Single Walled Carbon Nanotubes based Ionic Building Blocks for Nanoelectronic Devices

Yamini Yadav and Shalini Prasad*

Department of Electrical and Computer Engineering, Portland State University
Post Office Box 751, Portland, OR 97207-0751, *prasads@ece.pdx.edu

ABSTRACT

We present the electrical characterization of crossbar ionic nanoscale devices built using surfactant coated single walled carbon nanotubes (SWCNTs) via micro contact printing. These electro-ionic building blocks were synthesized by doping intrinsic semi conducting SWCNT doped with surfactant molecules, thereby altering the Fermi energy levels of SWCNTs and their electrical properties. The surfaces of these SWCNTs, were modified by two types of surfactants; sodium docedyl sulfate and cetyl trimethylammonium bromide, to produced anionic SWCNT (P-type) and cationic SWCNT (N-type) respectively. Using dual micro-patterning process, anionic and cationic SWCNT ionic blocks were alternatively symmetrically patterned into a parallel array to form crossbar p-n junctions. Functionality of the nanodevices was demonstrated by studying the current – voltage (I-V) characteristics that shows promise towards the formation of nanoelectronic diode arrays.

Keywords: Carbon nanotubes, microcontact printing, nanoelectronics, ionic junction, surfactants

1 INTRODUCTION

Fundamental need for high throughput and improved device performance has lead to the investigation of incorporating both organic and inorganic materials in multi-scale architectures[1]. Secondly, organic chemical doping of nanomaterials enables the modulation of nanomaterial electrical properties by nanoionic transport[2]. These capabilities have potential for developing nanoelectronic device building blocks that are suitable for a wide range of device application. Numerous nanoscale semiconductor fabrication techniques and materials engineering processes have guided the development of rapid synthesis of extrinsic nanomaterial, assembly and patterning of nanomaterials to form electronic nanodevice components[3]. Development of these nanoelectronic systems has wide range of applications in semiconductor business as well as sensors based biomedical and defense industries [4].

Various techniques such as Langmuir Blodgett method, superlattice nanowire pattern transfer (SNAP) and fluidic alignment for positioning these surface modified nanomaterials have been studies [5, 6]. These methods are complex, difficult to implement and require complex laboratory equipment for nanomaterial patterning[6]. In contrast, in our research we have adopted and illustrated an integrated approach of simple, hard and soft lithography techniques to fabricate and assemble crossbar ionic junctions comprising of bundles of extrinsically functionalized SWCNTs.

For building junction devices, chemical properties of nanomaterials are typically modulated by adding dopants using most common techniques such as diffusion and ion implantation methods [7, 8]. These techniques show crystallographic damage. Amorphization and sputtering have also been used to dope nanomaterial, but these techniques use hazardous materials such as antimony, arsenic, phosphorus, and boron and require high voltages [9]. In contrast, in the current paper, we have chemically doped SWCNTs using non-hazardous organic surfactants. Also, control over the dopant concentration is achieved by varying concentration of surfactant.

2 MATERIALS AND METHODS

Fabrication and assembly of cross bar ionic junction based nanodevices consist of following five steps: (i) Synthesis of extrinsic SWCNT by chemically doping using surfactant (ii) fabrication of microelectrode arrays using photolithography techniques, (iii) fabrication of polymer PDMS stamps using rapid soft lithography techniques, (iv) patterning of cationic and anionic SWCNTs using PDMS stamp in crossbar fashion and (v) Electrical characterization of crossbar ionic junctions.

2.1 Synthesis of extrinsic SWCNTs

The charge transport in the ionic p-n junctions is by ion molecules in contrast to semiconductor p-n junction where the flow of current is by holes and electrons. The extrinsic SWCNTs were synthesized using surfactants having positive and negative charge ions at its hydrophilic ends. Two types of surfactants were used; sodium dodecyl sulfate (SDS) and cetyl trimethylammonium bromide (CTAB) having having Na+ positive ionic charge (anions) and Br- negative ionic charge (cations) on its hydrophilic ends were used respectively to achieve this doping. The intrinsic SWCNTs were dispersed into surfactant, by forming an encapsulate over the SWCNTs by generating a micelle layer around SWCNTs. Figure 1 shows orientation of the micelles in perpendicular and parallel onto the surface of

the SWCNTs. Doping SWCNT with SDS and CTAB produces anionic SWCNT and cationic SWCNT respectively.

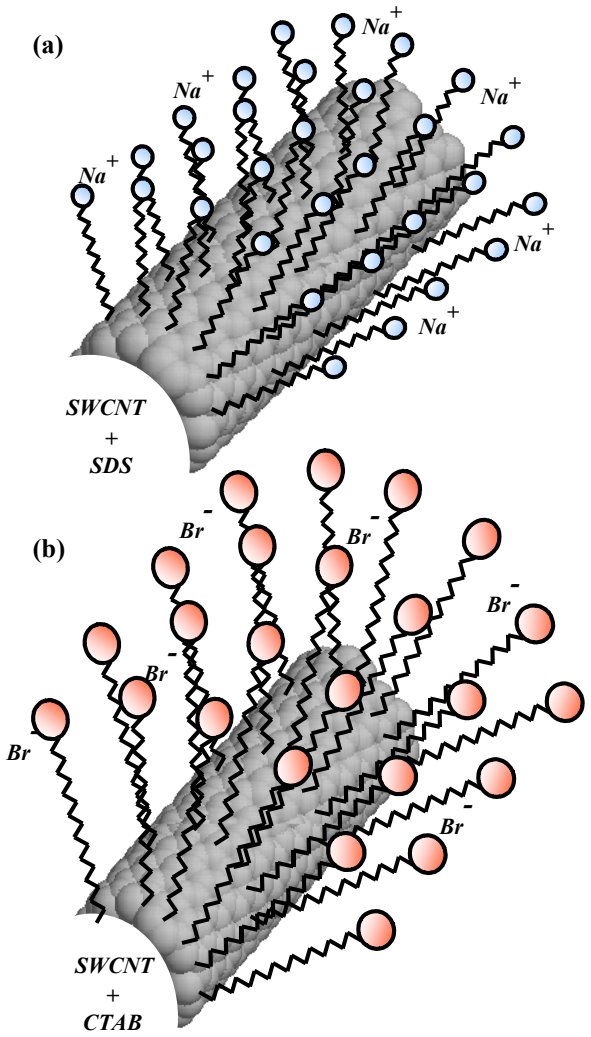

Figure 1: Surfactant molecules on the SWCNT. (a) and (b) SDS and CTAB form a uniform layer or a micelle around nanotubes with hydrophobic group adsorbed onto SWCNT surface and hydrophilic heads having Na^+ and Br^- ions

2.2 Microelectrode array and PDMS fabrication

The microelectrode platform consists of 2x2 array of metallic gold microfingers. The microfingers were placed opposite to each other in cross bar junction fashion to obtain electrical I-V measurements. Traditional, simple and standard photolithography techniques were used for fabrication of the microelectrode array. The technique follows the following process sequence; (a) substrate preparation, (b) positive photoresist application, (c) exposure and pattern development and (d) finally metal sputtering and lift off.

For crossbar pattering of the extrinsically doped SWCNTs in a parallel symmetric array, primarily a master template having a micro- channel surface topology was fabricated using the previously described photolithography process. Later, softlithography techniques were incorporated for fabricating soft, flexible PDMS stamps having micro-relief structures using the master templates. This technique involved mixing of elastomer and curing agent, followed by curing of the mixture and finally peeling off the flexible PDMS stamp, having the negative replica of the master template for stamping of anionic and cationic SWCNTs.

2.3 Patterning nanomaterial

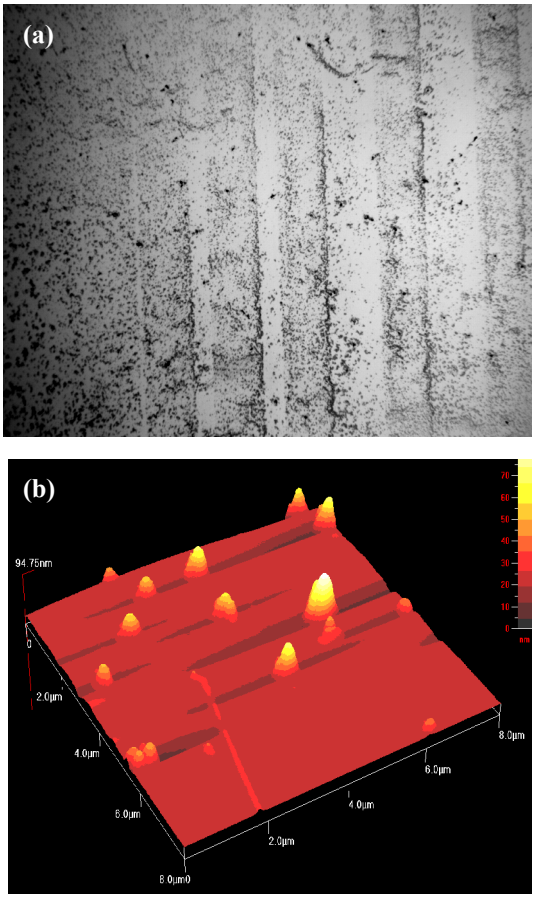

Figure 2: (a) Optical micrograph and (b) AFM image representing patterned SWCNT in parallel array by imprinting inked PDMS stamps with surfactant dispersed SWCNT

Double microimprinting techniques were involved for pattering of extrinsic SWCNTs. Due to the parallel relief structure on the PDMS stamps, repetitive parallel pattering of SWCNT was achieved which is shown in figure 2. The PDMS stamp was inked alternatively with anionic and

NSTI-Nanotech 2008, www.nsti.org, ISBN 978-1-4200-8503-7 Vol. 1

cationic SWCNTs and these were transferred in a grid like manner onto the base microelectrode platform to form crossbar p-n ionic junction comprising of clusters of SWCNTs. Finally, the assembled crossbar ionic junction was electrically characterized to demonstrate the formation of the ionic junction.

3 RESULTS AND DISCUSSION

In our earlier research we have shown that randomly dispersed CNT's have a resistive lumped element characteristics. These randomly dispersed SWCNT when physically assembled in well-ordered patterns demonstrate device configuration such as transmission lines and transistors. The P-type and N-type SWCNT in this application were stamped in a crossbar manner to form p-n ionic junction nanodevices. Figure 3 demonstrates the forward and reverse bias junction characteristics.

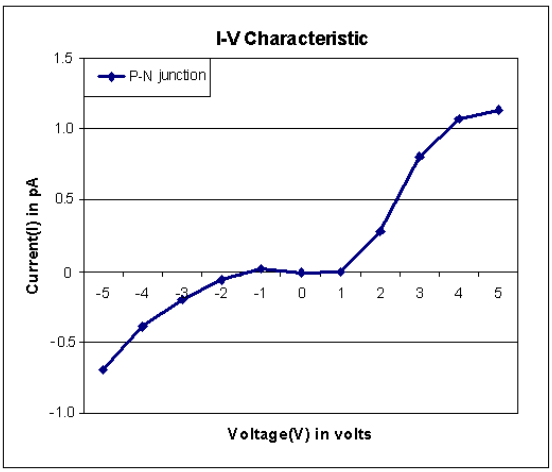

Figure 3: Represents I-V characteristics of P_N ionic junction. The graph shows rectifying forward junction with a turn ON voltage of 1V.

In this paper, micro contact patterning techniques associated with soft lithography polymer based processes were implemented for the simultaneous and rapid assembly of nanomaterial. This technique has helped to overcome the issues associated with the use of standard electron beam lithography techniques that are currently being adopted for individual patterning of nanomaterial, namely time and cost per structure. We have demonstrated the formation of crossbar p-n junction arrays using ion doped SWCNT by adopting micro contact printing techniques. We have currently established that integrated SWCNTs with microstructures in a patterned manner is a nanoelectronic tool for understanding nanoscale electro-ionic transport, as these tools can be easily probed for electrical characterization. This device is a good example of multi-dimensional integration of SWCNTs with metallic microelectrodes. These microelectrodes can be probed using standard lead based address lines associated with IC technology.

Analogous to the electrons and holes transport in a semiconductor p-n junction, ionic charge transfer occurs through the ionic junction in chemically doped nanomaterial. When anionic and cationic SWCNTs are patterned to form crossbar ionic junctions across base electrodes, ions transfer between two electrodes. We observe this behavior in the electro-ionic tool that we have developed by using the dually doped SWCNT grid. We anticipate that ionic tunneling and ionic charge transfer occurs between two adjacent SWCNTs. This behavior when cumulated over clusters of SWCNTs in the ionic unction result in a potential difference across the nanomaterial junction resulting in tuning of Fermi energy level. Hence, rectification is observed in an ionic junction similar to the rectification behavior due to electron-hole transport in a semi conducting junction.

4 CONCLUSIONS AND FUTURE WORK

In summary, we have demonstrated a method for chemically modulating the electrical properties of nanomaterial and implemented simple, low cost and rapid prototyping technique for developing crossbar SWCNT p-n junction arrays. The electrical rectification characteristics show promise towards assembling of junction array for building highly integrated circuits. Future work involves building of complex functional devices by assembly ionic nanodiode as principal building blocks.

REFERENCES

[1] Y. Oaki and H. Imai, Chem. Commun., 6011-6013, 2005.

[2] T. Schenkel, Nature Materials 4, 799–800 2005.

[3] D. Whang, S. Jin, Y. Wu, and C. M. Lieber, Nano Letters 3, 1255-1259, 2003.

[4] B. L. Allen, P. D Kichambare and A. Star, Adv. Mat. 19, 1439-1451, 2007.

[5] N. A. Melosh, A. Boukai, F. Diana, B. Gerardot, A. Badolato, P. M. Petroff, and J. R. Heath, Science 300, 112-115, 2003.

[6] P. Yang, Nature 425, 243 - 244, 2003.

[7] P. L. Degen, Physica Status Solidi (a) 16, 1973, 9-42.

[8] K.-S. Kim, Y.-H. Song, K.-T. Park, H. Kurino, T. Matsuura, K. Hane, and M. Koyanagi, Thin Solid Films 369, 207-212, 2000.

[9] S. G. Tavakoli, S. Baek, and H. Hwang, Materials Science and Engineering B 114-115, 376-380, 2004.