Characterization of Carbon Nanotubes for exact structure of the CNTs in range of tens of nm.

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***Abstract*-In this paper a method for characterizing the Carbon Nanotube (CNTs) is proposed. The method proposed uses Raman Spectroscopy, AFM and STM so as to characterize the CNT structure. This method is useful as it gives a better understanding about the behavior of the CNT based devices and will help us develop better models for CNT based electronic devices.**

I. INTRODUCTION

Silicon has reached its smallest size and nor researchers have started looking for some other alternatives. One of the alternatives is the use of Carbon Nanotubes [1]. CNT are formed by rolling a sheet of graphene. CNT formed can be semi-conducting or metallic by nature and it completely depends on the chirality which in turn depends on the way the graphene sheet is rolled (meaning the structure of the atoms in CNT) [1].

It becomes very important to analyze and determine the chirality of CNTs. A little change in the chirality (change in the structure of placements of atoms) will result in completely different properties making it metallic or semi-conducting. The chirality has to remain constant over the length of the CNT else it will result in a completely different behavior.

II. PROBLEMS

There have been many different methods for growing Single Walled Carbon Nanotubes (SWNT) whose diameter lies in the range of 1-3 nm and the length can be several microns [3]. The basic diagram for the Carbon Nanotube Field Effect Transistor (CNFET) is as shown in the figure (1) [2]. As per the proposed models for the CNFET [2, 4, 6] the length of the CNTs have to be in the range of 10-50nm. From [3], it is clear that the CNTs grown are of length in the range of micron and so in order to get CNTs of smaller lengths, the longer CNTs have to cleaved/cut. There are various methods for cutting the CNTs and one of the very well known methods for cutting the CNTs is using the fluorination of the CNT and then breaking the bonds and creating the CNTs.

The method of fluorination proposes to make the CF_2 bonds and then breaking the C-C bonds and in this way generating the small length Carbon Nanotubes. The lengths of the CNTs obtained by the above mentioned method can be about 100nm long with the yield of 70-80% [5]. An example of the image of the CNT with the defects is as shown in the figure (2) [3].

But as proposed in the models if we plan to use them for designing the electronic devices then we need CNTs with the length of 10-50nm. As mentioned in [5] the method can also be used to obtain smaller length CNTs. Even at 100nm and below it becomes very important to know the shape of the CNTs formed especially at the end, after the cut. This cutting might introduce the change in the shape and the structure of the atoms at the two cut ends of the CNTs resulting in the change in their electrical behavior. Also it becomes very important to determine whether the CNTs are pure or are they contaminated by the Fluorine atoms anywhere over the length of the CNTs. The addition of the Fluorine atoms may result in the change in the electronic properties of the CNTs. So it becomes important to determine the characteristics of the fluorinated CNTs and its effect on the electrical behavior.

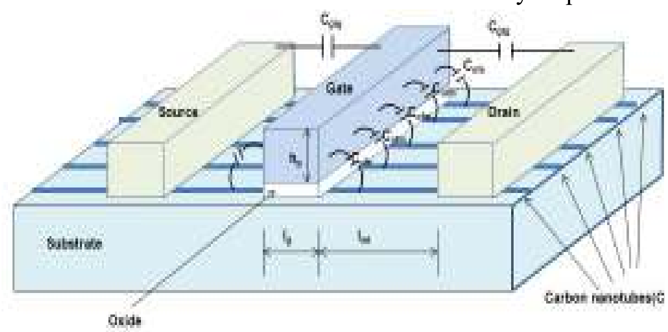

Fig. 1. Carbon Nanotube Field Effect Transistor

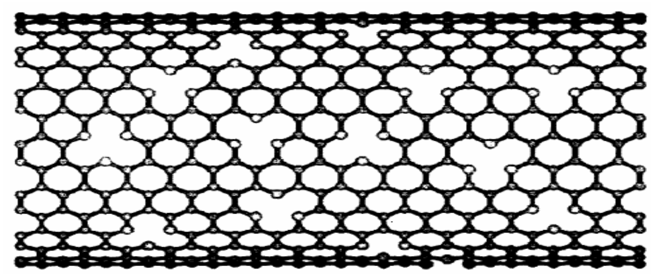

Figure (2): STM image of CNT with defects. As seen from the Image some of the atoms are missing over the length of CNT

III. PRIOR WORK

All the proposed method for fabrication uses SEM, TEM, Raman scattering method for characterizing the CNTs [7, 8]. Raman Scattering is a very basic tool which can be used to determine the CNT with a specific chirality and diameter. The TEM is useful when using for imaging the CNTs while being cut using the Ball milling method. Its gives us images of the CNTs after specific time interval. It is helpful as we can determine the change in the length of the CNTs, if we know the rate of milling and the time for which milling is on [9]. But as this method of ball milling is useful until the CNTs of length .8u and not less, it becomes very difficult to image the structure of the CNTs with the length of 10 - 50nm. RBM mode in Raman scattering is very useful in determining the diameter and the chirality of the CNTs and also the metallic and semiconducting nature of the CNTs. Raman signal also increases with the increase in the laser power but this increase in power can also result in the heating of the sample [10]. None of the above mentioned method actually gives the actual structure of the CNTs and the shape of the CNTs at the two ends. This is of prime importance at 10 – 50nm length CNTs as the model of the transistor is completely dependent on the length as we consider the ballistic mode of transport of electrons at such small gate length. This ballistic mode of transport is only possible when we consider the CNTs used to be completely cylindrical in shape. But if its shape changes from cylindrical to something else then it results in scattering of electrons and this reduces the current. Also as shown in figure (1) the ends are used at the drain and source contacts. From [11] it is proposed that there is a formation of the Schottky barrier diode at the source and the drain contacts because of the interface between the metal and the semiconductors.

IV. Proposed Solution

In the proposed method we use an AFM to determine the physical structure of the CNT. This can be done by using the AFM to determine the actual topography of the CNT at the ends after the cutting procedure is over. The use of AFM to determine the structural changes is very much similar as mentioned in the paper by [12]. Where the publishers have used it for the use of the determining the atomic structure of the Pentacene. G. Meyers et al. were able to take images of the five benzene rings present in Pentacene. So working on the similar lines of [12] we operate the AFM in the Non-contact mode with frequency modulation mode so as to receive the maximum resolution. This will give us idea about the location as well as the topography at the end of the CNTs.

The second analysis that is planned is by using the Scanning Tunneling Microscopy (STM). The CNTs when used in the CNFET act as semiconducting channel and there is ballistic mode of transport present in the CNFET. This ballistic mode of transport uses transmission probability of the channel. Now during the cutting procedure as there is a change in the atomic structure of CNTs this result in the change in the transmission probability of the CNTs channel. At the same time the change in the atomic structure also results in a different density of states because of the introduction of broken cylindrical shape of the CNTs. So by using STM methods we can know about the local density of states and if we gather sufficient information for different CNTs of similar length then we can add some modifying factors to the original drain current equation of the CNFET, which is based on the LDOS of the tip and the sample and the transmission probability of the device. The present equation for the drain current in the CNFET is as shown below [2, 6].

$$I = \int_{+k} T.DOS.v.f.dE - \int_{-k} T.DOS.v.f.dE$$

There will be an observation to be made on the band gap energy of the CNTs which will be fabricated as it is dependent on the diameter of the CNTs formed. If there is a change in the placement of the atoms then there is a possibility of the change in the diameter of the CNT over the length of the CNT. Thus this study of the band gap will be incorporated while doing the Raman Scattering studies of the CNTs. The Raman Scattering gives us the diameter of the CNT by giving a shift in the Raman Frequency.

V. Intellectual Merit and Impact

The output of this research will be very helpful for the researchers in the field of Carbon Nanotubes Based electronic devices. This will give a much better understanding of the transport feature in the Carbon Nanotube. Till now the models have been based on Ballistic mode of transport and do not take into consideration any possible defects due to change in the atomic structure of the Carbon Nanotubes. The results of this research will help in developing a realistic model for the CNFET which will also incorporate the effects of the defective CNTs. Also this research will help the people in the field of Chemistry to determine and use the best possible method to cut to Carbon Nanotubes without any harm to the dimensions and chirality of CNTs.

Apart from this, a similar approach can also be designed for the characterization of Graphene. Graphene is used for RF applications because of the semi- metal nature. But for use of Graphene in the design of any digital logic we need to have a band gap. If there is a change in the atomic structure in Graphene then there will be a change in the band gap of Graphene. So proposed method will help in determining the change in band gap and formation of digital logic blocks using graphene.

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