

## Study of Performance Enhancement of SBCNFET

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### ABSTRACT

Carbon Nanotube Field Effect Transistors (CNTFET) are promising nano-scaled devices for implementing high performance, very dense and low power circuits. Most carbon nanotube field-effect transistors (CNTFETs) directly attach metal source/drain contacts to an intrinsic nanotube channel known as SBCNFET. When the gate oxide thickness is reduced, such transistors display strong ambipolar conduction. The leakage current, which increases exponentially with the drain voltage, constrains the potential applications of such devices. This paper reviews such problems and their required solutions.

**Keywords** - Carbon Nanotube; Schottky Barrier CNTFET; Schottky Ohmic CNTFET.

### I. INTRODUCTION

Advanced miniaturization is a key thrust area to enable new science. Nano technology presents a whole new spectrum of opportunities to build electron devices and exploit their mechanical and electronics properties through control of matter on the nanometer length scale. Nanoscience research focuses primarily on the search for new physical concepts and on creating the technology necessary for the development of nanodevices. As the scaling of Si MOSFET approaches towards its limiting value, new alternatives are coming up to overcome these limitations. The most promising ones so far include carbon nanotube field-effect transistors (CNTFETs), FinFETs, nanowire, III/V compound-based devices, graphene nanoribbon devices, resonant tunneling diodes, and quantum dot devices[1]. Carbon nanotubes (CNTs), with exceptional electronic and optical properties, have become great interest for future electronic applications. Many digital circuits are being designed using CNTFET because of the higher mobility of CNT. Superior performance for the CNTFETs can be expected if multiple parallel CNTs with highly transparent contact and good spatial control can be utilized to construct the CNTFETs, which includes high drive current and transconductance, low-power dissipation and noise. This paper reviews types of CNTFET and the focus is on SBCNFET, since the  $I_{ON}$  to  $I_{OFF}$  ratio of SBCNFET is low,

So ideas to overcome this problem have been discussed here. The paper is organized as follows. Basics of CNT and its applications are in section II. CNTFET and its type in section III. Further section IV comprises problems of SBCNFET and methods to overcome it. Sections V discuss the conclusion and future scope.

### II. CARBON NANOTUBE (CNT)

Carbon is a Group 14 element that resides above silicon in the Periodic Table. Like silicon and germanium, carbon has four electrons in its valence shell. In its most common state, it is an amorphous nonmetal, like coal or soot. In a crystalline, tetrahedrally bonded state, carbon becomes diamond, an insulator with relatively large band gap. However, when carbon atoms are arranged in crystalline structures composed of hexagonal benzene-like rings, they form a number of allotropes that offer exceptional electrical properties. In their semiconducting forms, these carbon nanomaterials exhibit room-temperature mobilities over ten times greater than silicon. In addition, they can be scaled to smaller feature sizes than silicon while maintaining their electrical properties.

Carbon nanotubes were discovered by S. Iijima in 1991 [2] while performing some experiments on molecular structure composed of carbonium. CNTs are hollow cylinders composed of one or more concentric layers of carbon atoms in a honey comb lattice arrangement.

It can be classified into:

1. SWCNT (Single Walled Carbon Nano Tube)
2. MWCNT (Multi Walled Carbon Nano Tube)

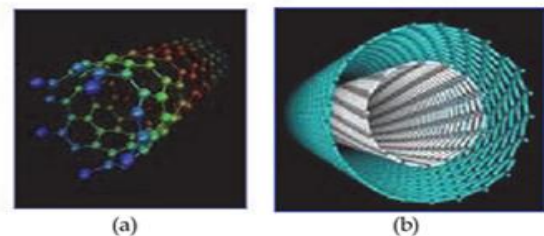


Fig. 1: (a) single walled carbon nanotube, (b) multi walled CNT

The way that graphene is rolled is described by a pair of indices ( $n$ ,  $m$ ), which are called "chiral vector". Here  $n$  and  $m$  are both integers and they denote the number of unit vectors along two directions in graphene lattice. According to the chiral vector of a CNT, it can be determined whether it's a metallic or semiconducting CNT.

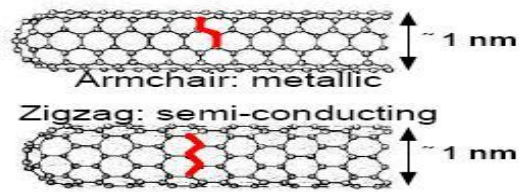


Fig.2: metallic and semiconducting CNT

Application of Carbon Nanotubes:

1. Carbon nanotube field effect transistor
2. Carbon nanotube as rectifier
3. Carbon nanotube as interconnects
4. Carbon nanotube based display devices

### III. Carbon nanotube field effect transistor (CNTFET)

A silicon wafer is covered with a thick silicon-dioxide film and then fabricated gold or platinum electrodes on it using standard semiconductor manufacturing technique. A single carbon nanotube was then positioned as a channel between two electrodes which are source and drain. The underlying silicon wafer, heavily doped with impurities to make it good conductor, served as gate electrode. Applying the appropriate voltage to gate the nanotube is on or off. The first carbon nanotube field-effect transistors (CNTFETs) were reported in 1998. There are several types of CNTFETs, but CNTFET geometries may be grouped in two major categories: planar and coaxial CNTFET. CNTFET design's performance is limited by the gate overlap capacitance and the quality of nano contacts to these promising transistors [3]. Packing density in CNTFET arrays is determined based on circuit application.

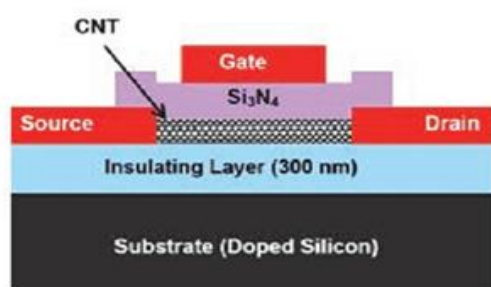


Fig. 3: structure of CNTFET

Classifications of CNTFET:

Based on the type of electrodes used CNTFET is classified into three categories.

#### (a) Schottky-barrier (SB) CNTFET

In this type of CNTFET an intrinsic CNT is used in the channel region [2]. This is connected to metal Source/Drain and forms Schottky barriers at the junctions. Carbon nanotube transistors operate as unconventional Schottky barrier transistors in which transistor action occurs primarily by varying the contact resistance rather than the channel conductance. The presence of Schottky barrier lowers the on-current.

#### b) Partially gated (PG) CNTFET

PG-CNTFET, is a depletion mode CNTFET in which the nanotube is uniformly doped with Ohmic contacts. PG-CNTFETs can be of n-type or p-type when respectively n-doped or p-doped. In these devices the gate locally depletes the carriers in the nanotube and turns off the p-type (n-type) device with an efficiently positive (negative) threshold voltage.

#### c) Doped- source or drain (S/D) CNTFET

Doped-S/D CNTFETs [4] are composed of three regions. The region below the gate is intrinsic in nature and the two ungated regions are doped with either p-type or n-type. The ON-current is limited by the amount of charges that can be induced in the channel by the gate and not by the doping in the source. They operate in a pure p- or n-type enhancement-mode or in a depletion-mode, based on the principle of barrier height modulation when applying a gate potential.

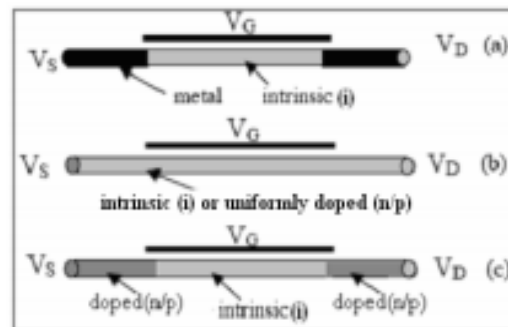


Fig.4: Three possible types of CNTFETs (a) Schottky barrier, (b) partially-gated and (c) doped-S/D transistors

### IV. SCHOTTKY-BARRIER (SB) CNTFET

CNTFET-based devices offer high mobility for near-ballistic transport, high carrier velocity for fast switching, as well as better electrostatic control due to the quasi one-dimensional structure of carbon nanotubes. CNTFET utilizes a semiconducting carbon nanotube (CNT) channel controlled by isolated electrostatic gates.

In SBCNFET an intrinsic CNT is used in the channel region and this is connected to metal Source/Drain which forms Schottky barriers at the junctions. The performance of SBCNFET [5] critically depends on the device geometry. Asymmetric gate contacts, the drain and source contact thickness, and inhomogenous dielectrics above and below the nanotube influence the device operation. The best performance improvements can be achieved using asymmetric gates centered above the source contact, where the optimum position and length of the gate contact varies with the oxide thickness. Ambipolar conduction is an important factor that must be carefully considered in device design, especially when the gate oxide is thin. A C-CNFET [6] with a doping profile similar to a "conventional" p-or n-MOSFET in principle



exhibits superior device characteristics when compared with a Schottky barrier CNFET.

### ISSUES

1) Using a large diameter tube increases the on-current, but it also increases the leakage current. In SBCNFET due to schottky barrier which are present in source to channel and drain to channel region, the leakage current increases thus reducing on current to off current ratio.

2) SB-CNTFETs exhibit strong ambipolar characteristics that limit the use of these transistors in conventional CMOS like logic families [7] because these SB-CNTFETs convert their functionality from n-type to p-type and vice versa depending on the gate bias.

3) SB CNTFETs are likely to suffer from the need to place the gate electrode close to the source which increases parasitic capacitance and metal-induced gap states, which increase source to drain tunneling and limit the minimum channel length

### SOLUTIONS

1) The DG-CNTFET [8] is effective in controlling the ambipolar conduction that is inherent to Schottky barrier (SB) CNTFETs using two independent gates, namely, the primary gate and the polarity gate. Whereas the primary gate serves to turn the device on and off, the polarity gate can be used to configure the device in either the p-type or the n-type mode of operation. The DG-CNTFET exhibits unipolar conduction and can achieve a large  $I_{ON}/I_{OFF}$  ratio of over six orders of magnitude.

2) When the gate oxide is thick, reducing the Schottky barrier height to zero suppresses the ambipolar conduction.

3) The MOSFET-like CNTFETs will suppress the ambipolar conduction that occurs in SB CNTFETs. They will also extend the channel length scaling limit because of the density of metal-induced-gap-states will be significantly reduced. Under on-state conditions, the MOS CNTFET will operate like a SB CNTFET with a negative Schottky barrier height, which delivers more on-current than SB CNTFETs with positive barrier heights [9]. Finally, the parasitic capacitance between the source and gate electrode will be reduced, which will allow faster operation.

4) A new structure in which one end of the carbon nanotube which forms the source is put in contact with the metal intrinsically and the other end of the CNT which forms the drain is doped with potassium and then contacted to the metal. This kind of CNTFET is known as **Schottky-Ohmic CNTFET (SO-CNFET)** [10]. Its current-voltage characteristic is unipolar. The off-current of the SO-CNTFET has a lower magnitude than conventional SB-CNFET. This is because in the SO-CNTFET in all the bias voltages the majority carriers are electrons and the

current originates from the tunneling of the electrons from the Schottky barrier at the source.

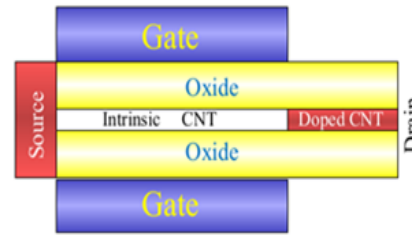


Fig.5: structure of SOCNFET


### V. CONCLUSION AND FUTURE SCOPE

Carbon Nanotubes possess number of remarkable electrical as well as mechanical properties and all in one single material. CNTs, which can be far stronger than steel, lighter than aluminum, and more conductive than copper, is one of the most promising materials of nanotechnology. Due to ambipolar behavior and low  $I_{ON}$  and  $I_{OFF}$  ratio, digital circuits designed using SBCNFET will have some defects which can be reduced using SOCNFET, in this there is no Schottky barrier and it is a unipolar device, so designing digital circuits by SOCNFET will give better performance in terms of delay, power consumption etc.

While CNTs are the most promising material, one of the challenges is fabrication techniques for CNT of particular type, length and diameter in controlled fashion. In SBCNFET ambipolar characteristic can be explored to build some new logic architectures that are different from conventional CMOS logic. This direction can create a new logic family based on CNTFETs.

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