Carbon Nanotube Transistors: A Review

Irfan Ahmad Pindoo¹, Sanjeet K. Sinha²

¹²School of Electronics and Electrical Engineering, Lovely Professional University, Punjab, India.

ABSTRACT

Due to the continuous scaling of the conventional metal oxide semiconductor field effect transistor (MOSFET), we have finally reached to a limit where industry is not able to sustain the scaling of MOSFET due to its ultra nano scale range (below 50 nm). The reason attributed are the leakage currents, higher power dissipation, threshold roll-off, etc. Thus, other alternatives need to be studied in order to sustain the scalability. In that regard, this paper focuses on carbon nano tube field effect transistors (CNTFET) as one of the solutions to the existing problems. We have explained the device details, operation and the characteristics of CNTs.

Keywords: carbon nanotube, scaling, MOSFET, tunneling, CMOS

1. INTRODUCTION

Gordon Moore had predicted in 1965 that the number of transistors on a given IC would double after every 18 months. This progress has been made possible in metal oxide semiconductor field effect transistor (MOSFET) due to the continuous scaling of its dimensions. From the past five decades, this law has paved a pathway towards the miniaturization of devices. However, as the size approaches to a nano-scale range (below 50 nm), the leakage currents increase tremendously. This lead to the increased power dissipation. Moreover, the short channel effects like threshold voltage roll-off, velocity saturation, drain induced barrier lowering (DIBL), etc. degrade the performance of the MOSFET further. These drawbacks have compelled researchers to investigate the other alternatives of scalability to keep the Moore’s Law get going.

Many alternatives were proposed in the beginning, such as, Silicon on Insulator MOSFET, FinFET, Junction Less MOSFET, and Double Gated MOSFET. However, carbon nanotube FETs have been regarded as a potential candidate that can replace MOSFETs in future. This is mainly attributed to its electrical properties and easy manufacturing process. CNTFETs will allow designers to scale the transistors further in nanometer scale range. The major difference between CNTFET and MOSFET is that the channel is made up of carbon nanotubes, instead of a silicon. This enables them to drive higher currents and improved mobility compared to the bulk silicon.

In this paper, we have explained the characteristics and the operation of CNTFET devices.

2. CARBON NANOTUBES

A carbon nanotube (CNT) was discovered by S. Iijima in 1991, and ever since that there has been groundbreaking research in this field. CNTs are carbon atoms in hexagonal matter that are being rolled up in tubularform with a diameter of few nanometers. Carbon consists of four valence electrons, three among them are utilized for the sp² bonds. During sp² hybridization an electron is stimulated from the 2s-orbital to a p-orbital and it is followed by two electrons from different 2p orbital combine with the single electron left in the 2s-orbital to give rise to three equivalent sp² orbitals. These orbitals are arranged at 120 degrees apart between the major lobes and the rest of the p-orbital is perpendicular to this plane. Carbon nanotubes are cylindrical tubes of graphite sheets with diameters of nanoscale and high length/diameter ratio. They are made of carbon atoms linked in hexagonal shape and each carbon atom is linked to three other carbon atoms with a covalent bond. The ends can be open or closed. Fig. 1(a) represents the molecular structure of carbon nanotubes. Furthermore, the single graphene sheet with carbon atoms located at each crossings is shown in Fig. 1(b) where the CNT has been rolled up.
The chiral vector, $C_h$, is perpendicular to the tube axis, and is given as:

$$C_h = p\overrightarrow{x_1} + q\overrightarrow{x_2}$$  \hspace{1cm} (1)

Where $p$ and $q$ are a pair of integers and $\overrightarrow{x_1}$ and $\overrightarrow{x_2}$ are the lattice vectors, given by:

$$\overrightarrow{x_1} = \left(\frac{\sqrt{3}}{2}a_0, \frac{3a_0}{2}\right) \text{ and } \overrightarrow{x_2} = \left(-\frac{\sqrt{3}}{2}a_0, \frac{3a_0}{2}\right)$$  \hspace{1cm} (2)

$a_0$ represents the inter-atomic distance between each carbon atom. For the simulation, this value is kept around 1.42 Angstrom.

Single walled carbon nanotubes (with a diameter of less than 1 nm) are composed of single-atom rolled graphite layers. While as, multi-walled carbon nanotubes (with diameters reaching more than 100 nm) consist of multiple rolled graphite sheets. Due to its properties like low weight material, ultra strength, highly conductive, carbon nanotubes are found highly attractive in numerous applications.

3. CNTFET

Carbon nanotube field effect transistor (CNTFET) are the devices in which the channel is made up of carbon tube. The CNT sometimes may become ballistic when the channel length is shorter, thus the schottky barriers and the metal contact resistance at the drain and the source terminals limit the current drive through the tube. The schematic diagram is provided in Fig. 2. The MOS like CNTFETs shows the best performance in terms of ON-OFF currents and a subthreshold swing.
The application of positive drain source voltage gives rise to the constant current in the CNT, which can further be calculated at the commencement of the channel at the source. The advantages that MOS like CNTFETs offer are: greater scalability, unipolar characteristics, and lesser leakage current and higher drive. However, sometimes it becomes difficult to control the amount of doping during ion implantation. It occurs due to the probability that the desired properties of CNTs can get destroyed when carbon atoms would be replaced by the ions.

Table I: Parameter Specification:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chirality (n,m)</td>
<td>(7,7)</td>
</tr>
<tr>
<td>Tight Binding Energy</td>
<td>3 eV</td>
</tr>
<tr>
<td>Carbon-Carbon Spacing</td>
<td>1.42Å</td>
</tr>
<tr>
<td>Simulation method</td>
<td>Real space approach</td>
</tr>
<tr>
<td>Source contact CNT work function difference</td>
<td>0.41 eV</td>
</tr>
</tbody>
</table>

CONCLUSION
In this brief, we have highlighted the shortcomings of the conventional MOSFET structures, as the channel length is reduced to a nanometer scale. Further, we have studied the other alternatives that can replace MOSFETs in future. In that regard, carbon nanotubes (CNT) has been one of the attractive topics researchers have been exploring to improve the device performance. Here, we given a detailed explanation of its advantages, operation and characteristics. CNTs should be explored further, so that it can be used for various low power applications.