Randomized Network of Single Walled Carbon Nanotubes Thin Film Transistor: Fabrication, Simulation and Application as Biosensor

By

Sayed Alireza Mousavi

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Approved Thesis Committee
University of Salerno

Prof. Vincenzo Tucci

Prof. Veit Wagner

Prof. Giuseppe Milano

Prof. Danilo Roccatano

Approved Thesis Committee
Jacobs University Bremen

Prof. Veit Wagner

Prof. Vincenzo Tucci

Prof. Jürgen Fritz

Prof. Patrizia Lamberti

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Abstract

Nanoelectronic devices based on nanomaterials, such as carbon nanotubes (CNTs) have attracted remarkable attention as a promising building block for future nanoelectronic circuits due to their exceptional electrical, mechanical and chemical characteristics. The electrical characteristics of CNTs, such as high mobility, quasi-ballistic conductance and resistance against electromigration, allow to surpass the properties of current Si based complementary metal oxide semiconductor (CMOS) devices. In particular, the large surface area and nanoscale structure makes SWCNTs promising candidates for chemical and biological sensing applications as well. Current research covers broad scientific fields, such as study of materials properties at nanoscale, development, fabrication and simulation of nanoscale structures, for electronics and biomedical applications. However, there is ample space for advancements in both theoretical studies and practical applications for CNT-based systems.

This thesis addresses the design and manufacture of thin film transistor (TFT) based on randomized network of single walled carbon nanotubes (SWCNTs) that exploit the unique properties of such materials to create a label-free biosensor for detection of variety biomolecules, particularly proteins. In addition, in order to analyze the electric transport of SWCNTs network in the TFT channel a numerical 3-dimensional (3D) model for the thin film layer is developed.

The SWCNTs-TFTs are fabricated by using microfabrication to obtain a micro-interdigitated electrode (μ-IDE) as drain-source electrode. The sizes vary between 2 to 50 μm. Thin-film transistors (TFTs) are fabricated by using SWCNTs thin film as the semiconducting layer and SiO_2 thin film as the dielectric layer. The high purity semiconducting network of SWCNTs layer is deposited with an effective technique that combines the silanization of the substrate with vacuum filtration process from dispersed SWCNTs in surfactant solution. . The adopted technique provides a low-cost, fast, simple, and versatile approach to fabricate high-performance SWCNTs-TFTs at room temperature. The morphological arrangement of SWCNTs forming the active layer in the channel of the transistor is checked with scanning electron microscopic (SEM). The TFTs

obtained exhibit p-type transistor characteristics and operate in accumulation mode. The results are interpreted by considering the percolation theory. The exponent α of the power law describing the conductivity can be linked to the structural complexity of the SWCNT network. In particular an exponent $\alpha = 1.7$ was found experimentally, showing that the obtained thin film is relatively dense and near percolation. In addition, the experimental data have been compared with the results of the 3D model simulating the charge transport in the SWCNT structures formed in the TFT channel. The simulation results lead to an exponent $\alpha = 1.8$ that is in good agreement with the experimental data. The proposed model seems to be able to reliably reproduce the transport characteristics of the fabricated devices and could be an effective tool to improve the SWCNTs-TFTs structure. Moreover, the fabricated SWCNTs-TFT devices provide a suitable platform for high-performance biosensors in label-free protein detection. The sensing mechanism is demonstrated on a proof of principle level for the interaction of biotin and streptavidin on the SWCNTs surface. It is used as a research model for biosensor application. The SWCNTs thin-film biosensor has high sensitivity and it is capable of detecting streptavidin at concentration of 100 pM.