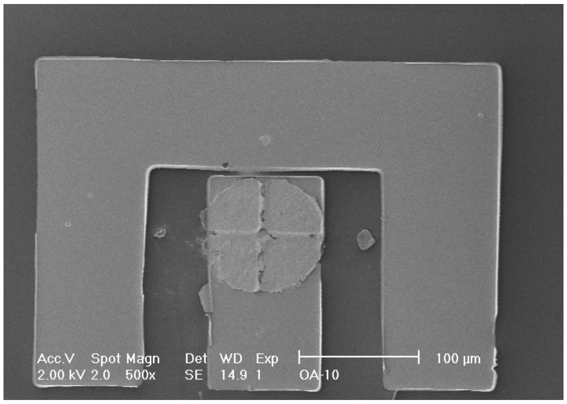

Figure 4. SEM of a CNT bridging the 4.61-µm gap between two electrodes at an oblique angle.

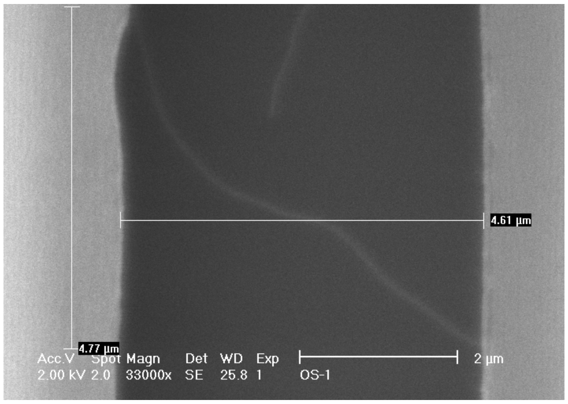

Figure 5. SEM image of the metal pattern for measurement in this study after growing nanotubes.

3.2 *Bridge fabrication*

The oxide bridge structure was fabricated last. As shown in Fig, 6, two symmetric etch windows were patterned on the oxide layer adjacent to the CNT. HF was used to open the oxide windows, followed by silicon wet etching with tetra-methyl ammonium hydroxide (TMAH). TMAH was used because it does not attack the metal electrodes nor the CNT. Initial results indicated that some undercutting was achieved, but it was not sufficient to create a completely released oxide bridge. Nevertheless, this partial release resulted in observable and substantial difference in the measured S_{11} coefficients, as discussed in the Measurement section.

(a) Thermal SiO_2 (0.2 μm)

(d) Metal contact pads

(b) Catalyst deposition

(e) SiO_2 etch windows (top view)

(c) CVD deposition of CNTs

(f) Si etching with TMAH

Figure 6. Process flow to create the oxide bridge after nanotube deposition and electrode metallization.

4 Measurement

4.1 *Set-up and Calibration*

To improve the robustness of the measurement, we eliminated the use of off-chip components for impedance matching and instead used a microwave probe station and a network analyzer (Agilent 8722ES) capable of collecting data at up to 40GHz. The measurement setup including the adapters, cables, and the probe station was first calibrated by applying a one-port (S_{11}) open/short/load calibration, achieving in average less than ±0.05 dB, as shown in Fig. 7.

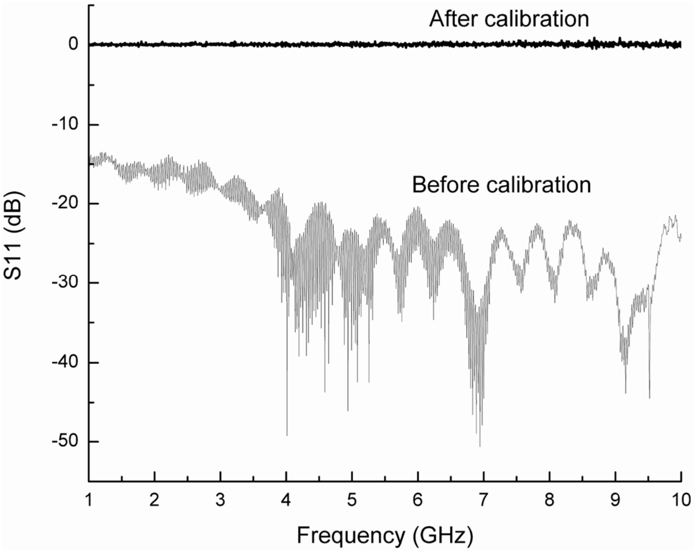

Figure 7. Measured S_{11} of the system before and after calibration.

4.2 *Bridge Performance*

Figure 8 shows the measured S_{11} vs. frequency for the nanotube before and after partial release of the oxide bridge. A difference of 5dB was observed, demonstrating the influence of the silicon substrate as expected.

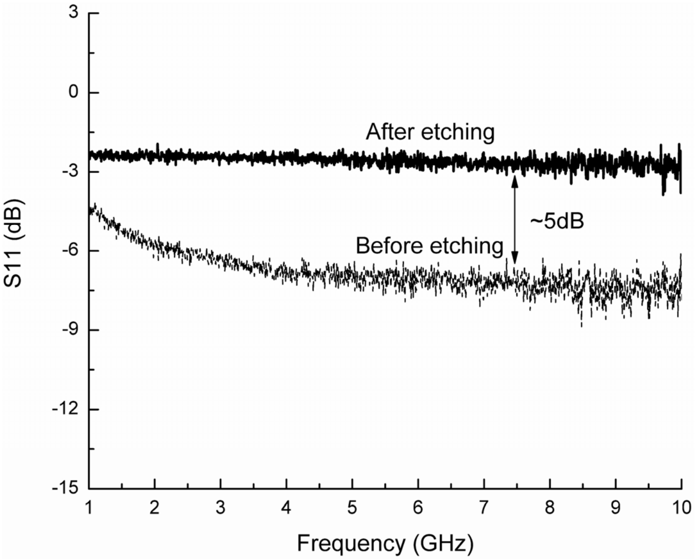

Figure 8. Measured S_{11} of the nanotube before and after partial oxide release.

5 Conclusion and Future Work

We have conceived, designed, and obtained preliminary results of suspending CNTs on a silicon dioxide micro bridge to suppress capacitve feedthrough during RF measurement. The S_{11} coefficients of the device have been measured before and after partial bridge formation, demonstrating the effectiveness of the design. Future work includes further development of the process to completely release the oxide bridge, refinement of the measurement techniques, and demonstration of high-frequency resonance of the nanotubes.

Acknowledgments

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