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Performance Analysis of Mixed Carbon Nano Tubes as VLSI Interconnects

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Abstract

Background/Objectives: This paper presents various possible structures of Mixed Carbon Nano Tubes bundle which consists of different topology of Single Wall Carbon Nano Tubes (SWCNTs) and Multi wall Carbon Nano Tubes (MWCNTs). **Methods/Statistical Analysis**: It is assumed in this paper that SWCNTs and MWCNTs are densely packed. An equivalent single conductor model is derived for all the bundles of Mixed CNT. **Findings:** Performance is analyzed by considering parameters like Propagation delay, Power dissipation and Crosstalk delay of the interconnects having different lengths. **Applications:** Carbon Nanotubes finds applications in many fields such as biomedical applications, air and water filtration, structural applications etc.

Keywords: Crosstalk, Equivalent Single Conductor (ESC), Mixed Carbon Nano Tubes (MCB), Power Dissipation

1. Introduction

Carbon nanotubes, just by conduction, tend to be classified directly into Metallic as well as Semiconducting. The semiconducting CNTs will never play critical role throughout conduction therefore for interconnects metallic are preferred. The categories of CNTs tend to be decided by chirality. Chiral index/catalog decides perhaps the CNT formed will be metal or perhaps semiconducting. Around the time framework of geometric design CNTs usually are broadly categorized as SWCNT (Single walled CNT) and as well MWCNT (Multi walled CNT). CNTs having a thin layer of graphene wall sheet will tend to be SWCNTs. The CNTs which will include a multiple involving concentric SWCNT are named as MWCNT. Multiwall CNT contains concentric SWCNTs. While SWCNTs could possibly be either metallic as well as semiconducting conditional after their own chirality. Chirality defines as the way the graphene rolls up when it is fabricated. There are of three types namely armchair, zigzag and chiral nanotubes. Zigzag and chiral nanotubes are mainly semiconducting i n nature whereas armchair are mainly metallic Also, Multi Wall CNTs possess comparable latest having potential (as steel SWCNTs) nevertheless are more advanced than fabricate in comparison with SWCNTs caused by easier control in the growth method. Even therefore, due for their simple design, SWCNTs could possibly be modeled more very easily than MWCNTs. The sophisticated structure shaped by several concentric shells makes analysis as well as design involving MWCNT interconnects accumulates difficulty[1-5]. Some carbon nano tube can stand up to a temperature of 200°C. They have current density of 10^{14}A/m^2, high thermal stability of around 5800W/mK and high mechanical stability also. If an isolated CNT is used then it becomes tedious to possess a good contact and these imperfect get in touch which increases the resistance to an array of 7kΩ-100kΩ. To avoid this, a bundle of CNTs are used to make interconnects. A bundle of CNT is many CNTs connected electrically parallel together. In the bundle some CNTs are metallic and several are semiconducting in nature. The SWCNT within the bundle have higher conductivity seeing that compare to MWCNTs as SWCNT provides longer mean

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free as compare to MWCNTs. Metallic carbon nano tubes tend to be potentially viable for use as interconnects greatly assist large mean-free path which brings about low resistance and low electro-migration which in turn increases current carrying capability. VLSI interconnects are categorized in line with their lengths as Local, Semi- Global and Global. If the interconnect connects the nearby nodes and is also of shorter length then it truly is categorized as local interconnect and when it is of intermediate length then it's named Semi-global. The one that connects several nodes throughout the chip like ground lines, clock lines etc is known as Global interconnects. If interconnect duration is increased then R, L, C also increases which even more delay the signal propagation and makes the circuit unreliable[1-5].

In recent past various analyzes is been carried out for SWCNTs and MWCNTs of different diameters. It is been observed and validated that SWCNT bundle gives better results in case of global and intermediate interconnects. When the mean free path is restricted to 1um but MWCNTs have been optimistic in on-chip applications.

2. Various Mixed CNT Structures

SWCNTs deliver more desired results as compared to MWCNTs as, only the outer most shell makes contact with the metal. A mixed CNT bundle are usually a combined CNT bundles consisting of multi-walled as well as single walled CNTs. By this, various structures are usually possible Figure 1 shows various possible structures which can be taken for making a Mixed CNT Bundle. In MCB-I, SWCNTs are placed at the center whereas MWCNTs are placed on the periphery. MCB-II is exact replica of MCB-I i.e SWCNTs at the periphery and MWCNTs at the center. In MCB-III and MCB-IV, SWCNTs and MWCNTs takes equal halves as horizontally and vertically respectively.

The average no. of conducting channels of shell in Multi Wall CNT is calculated as

$$N_i(D_i) \approx k_1 T D_1 + k_{2,} D_i \succ d_T / T$$
$$N_i(D_i) \approx 2/3, D_i \leq d_T / T \quad (1)$$

Right here, Di denotes the actual diameter belonging to ith shell within the Multi Wall CNT (or the actual Single Wall CNT), k_1 in addition to k_2 tend to be equal to (3.87 × 10^{-4}) $nm^{-1}K^{-1}$ and (0.2 × 10^{-4}) $nm^{-1}K^{-1}$, respectively. The thermal strength of electrons in addition to hole involving the subbands establishes the actual quantitative benefit of equal to 1300 nm•K for temperatures of 300K[4].No. of channels for Mixed CNT bundle taking into consideration all SWCNT and MWCNT bundle can be seen as summation of all its channels (Ni)[5,6].

$$N_{Total} = \sum_{i=1}^{n_{CNT}} N_i \quad (2)$$

The Mean Free Path is proportionally to the diameter of each Single Wall CNT and Multi Wall CNT is given by[5]

$$\lambda_{(mfp)} = \frac{10^3 D_i}{\left(\frac{T}{T_o}\right) - 2} \quad \textbf{(3)}$$

Where, To=100k.

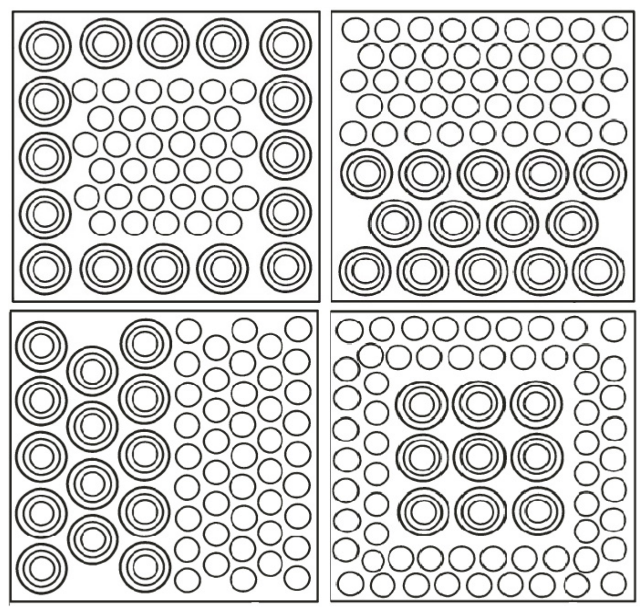

Figure 1. Various Mixed CNT structures named as MCB-I, MCB-II, MCB-III, MCB-IV.

Figure 1 the assumption is that most shells regarding MWCNTs have been in parallel and also related on the two finishes. By taking into consideration an equal prospective throughout just about every shell, an easier comparative type is actually presented intended for MWCNTs possessing distinct number of shells. The effectiveness for every unit size inductance and also capacitance might be indicated by[5,6].

$$L'_{ESC} = L'_{kESC} + L'_{eESC} \tag{4}$$

$$C'_{ESC} = \left(C'^{-1}_{qESC} + C'^{-1}_{eESC}\right)^{-1}$$

Where,

L'_{kESC} = Kinetic Inductance of the Bundle

L'_{kESC} = Kinetic Energy produced

C'_{qESC} = Quantum capacitance of the bundle

C'_{qESC} = the finite density of states at Fermi energy[5].

Therefore, L'_{kESC} and C'_{qESC} is calculated as

$$L'_{kESC} = \frac{L'_{K0}}{2N_{Total}}; L'_{k0} = \frac{h}{2e^2 v_f} \tag{5}$$

$$C'_{qESC} = 2N_{Total} C'_{qo} \tag{6}$$

$$C'_{qo} = \frac{2e^2}{hv_f} \tag{7}$$

Where, L'_{k_0} and C'_{q_0} indicates the kinetic inductance and quantum capacitance respectively. At the two finishes, tube has a lumped resistance $R_{tESC}/2$. The R_{tESC} can be calculated as

$$R_{tESC} = \frac{R_0}{N_{Total}} + R_m \tag{8}$$

Where, R_0 denotes the intrinsic DC resistance of Carbon nano tube and is equivalent to $h/4e^2$ ≈ 6.45 kΩ. The term R_m denotes incomplete metal and nanotube contact resistance which almost equals to 3.5 kΩ. .The R'$_{ESC}$ can be expressed as [5,6].

$$R'_{ESC} = \left(\frac{h}{4e^2}\right) \cdot \frac{1}{\lambda_{mfp} N_{Total}} \tag{9}$$

(9)

Here, the external capacitance C'_{eESC} is the electrostatic capacitance of the CNTs w.r.t ground. The common mode capacitance of bundled CNTs C'_{eESC} is calculated as

$$C'_{eCM} = \left[\frac{2\pi\varepsilon}{Cosh^{-1}(H/d_g)}\right] \tag{10}$$

$$C'_{eCM} = \sum_{i=1}^{N_{ground}} C'_{eESC}(i)$$

Here, d_g denotes the diameter of every distinct nanotube w.r.t ground. H = $h_t + d_g/2$ denotes the space from ground to Single wall CNTs and Multi Wall CNTs. The effective magnetic inductance L'_{eESC} denotes the stored energy of particular current flow and is given as

$$L'_{eESC} = \frac{1}{N_{Total}}\left[\frac{\mu_0 \varepsilon_0}{C'_{eESC-CM_0}}\right] \tag{11}$$

Here, $C'_{eESC-CM_0}$ is the common mode electrostatic capacitance of the Equivalent Single Conductor implanted in the free space.

3. Performance Analysis Of Mixed CNT Bundle

3.1 Power Dissipation

Figure 2 a CMOS driver is used to drive the mixed CNT Bundle. Also, Figure 3, it is stated that due to more no. MWCNTs in MCB-I as compare to MCB-IV, there is less propagation delay in MCB-IV as compare to MCB-I. This is due to the reason that MWCNTs are low in conductance as compared to SWCNTs and in MCB-I there are less in count[7].

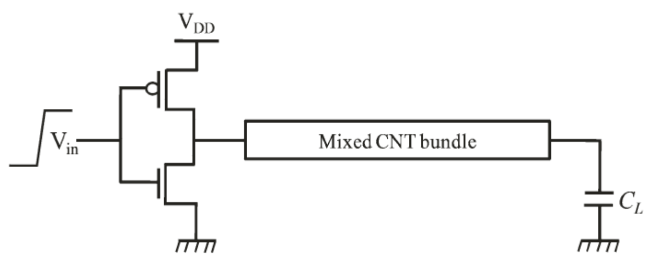

Figure 2. Driver In Line with CMOS Driver.

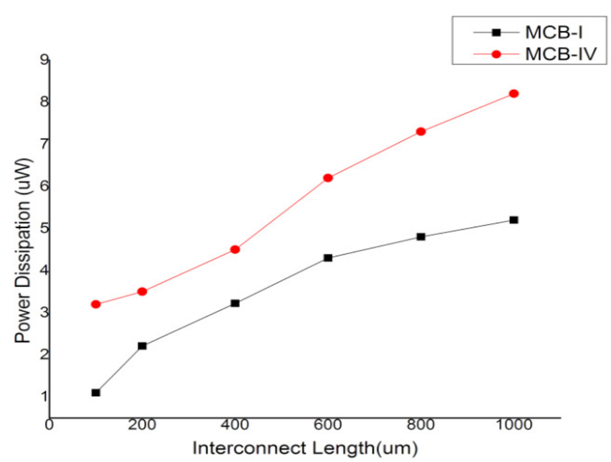

Figure 3. Power dissipation of MCB-I, IV at various lengths of interconnects.

3.2 Propagation Delay

For Figure 4 as stated earlier, no. of MWCNTs are less in MCB-IV as compared with MCB-I, therefore there is high current conduction which leads to more power dissipation in MCB-IV as compared to MCB-I[8-10].

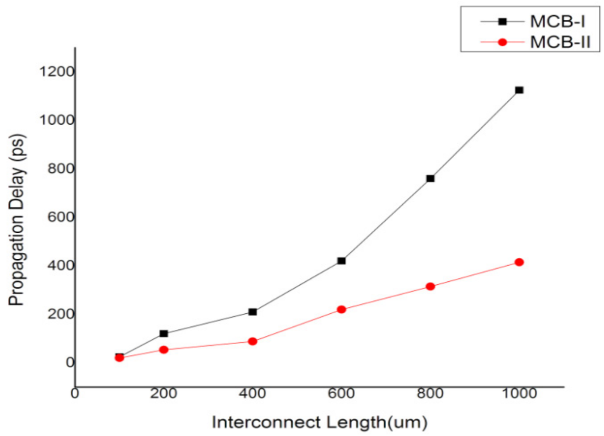

Figure 4. Propagation delay of MCB-I, IV at various lengths of interconnects.

3.3 Delay Due to Crosstalk

In the Figure 5, there are two capacitive coupled lines in which one is taken as aggressor and the other is used as a victim. Here, we are using CMOS driver to calculate the exact delay caused by the crosstalk. For different structures of mixed CNT, crosstalk induced delay is calculated for lengths ranging from 100um to 1000um[8-10].

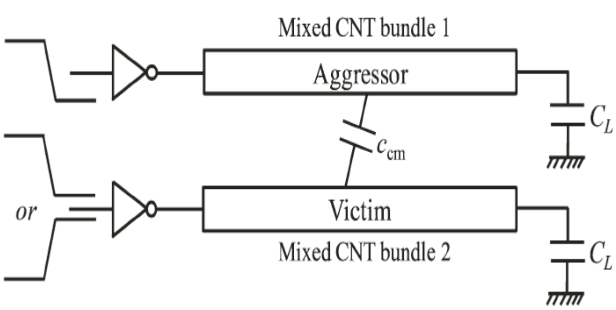

Figure 5. Capacitive based coupled interconnects lines.

It is been noticed that as the lengths of interconnects increases, so is the crosstalk caused delay as shown in Figure 6 and Figure 7. Because of Miller Capacitive Effect, it is perceived that for a fixed length of interconnect, out phase delay is more than in-phase delay.

Out of all MCBs considered, crosstalk caused delay in MCB-I is lesser that MCB-II, III, IV as shown in Figure 6-9. and this is due to the arrangement of SWCNT and MWCNT in it. The MWCNT are in the periphery which is actually working as a good shield between two coupled lines.

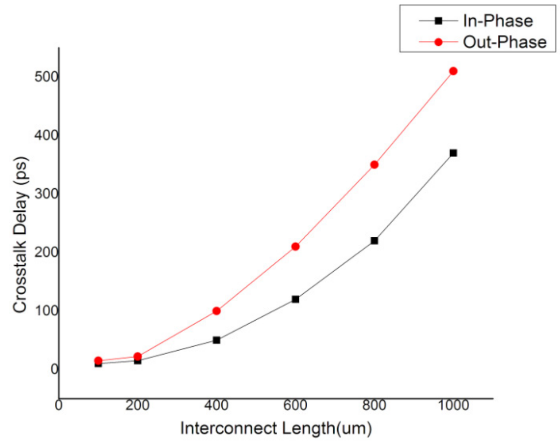

Figure 6. Crosstalk causing delay of MCB-I at various lengths of interconnects.

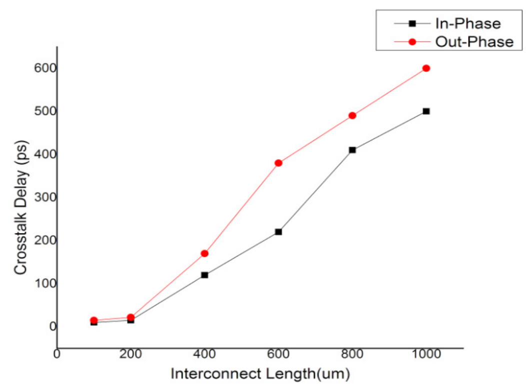

Figure 7. Crosstalk causing delay of MCB-II at various lengths of interconnects.

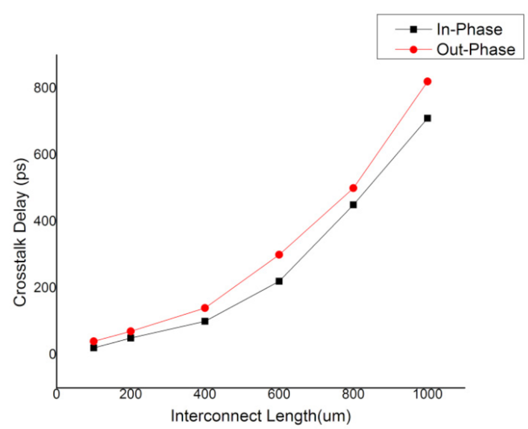

Figure 8. Crosstalk causing delay of MCB-III at various lengths of interconnects.

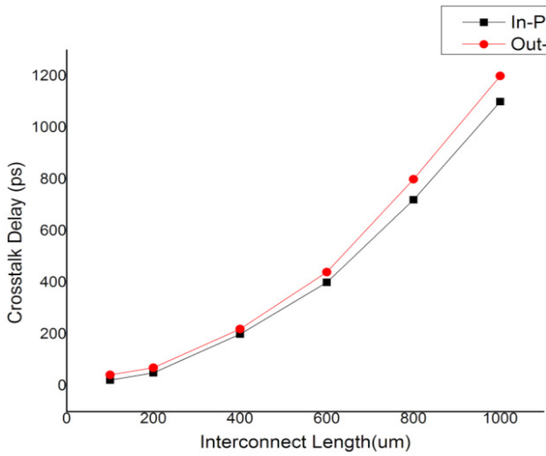

Figure 9. Crosstalk causing delay of MCB-IV at various lengths of interconnects.

4. Conclusion

Simulation set up used CMOS driver at 32nm technology node. It is concluded that propagation delay of MCB-I is more in comparison to MCB-IV whereas power dissipation of MCB-I is less than MCB-IV. The contagious layout of MCB-I, in which all the MWCNTs are placed at the boundary serving as armour between the coupled lines. Due to this reason, crosstalk delays in In-phase and Out-phase using MCB-I is almost 63.67% and 53.91% respectively as compared to MCB-IV.

5. Acknowledgment

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