Abstract

With the development of separation and sorting techniques, highly enriched semiconducting single-walled carbon nanotubes (SWNTs) have become widely accessible, which has led to the rapid growth of high-performance solution-processed SWNT-based thin-film field-effect transistors (TFTs) with capabilities comparable to the current state of the art transistors. Additionally, with the emergence of facile, cost effective techniques such as inkjet and aerosol jet printing, fully printed SWNT TFTs exhibiting high quality transport properties have also been reported. Such advancements has made the fabrication of SWNT TFTs more accessible in recent times. Although a lot of experimental work is being carried out in the development of SWNT network based transistors and sensors, there is a dearth of suitable theoretical models and literature that deals with the field effect electrical transport in SWNT network based devices. Based on the current scenario, a detailed theoretical study of field dependent transport in single wall SWNT networks, followed by the experimental realizations of SWNT TFTs and validation of the proposed models have been carried out and reported in the thesis. Furthermore, based on the fabrications a SWNT TFT based gas sensing application is also developed and presented in the thesis. The principle contributions are briefly mentioned below.

In the first work, the field-dependent resistive properties of the networks are calculated using a numerical solver based on the derived individual resistances of SWNTs and the intertube couplings. The simulations reveal that networks of high SWNT density have large current carrying capabilities where the current carried by an individual tube within the network is able to exceed the limits observed in the single tube counterparts. The high electrical currents in networks is largely attributed to the suppression of optical phonon scattering and strong intertube couplings in highly dense SWNT networks (>30-40 SWNTs/μm^2). Comparisons between the simulated and experimental results also have been carried out to verify the accuracy of the proposed model.

In the second work, a numerical simulation of current transport in SWNT TFTs is presented. The developed model considers both Ohmic and Schottky type contacts that are exhibited by such field effect transistors which is attributed to the interface physics between the contact metals and the carbon nanotubes. Based on the above, two separate modes of transport are defined where transport in the Schottky contacted device is described through a

tunnelling transmission process while in the Ohmic contacted device, transport is primarily defined by a thermionic transmission process where the model treats each SWNT individualistically and determines the overall current through a novel iterative scheme. The accuracy of the proposed model is verified by comparisons with experimental data.

Following the theoretical analyses, the experimental realization of SWNT TFTs have been carried out. In order to compare and validate the theoretical models, two batches of devices, one being gold (Au) contacted and the other silver (Ag) contacted have been fabricated. From the transfer characteristics it is observed that the gold contacted devices exhibit unipolar p-type characteristics while the Ag contacted devices are found to show ambipolar characteristics, which are also expected from theoretical predictions. Using the derived transistor models, the transfer and output characteristics are also simulated and compared with the experiments and close match has been established between the experiments and simulations. However, the devices are found to exhibit large subthreshold swings and poor mobility that possibly limit their applicability in high speed electronic devices. Nonetheless, due to the possibility of leaving the channel exposed, the devices pose as an ideal platform for sensing applications, and is explored as the last contributory work in the thesis.

In the last work contributing to this thesis, the effects of gate voltage on the ammonia sensing properties of a SWNT TFT are investigated. It is observed that under the influence of a gate field, the device sensitivity and detection limit (LOD) can be improved by more than 11 and 6 times respectively. Moreover, the amplification of sensor response is found to occur for both the gate polarities. The working principle behind the gate induced sensitivity amplification is investigated theoretically and is attributed to a combination of two phenomena. Firstly, density functional theory (DFT) based adsorption studies of ammonia molecules to a SWNT device indicate that the introduction of a gate field leads to an increase in the adsorption energy of ammonia to the device especially for a positive gate which is directly relatable to the observed amplification in sensing. Additionally, in the negative gate regime, a reversible increase of the contact resistance induced by ammonia exposure is thought to be the primary contributing factor in increasing the responsivity of the sensor.