CARBON NANO-TUBE FIELD EFFECT TRANSISTORS WITH IMPROVED CHARACTERISTICS

DR. DIWAKAR NATH JHA
ASSITANT PROFFESOR
DEPARTMENT OF PHYSICS,
M. K. COLLEGE, LAHERIASARAI, DARBHANGA, BIHAR, INDIA.

Abstract: Using Schrodinger –poison formalism, a Carbon Nano-tube Field Effect Transistor (CNTFET) has been studied. To improve the saturation range in the output characteristics, new transistor structures has been proposed. These structures are simulated and compared with the conventional structure. It is found that proposed structures have better output characteristic.

KEY WORD-Mathematical physics, electronics, double dielectric medium.

1.Introduction:

A CNT is a sheet graphene rolled-up as a tube ,with a diameter typically in the nanometer range, which can be from less than one nanometer,up to several nanometers. CNTs are one dimensional (1-d)device in which electron transport is quasi ballistic . Moreover, mobility of CNTs is considerably larger than silicon and can be as large as 10cm2/v.s. These properties have emerged CNTs as candidate for nanometer(10nm) electronic technology. CNTs can be semiconducting or metallic according to the chiral vector .Single wall semiconducting CNTs, with few nanometers in diameter can be as channels for field effect transistors (FETs).a zig-zag CNT field effect transistor with schottky barrier contacts is simulated and its characteristics are evaluated. Then, novel structures are proposed which have superior characteristics ,specially, for digital application.

2. CNT modeling:

We consider a (16.0) nanotube with radius R1=0.6nm, bandgap Eg=0.62ev,dielectric constant $\varepsilon_{r=1}$, **and the tube length Lt=20nm**. Due to the azimuthal symmetry of the tube, the simulation domain is two dimensional (2-D). The gate insulator has $\varepsilon_{ins}=25$ and thickness $R_g=2.5nm$. Drain and source metals make Schottky contact to the channel with $\Phi_b=0.3ev$.Figure1 shows the CNTFET structure.

To derive I-V characteristics of the transistor, the ID schrodinger equation is solved consistently with the Poisson's equation. Poisson's equation with azimuthal symmetry is:

$$\frac{\partial \frac{\partial v}{\partial \rho}}{\partial \rho} + \frac{1}{\rho} \frac{\partial \partial v}{\partial \rho 2} + \frac{\partial \partial v}{\partial z2} = -Q/\varepsilon - (1)$$

In this equation **ρ** is the tube radial direction, z is the channel direction, Q is the charge density on the tube surface and is derived from schrodinger equation.Poission's equation is solved using finite difference method. The charge density is zero everywhere except at the tube surface:

$$Q = \frac{q(p-n)\delta(\rho-Rl)}{2\pi\rho} - - - - - - - - - - - - - - - - - - - (2)$$

Where n and p are electron and hole densities respectively and are derived from the Schrodinger equation. In the carbon nanotube, the electron transport is almost ballistic therefore, the Schrodinger equation is solved to compute the charge density and the transmission probability:

$$\frac{\partial \partial \psi}{\partial z2} = -\frac{8\pi 2m}{h2}(E - U)\psi - - - - - - - - - - - - - - - - (3)$$

Where E is the electron or hole energy U is the potential energy, which is $-qv$ for the electron and $qv + E_g$ for the hole. The Schrodinger equation is solved using central difference discretization method.

For a conventional CNTFET depicted in fig.4.1, drain current (Id) versus drain-source voltage (v_{ds}) for various gate-source voltage (v_{gs}) is shown in fig.4.2. For V_{ds} up to 0.6v, output characteristics is similar to conventional FET transistors. But for larger voltages, the drain current is suddenly increased. This is due to the hole injection from the drain to the source. As this figure shows, the saturation region in the output characteristics is about 0.6v, which is small for typical applications. Figure 4.3 shows the electron potential energy for the gate voltage V_{gs}=0.4v and three values of drain voltages. For V_{ds} =0.2v electrons surmount (or tunnel) through the source and drain schottkey barriers and makes the drain current. With increasing the drain voltage, the potential on the drain side decreases and the electron current increases. At a special Vds, the drain barrier vanishes. If the schottky barrier equals $E_g/2$,at Vds=Vgs the drain barrier vanishes. In Fig.4.3 this happens for Vds=0.4v. For larger Vds, hole injection is increased. At Vds=2Vgs hole and electron current would be equal. Beyond V_{ds}=2Vgs, hole current will increase exponentially as is known for a schottkey diode.

3. Novel transistor structures:

In the conventional CNTFETs, for low vgs, exponentially increasing of the drain current takes place at low drain voltages (tens of iv). This limits usage of the transistor for most applications, especially for digital circuit. To overcome this problem one most prevent the drain schottky diome form entering on stat, and consequently increase the saturation rang in the output characteristics. In this section, novel structures are proposed in increase the saturation range.

4. Double dielectric:

For the transistor of Fig.4.1. if an insulator with higher dielectric is used, the gate control on the channel increases and vice versa. Keeping this in mind, the transistor in Fig.4.4 is proposed, in which, gate length is divided into two equal section. In this transistor, the gate dielectric at the drain side selected from a material with lower dielectric constant. Therefore, the gate control on the drain side of the channel is decreased. Fig. 4.5 shows Id-V_{ds} for this transistor. The dielectric constant at the drain side is assumed 5, where as at the source side the dielectric constant is assumed 25, As Fig.5.5 shows, the saturation range of the transistor is slightly increased.

5. Double metal gate:

In this structure, as the previous one, the gate length is divided into two parts, with uniform dielectric, but with different gate metals The gate metal on the drain side is selected with lower work function.Fig.4.6 shows I_d-V_{ds} for a transistor with gate metal of 0.2v lower work function. The figure shows that current saturation portion is almost 0.2v wider than the conventional transistor.

6. Partially gate metallization:

In this structure the gate metal on drain side is not deposited. With this, gate affects the channel near the source, and has no effect on the channel near the drain.Fig.4.7 depicts the I_d-V_{ds} characteristics of the transistor. It is obvious from this figure that the saturation range of this transistor is wider than two former structures. Moreover this structure is easier to fabricate.
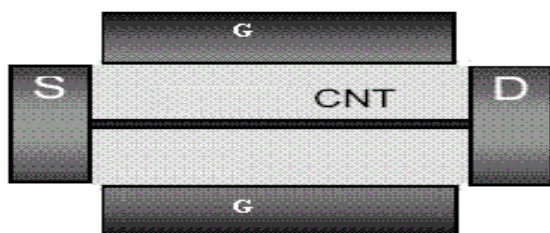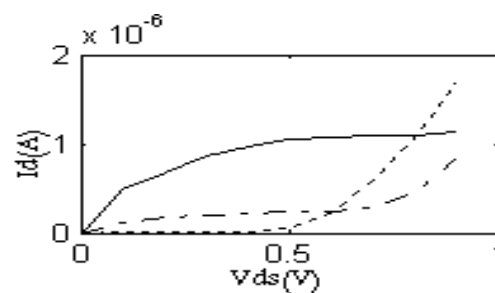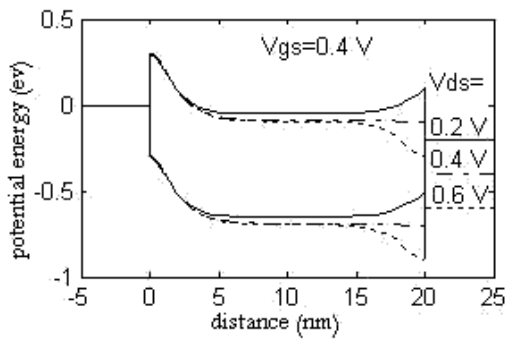

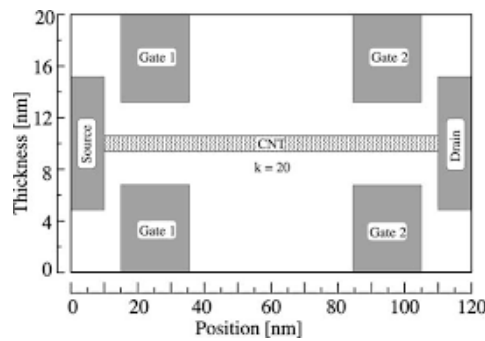Figure 4.1   Figure 4.2
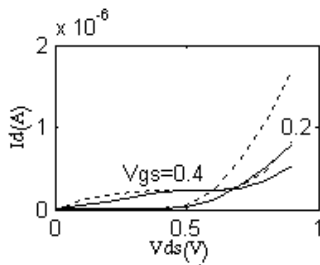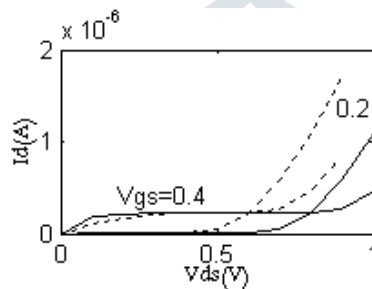
Figure 4.3

Figure 4.4
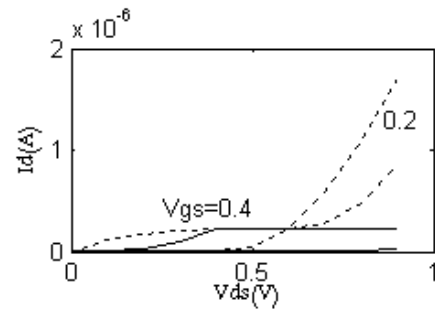

Figure 4.5

Figure 4.6

Figure 4.7

7. Discussion:

A CNTFET is simulated based on Schrodinger poisson formalism. This evaluation showed that the saturation range in the output characteristics is small. Three different structures are proposed to increase this range. It is shown that proposed transistors have wider FET saturation range. This makes them suitable for digital application.

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