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New Comprehensive Stability and Sensitivity Analysis on Graphene Nanoribbon Interconnects Parameters

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ABSTRACT

Based on the transmission line modeling for multilayer graphene nanoribbon (MGNR) interconnects, system stability was studied on intrinsic parameters. In addition to width, length, and height variation, dielectric constant, permeability, and Fermi velocity path change in multilayer graphene nanoribbon (MGNR) interconnects are analyzed. In this paper, the obtained results show with increasing dielectric constant and decreasing permeability and Fermi velocity system becomes more stable. Nyquist diagram and step response method results confirm each other and are matched with physical parameter variation like resistance, capacitance, and inductance in the following sensitivity analysis results show with increasing width and length sensitivity will decrease and increase respectively. Impulse response diagram results show with increasing 50% width sensitivity will be zero but with increasing 50% length amplitude will decrease and the time of setting will increase. On the other hand, from the step response of the transfer function, both width and length increase cause more stability for a system but the width parameter will be a better choice for manipulating the dimension of MGNR to reach a stable system.

Keywords: Multilayer graphene nanoribbon interconnects, Nyquist Stability, Step Response, intrinsic feature,RLC model.sensivity

1. INTRODUCTION

The role of graphene nanoribbon in the nanoelectronics industry is very prominent and many activities have been performed in this field. Length and width increase leads to a higher crosstalk voltage and the system becomes unstable. The graphene's superiority over the copper wires is kept even with the worst crosstalk [1]. Crosstalk effects on graphene stability Multilayers have been investigated using time-domain response and Nyquist stability in Akbari and his colleague's research, it is observed that the near-end output of the system together with both couplings is more stable and at its far-end output [2]. Modeling and Simulation-based on Carbon Nanotubes and Graphene Nanoribbons for FET Transistor [3]and Stability analysis of multilayer graphene for the effect of switching on the noise voltage using the Nyquist method[4] are other researches in this field. Bandwidth variations and their impact on the stability of multilayer graphene using the Nichols method based on a new model which increases the length or decreases the width of the MGNRs, the stability increases in near-end output, and an increase in the length or width of MGNRs, stability decreases in far-end output [5]. A comparative study on their distributed parameters and transmission characteristics is performed in Wen-Sheng Zhao et al paper. The transmission performance of the MGNR interconnects with different contacts is predicted and compared with their Cu and carbon nanotube counterparts at different technology nodes [6].

Chuan Xu et al. investigated the nanostructured graphene multilayer model and its analysis of zigzag distribution [7]. Problems in copper circuits can be solved by replacing carbon nanotubes, for example, the carbon system has a higher heat-carrying capacity than the copper system because of its bundle [8]. By studying the structural properties of graphene, we have found that graphene is a material from a layer of carbon atoms with hexagonal structures, which is a two-dimensional lattice. Since the thickness of this sheet of carbon atoms is only about the size of a carbon atom, it is considered to be a thin material [9]. Hafeng et al. investigated the physical properties of graphene and expressed the effect of adding nitrogen to the graphene structure, which graphene is used in energy and medicine, reducing pollutants and biotechnology [10]. Graphene optical interconnects for data centers need more interconnection between machines is another usage of graphene [11]. Manjit et al. investigated the impact of crosstalk on delay and the effect of crosstalk on the average power and noise of the multilayer graphene nanoribbon model [12, 13]. Nanorobots are very useful in the treatment of diseases, and the material of nano-robot used in this article is carbon [14].

In this paper, graphene stability criteria by the Nyquist diagram and step response method are investigated. Graphene communication lines can be used in industrial applications. Directly changing the intrinsic parameters of the communication lines such as the permeability, Fermi velocity, and dielectric constant of the nano-ribbon is analyzed. Any of these changes will certainly affect the performance of graphene nanotubes used in the design of electronic circuits. And achieving the optimum point in the nanoribbon stability will guarantee the best performance of the systems that used this technology. Also, the interaction between the mentioned intrinsic parameters is investigated. It is expected that with changing physical parameters, we will see relative stability change. In the meantime, the behavior of graphene communication lines will also change with changing parameters. And investigate the sensitivity of graphene nanoribbon models. Section 2 proposes a model of the system and in section 3 sensitivity algorithm is studied in part 4 result of the research is written.

2. MATERIAL AND METHODS

The schematic shape of the multilayer graphene nanoribbon-based communication lines is shown from the front view in Figure 1.

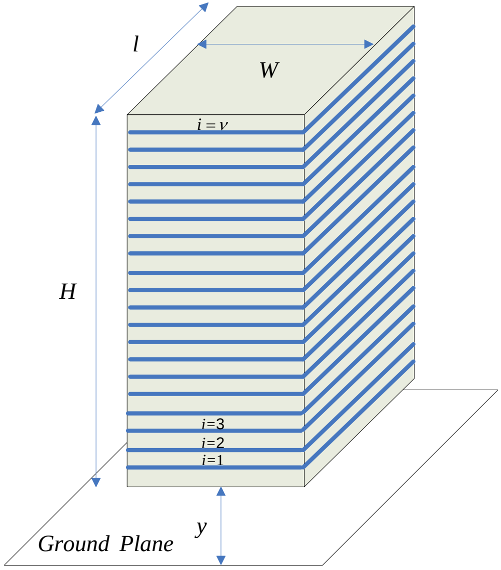


Figure 1:Schematic of graphene nanowire-based communication lines

Figure 2 and Figure 3 shows a distributed model of graphene nanoribbon.

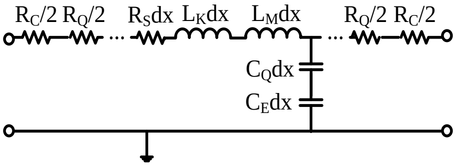


Figure 2:typical RLC model for MGNR interconnects

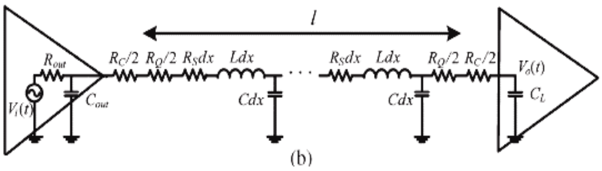


Figure 3: transmission line circuit model for a driver-MGNR interconnect

in typical RLC model for an MGNR interconnect made of N_{layer} single GNR layers of the same lengths l and widths W are represented. $R_Q = (\frac{h}{2e^2})/(N_{ch}\nu) = (\frac{h}{2e^2})/(N_{ch}N)$ is the minimum inherent resistance of quantum wire Planck's constant(h), and charge of electron(e)). When the wire length larger than the electron effective mean free path (λ), the distributed resistance (R_S) is introduced by electron scatting and can be written as $R_{\,s} = {}^{R_Q}/_{\lambda}$.[15]

$C_E \approx {}^{\varepsilon W}/_{d}$ and $L_M \approx {}^{\mu d}/_{W N_{layer}}$ are the length values of the equivalent capacitance per unit induced by the electrostatic effects and the magnetic inductance, in presence of the ground, in which e and μ are the dielectric permittivity in graphite and the graphene permeability (μ = 1)[16].Furthermore, $L_K = {}^{R_Q}/_{v_F}$ and $C_Q \approx \{R_Q v_F\}^{-1}$ are kinetic inductance and quantum capacitance, respectively [17,18].
y, R_{out} , C_{out} , C_L , N_{ch} , υ and ν and v_F are height from earth, output resistance, output capacitance, load of capacitance, Number of channels per layer, total available channels for carriers, layers of multilayer graphene nanoribbon, and Fermi velocity in graphite, respectively. single layer graphene nanoribbon has high resistivity and the number of transmission channels is limited to the only, so they increase the number of layers to reduce the resistance rather than increasing the bandwidth to achieve a higher channel number. Between the graphene nanoribbons.
In order to obtain the number of conducting channels in each GNR, one can add up contributions from all electrons in all conduction sub-bands and all holes in all valence sub-bands

$$N_{ch} = \sum_{i=1}^{n_C} [1 + e^{(E_{i,n} - E_F)/K_B T}]^{-1} \qquad (1) + \sum_{i=1}^{n_V} [1 + e^{(E_F - E_{i,h})/K_B T}]^{-1}$$

E_F , K,T and $E_i = {}^{ihv_F}/_{2W}$ are Fermi energy, Boltzmann constant , temperature and the quantized energy that corresponds to the i_{th} conduction respectively[19]. Taking advantage of the distributed nature of the interconnect into account, considering the interconnect as an *RLC* transmission line circuit model with perfect contacts ($R_C = 0$), and using the fourth-order Padé's approximation, the input–output transfer function becomes [20, 21].

$$H(S) = {}^{V_O(S)}/_{V_i}(S) \approx (\textstyle\sum_{i=0}^{4} b_i s^i)^{-1} \quad (2)$$

b_i.

3. Sensitivity analysis of GNR model

All circuits have performance that varies as the value of the components change. sensitivity importance is to choose the proper component selection and reach a stable system. Here the change of transfer function in equation 2 related to a specific component investigated. [22,23].the mathematical definition of sensitivity:

$$S_x^y = \underset{\Delta x \longrightarrow 0}{Lim} \left\{ \frac{\frac{\Delta y}{y}}{\frac{\Delta x}{x}} \right\} = \frac{x}{y}\frac{dy}{dx} \qquad (3)$$

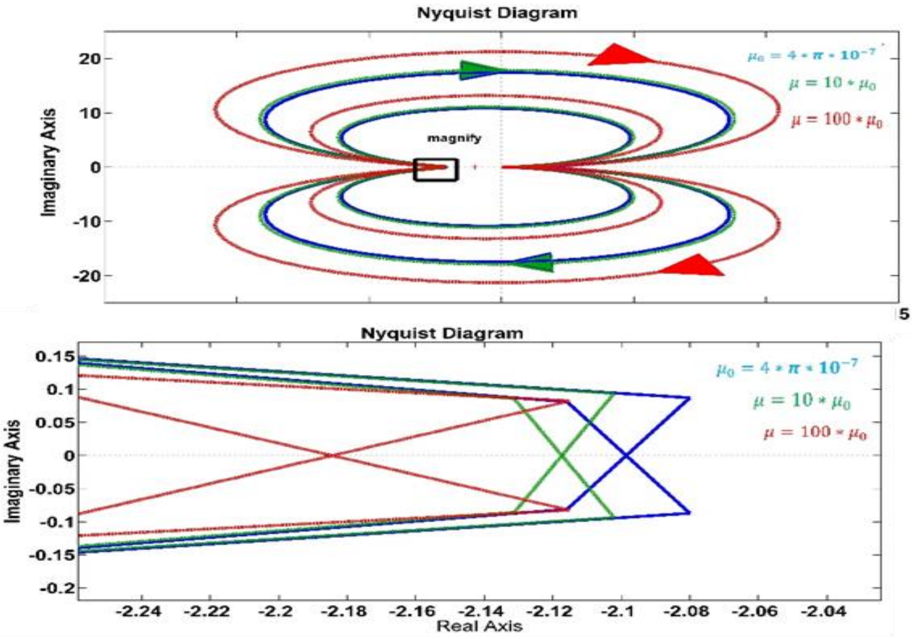
x:variable
y:transfer function.

According to equation (3), we may interpret the sensitivity is as the ratio of the little change in the circuit function y to the little change in the parameter x, provided that all changes are enough small (approaching zero theoretically). Sometimes we refer to S_x^y as the normalized sensitivity, in contrast with the unnormalized sensitivity, which is simply the partial derivative $\frac{dx}{dy}$. Sensitivity studies are a basic step before calibration to identify the main parameters. One of the parameters is changed by a certain percentage assuming the other parameters are constant. Sensitivity analysis can be applied to explore the robustness and accuracy of the model results under uncertain conditions.

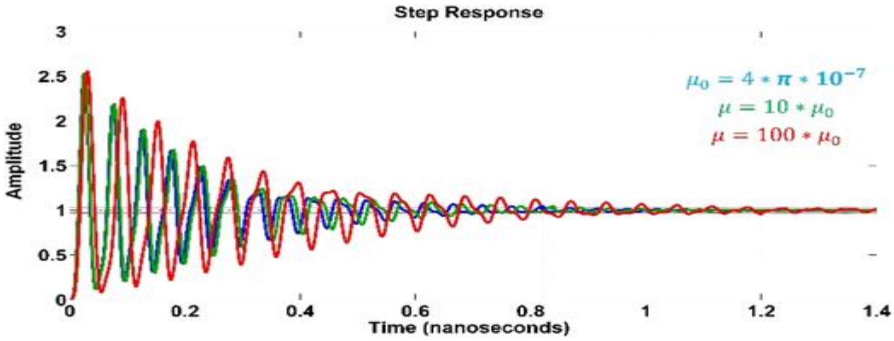
If A is more sensitive than parameter B (meaning that the decision d is more sensitive to a unit change in parameter A than to a change in parameter B).so parameter A is more important than another one.

3. RESULTS AND DISCUSSION

According to the MGNR model, Nyquist stability and step response for dielectric constant, permeability, Fermi velocity, and mean free path are investigated. The parameters value are: W=10 nm, H=10 nm, y=100 nm, L=100 µm, EF=0.3eV, p=0, $Rout$=0 kΩ, $Cout$ =5fF and CL=5fF. For Nyquist stability analysis, the critical point of (−1, 0) in the complex plane must be outside of the Nyquist diagram for a stable system, and for step response, stable system become damper.



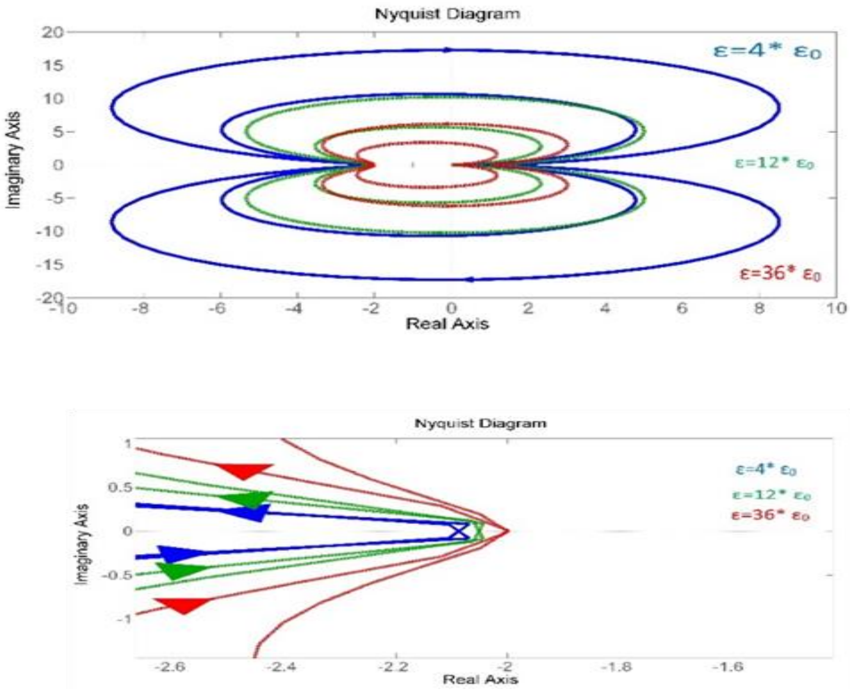
(a)



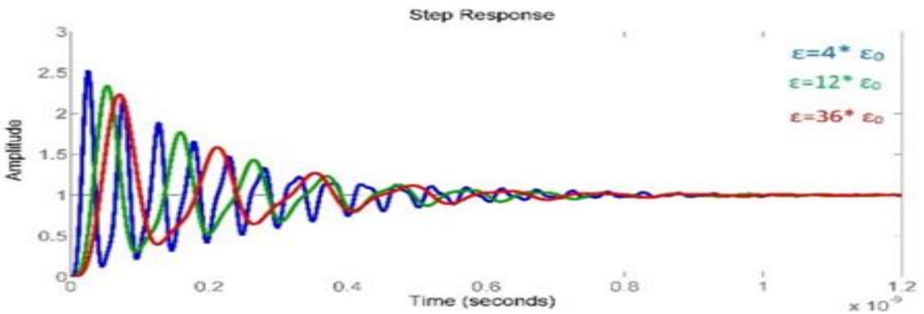
(b)

Figure 4: permeability change for μ_0 , $10\mu_0$, $100\mu_0$ investigated in (a)Nyquist stability analysis ,(b)Step response for MGNR model

Figure 4 show the effect of graphene nanoribbons permeability variation on the stability of the MGNR model. as shown in Figure 4 (a) with increasing amount of permeability system goes farther from the critical point (-1,0), which means our system becomes unstable because in Nyquist diagram critical point (-1,0) must be out of the diagram.in Figure 4(b) step response for ,10 ,100 are shown.that indicate our system with decreasing become damper. For RLC circuit damping ration is ζ=$\frac{R}{2}\sqrt{\frac{C}{L}}$ and L=$\mu d / W N_{layer}$ .with increasing, magnetic inductance increase and ζ decrease that means permeability (μ) effect on delay of system is undeniable.



(a)



(b)

Figure 5: dielectric constant change for $4 * \varepsilon_0$ *,* $12* \varepsilon_0$*,* $36 * \varepsilon_0$*investigated in (a)Nyquist stability analysis ,(b)Step response for MGNR model*

(a)

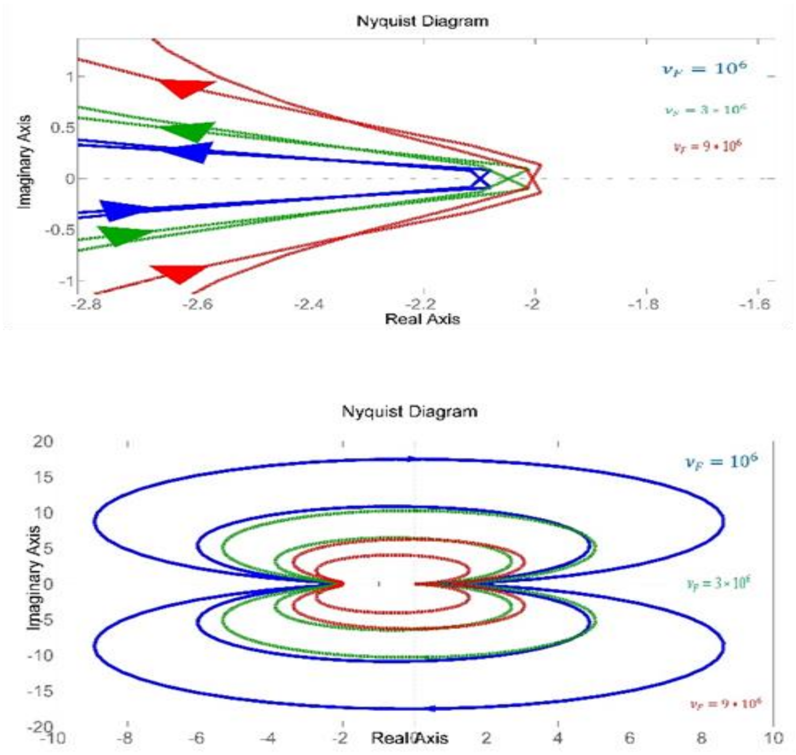
(b)

In *Figure 5*, graphene nanoribbons dielectric constant (ε) change effect on the stability of MGNR model is investigated.

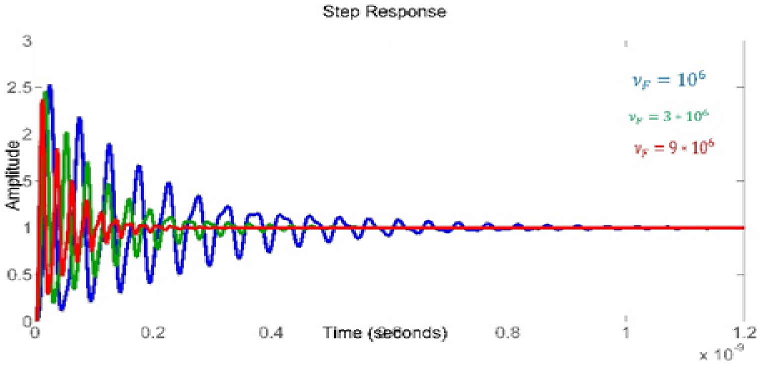
(a)

(b)

Figure 5(a) shows, with increasing amount of dielectric constant system goes closer to a critical point (-1,0), that means our system becomes more stable because in Nyquist diagram critical point (-1,0) must be out of the diagram.in Figure 5(b) step response for, are shown. That indicates our system with increasing become damper. For RLC circuit damping ration is $\zeta = \frac{R}{2}\sqrt{\frac{C}{L}}$ and $C = {}^{\varepsilon W}/_{d}$.with increasing ε, electrostatic capacitance of GNR increase and ζ increase that means system will be more stable.



(a)



(b)

Figure 6: Fermi velocity (v_F*) change for* 10^6 , $3 * 10^6$, $9 * 10^6$*investigated in (a)Nyquist stability analysis,(b)Step response for MGNR model*

Figure 6 show effect of graphene nanoribbons . V*elocity(*v_F *) variation on stability of MGNR model.as shown in* ***Error! Reference source not found.***(a) with increasing amount of Fermi velocity system goes farther from critical point (-1,0) ,that means our system become unstable because in Nyquist diagram critical point (-1,0) must be out of diagram.in (b) step response for10^6 , $3*10^6$, $9*10^6$ are shown.that indicate our system with decreasing $v_F$become damper. For RLC circuit damping ration is $\zeta=\frac{R}{2}\sqrt{\frac{C}{L}}$ and$L_K={}^{R_Q}/_{v_F}$ and $C_Q \approx \{R_Q v_F\}^{-1}$ kinetic inductance and quantum capacitance respectively.

$C_{total}={}^{(C_Q*C_E)}/_{(C_Q+C_E)}$ and $L_{total}=L_M+L_Q$

With increasing v_F , C_Q and L_K decrease so decreasing in C_{total} is more than L_{total} it cause decreasing ζ and system damping ratio decrease.

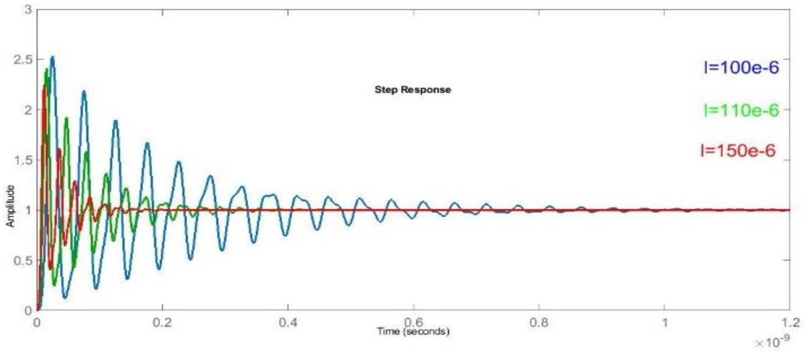


Figure 7:Step response for L=100e-6 , L=110e-6,L=150e-6 for MGNR interconnects(W=100e-6)

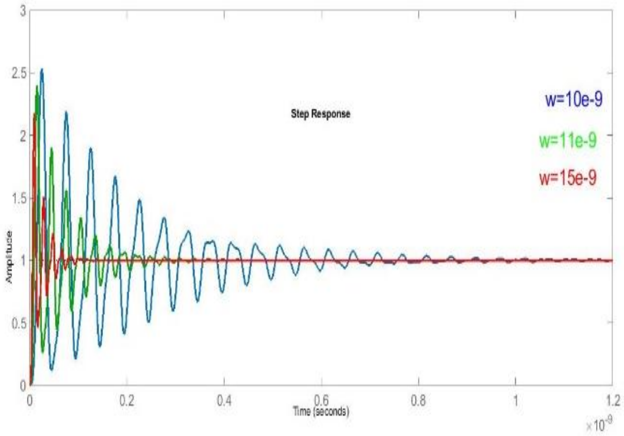


Figure 8: Step response for W=100e-6 , W=110e-6,W=150e-6 for MGNR interconnects(L=100e-6)

As shown in Figure 7 and Figure 8 with length and width increase system stability increase. Step response in 10% , 50% variation investigated.in addition to system sensitivity analysis for L,W proposed. $S_L^{H(s)}$ *and* $S_W^{H(s)}$ are sensitivity of system transfer function on length and width of MGNR.

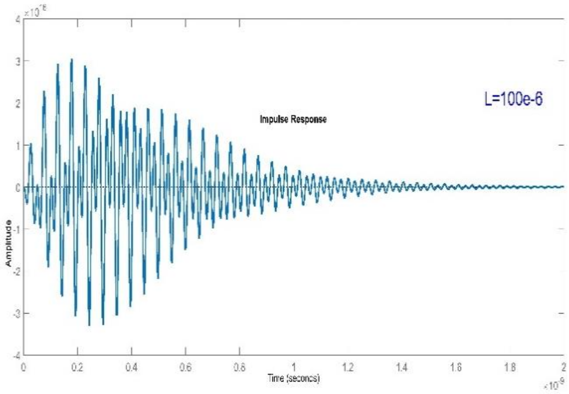


Figure 9: Impulse response for sensitivity of system on length with L=100e-6.

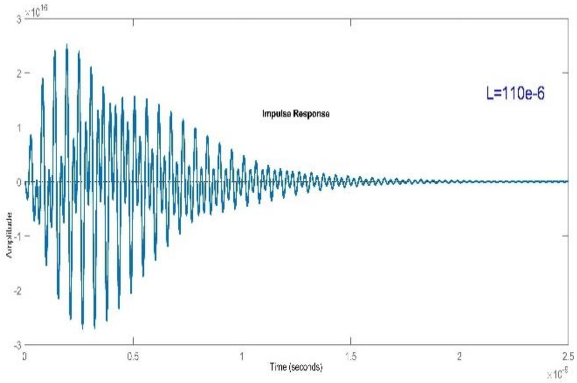


Figure 10: Impulse response for sensitivity of system on length with L=110e-6.

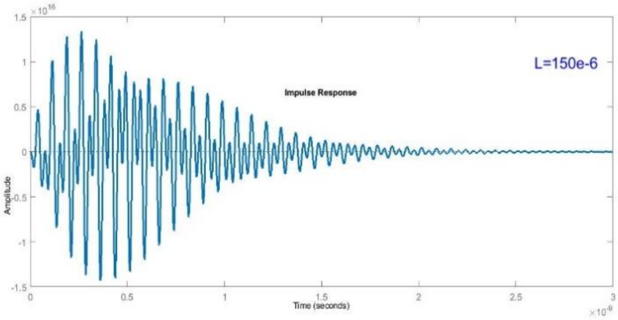


Figure 11: Impulse response for sensitivity of system on length with L=150e-6.

Figure 9 and Figure 10 and Figure 11 demonstrate sensitivity to change with increasing length of system. With length increase 10% and 50% amplitude of impulse function will decrease but time to reach zero will increase that mean sensitivity of the system to noise will increase.

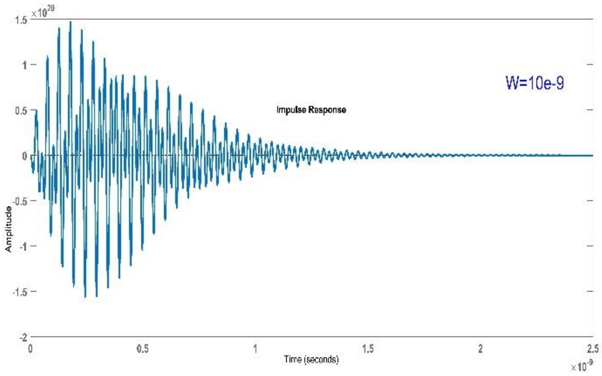


Figure 12: Impulse response for sensitivity of system on length with W=100e-9.

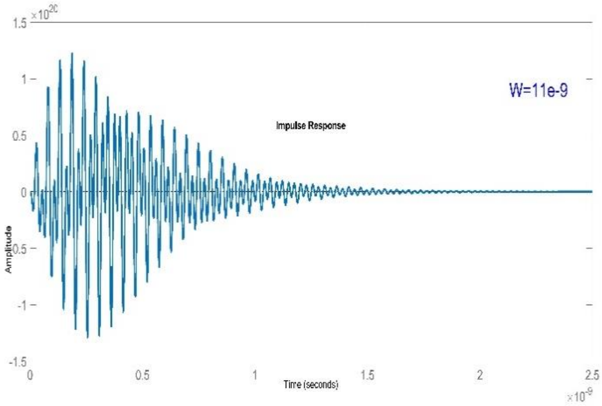


Figure 13: Impulse response for sensitivity of system on length with W=110e-9.

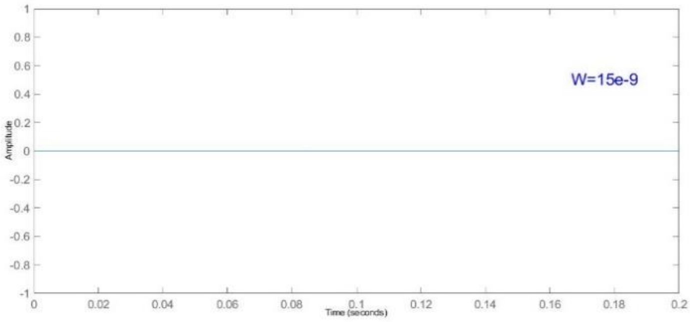


Figure 14: Impulse response for sensitivity of system on length with W=150e-9.

Figure 12 and Figure 13 and Figure 14 demonstrate sensitivity to change with increasing width of the system. With width increase, 10% and 50% amplitude of impulse function will decrease and time to reach zero will decrease the mean sensitivity of the system to noise will decrease and will reach zero in 50% increase in width of the system.

with compare impulse response of sensitivity function for six-figure, this results can be earned:1-ten and fifty percent increase in the amount of length and width reduces sensitivity.2-in fifty percent increase, sensitivity on width goes to zero.3.amplitude of sensitivity in transfer function on length variation goes to zero with the increase of length.

So to reach a stable system with minimum sensitivity, manipulating width against length is a better choice.

4. CONCLUSION

Based on the transient model of graphene nanoribbon, stability of graphene nanoribbons using Nyquist and step response method investigated and the result is that increasing dielectric constant and decreasing permeability and Fermi velocity cause increasing stability. In this paper, the effect of constant parameters is studied because changes in other parameters like length and width in some regions make the system unstable with changing these factors the total system stability will upgrade and the application of graphene nanoribbons will be robust. And sensitivity analysis on the width and length of the system is done and the result shows us the width of MGNR will be comfortable to manipulate to reach the stable system. On the other hand removing noise from the system by the width is very suitable and width parameter will be a better choice for manipulating the dimension of MGNR to reach a stable system. the main goal of sensitivity analysis is to reach zero sensitivity for reducing the noise effect Future research can discuss changes in intrinsic characteristics Simultaneous with physical parameters like length and analyze their effect on each other and system stability.

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