

Graphene Based Planar VLSI Interconnects

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Abstract- Recently graphene nano-ribbon is a strong candidate for future VLSI interconnects systems. Cu interconnect systems were used in past but as technology node decreases the above interconnect system faced many problems. The VLSI interconnects which are mainly used at high frequencies or in nano-scale region are planar interconnects (GNR) and non-planar interconnects (CNT). This paper review the published research work related to graphene based planar VLSI Interconnects.

Keywords— Interconnect, Graphene Nano-ribbon, Single wall CNT, Multi wall CNT, Multi layer GNR.

I. INTRODUCTION

In recent years graphene have attracted a lot of interests of researchers due to its applications in the area of devices and interconnects [1-4]. The electrons move without scattering in graphene [5-7] which makes it suitable for applications in the field of interconnects and switching devices. For small dimension devices, there are problems of grain boundaries and sidewalls scatterings in interconnects [8]. Therefore, it has become necessary to search an alternative solution for global VLSI interconnects. Literature shows that GNRs is a strongest contender due to its superior performance characteristics against the existing interconnects.

II. THEORIES FORMULATED FOR GNR

Giem et al. [9] shows that in the electronic and thermal properties graphene nano-ribbons (GNRs) and carbon nanotube interconnects (CNT) similar.

Han et al. [10] show that graphene ribbons can be patterned using lithography processes, and studied the electron movement. Author has investigated in this paper and indicated that the energy gap is created near the charge neutrality point due to the lateral confinement of carriers, and energy gap can be changed during the process of fabrication with appropriate choice of width.

Pribat et al. [11] suggested that recent researches show the graphene has many applications in many fields. Yu et al. [12][13] showed the performance of CNT based transistors that can be improved by making its electrodes through graphene, and used to realize better memory system. Since it is not possible in real sense to control the nano-ribbon of smaller width, therefore scientists unzip the multi wall carbon nanotube (MWCNT) to achieve smaller width GNR [14].

A comprehensive model to calculate the resistance value in GNR has been presented Ragheb in [15]. With the use of proposed model the resistance values of multi layer GNR has been compared with that of single wall carbon nanotube (SWCNT) and Cu interconnects.

Thermal conduction property of suspended single layer GNR is studied by Balandin [16] and concluded that the single layer GNR has 5300W/mK value of thermal conductivity at room temperature.

The delay performance of GNR has been studied by Banerjee et al. [17][18] using a conductive model. From the results presented in the paper authors revealed that zigzag multi layer GNR is superior over Cu and tungsten in local level interconnection but with proper intercalation doping and specular edges.

Sarto et al. [19] analyzed current distribution and signal propagation of multi layer GNR and multi wall CNT at GHz. From the analyses it has been pointed out that multi layer GNR have larger number of layers than the shells number of multi wall CNT of same dimension due to which multi layer GNR have excellent capability to carry current then that of its rival of same dimension.

Interconnects and inductors with minimum loss are designed at high frequencies using graphene [20]. A thorough study has been carried out on the processes which occur at high frequencies. Results presented in the paper indicate that GNR is an ultimate candidate for high frequency applications.

Energy delay product and propagation delay of GNR have been calculated by using an analytical model [21]. The same model is also used to calculate the value of resistances for multi layer GNR.

Superior performance of CNT and GNR interconnects system has been evaluated [22][29] using the time domain analysis and indicates that the interconnect systems based on CNT are more stable.

Fang et al. [23] analyzed delay performance of GNR by using an equivalent circuit, and considered contact resistance for analyzing the performance.

Majumdar et al. [24][25] calculated the delay and crosstalk for GNR, and concluded that multi layer GNR is superior to single layer GNR.

Dissipation of test circuit has been compared with the circuit using CMOS. Nonlocal spin torque circuit using GNR interconnect system is a test circuit [26].

Signal transmission of multi layer GNR has been studied by Cui et al. [27] and analyzed for 14 nm and 22 nm technology nodes. During this work author has noticed one wonderful thing which is that Fermi level also effects delay in the case of multi layer GNR.

GNR has been realized from graphene grow by chemical vapor deposition processes [28]. Low and high field electrical measurements are reported over a range of temperature and concluded that GNR which is presented in this paper have low field mobility and Raman signatures than that of the other GNRs obtained from other methods.

The movement of signal in GNR has been studied by combining the two theories – semi classical Boltzmann transport theory and classical transmission line theory [30]. The parameter which is known as conducting channel numbers used to expound kinetic inductance and quantum capacitance to study the behavior of zig-zag GNR and armchair GNR by considering the conducting channel numbers.

Rakheja et al. [31] has discussed the advantages and limitations of GNR, and also presented a physical model to compare the performance of GNR against with the existing copper/low-k interconnects.

Hasan et al. [32] has calculated resonant frequency of GNR interconnect system and discussed the effect of width variation and showed that resonant frequency is smaller in non degenerate region and high in degenerate region.

The problems faced by other interconnect systems are analyzed by using GNR [34] and reported that when GNR interconnect system is used with FinFET driver positive results are achieved in terms of delay and power dissipation.

III. CONCLUSION

On basis of literature survey it can be concluded that GNR VLSI Interconnect is one of the strongest candidate to meet the ever demanding challenges of modern high speed, high density VLSI circuits.

REFERENCES

[1] T. J. Echtermeyer, M. C. Lemme, M. Baus, B. N. Szafranek, A. K. Geim, and H. Kurz, *Nonvolatile Switching in Graphene Field-Effect Devices*, IEEE Electron Device Lett., vol. 29, no. 8, pp. 952-954, Aug.2008.

[2] M. C. Lemme, T. J. Echtermeyer, M. Baus, and H. Kurz "A Graphene Field-Effect Device," *IEEE Electron Device Lett.*, vol. 28, no. 4, pp.282-284, Apr. 2007.

[3] Y. Ouyang, Y. Yoon, J. K. Fodor, and J. Guo, *Comparison of performance limits for graphene nanoribbon and carbon nanotube transistors*, Appl. Phys. Lett., vol. 89, no. 20, pp. 203 107-1–203 107-3, Nov. 2006.

[4] L. Gengchiao, N. Neophytos, D. E. Nikonov, and M. S. Lundstrom, *Performance projections for ballistic graphene nanoribbon field-effect transistors*, IEEE Trans. Electron Devices, vol. 54, no. 4, pp. 677–682, Apr. 2007.

[5] D. Gunlycke, H. M. Lawler, and C. T. White, *Room-temperature ballistic transport in narrow graphene strips*, Physical Review B, vol.75, no. 8, pp. 085418-1- 085418-5, Feb. 2007.

[6] O. Roslyak, G. F. Gumbs, and D. Huang, *Tunable band structure effects on ballistic transport in graphene nanoribbons*, Phy. Lett. A, vol.374, pp. 4061–4064, Apr. 2010.

[7] S. Bhattacharya and S. Mahapatra, *Negative differential conductance and effective electron mass in highly asymmetric ballistic bilayer graphene nanoribbon*, Phys. Lett. A, vol. 374, no. 28, pp.2850–2855, May 2010.

[8] R. Murali, K. Brenner, Y. Yang, T. Beck, and J. D. Meindl, *Resistivity of Graphene Nanoribbon Interconnects*, IEEE Electron Device Lett., vol. 30, no. 6, pp. 611-613, Jun. 2009.

[9] A. K. Geim and K. S. Novoselov, *The rise of graphene*, Nat. Mat., vol. 6, no. 3, pp. 183–191, Mar. 2007.

[10] M. Y. Han, B. Ozyilmaz, Y. B. Zhang, and P. Kim, *Energy band-gap engineering of graphene nanoribbons*, Physical Review Letters, vol. 98, p. 206805, May 2007.

[11] D. Pribat and Y. H. Lee, *Carbon nanotubes and graphene for various applications in electronics: competition and synergy*, IEEE Technology Time Machine Symposium on Technologies Beyond 2020 (TTM), pp. 1-2, 1-3, June 2011.

[12] W. J. Yu, S. Y. Lee, S. H. Chae, D. Perello, G. H. Han, M. Yun, and Y.H. Lee, *Small hysteresis nano carbon-based integrated circuits on flexible and transparent plastic substrate*, Nano Lett., vol. 11, pp. 1344, Feb. 2011.

[13] W. J. Yu, S. H. Chae, S. Y. Lee, D. L. Duong, and Y. H. Lee, *Ultra transparent flexible single-walled carbon nanotube non-volatile memory*

device with oxygen-decorated graphene electrode, Adv. Mater., vol. 23, pp. 1889, Apr. 2011.

[14] M. Terrones, *Sharpening the chemical scissors to unzip carbon nanotubes: crystalline graphene nanoribbons*, ACS Nano, vol. 4, p. 1775, Apr. 2010.

[15] T. Ragheb and Y. Massoud, *On the Modeling of Resistance in Graphene Nanoribbon (GNR) for Future Interconnect Applications*, in Proc. IEEE/ACM Int. Conf. on Computer-Aided Design (ICCAD 2008), pp.593-597, Nov. 2008.

[16] A. Balandin, S. Ghosh, W. Bao, I. Calizo, D. Teweldebrhan, F. Miao, and C. Lau, *Superior thermal conductivity of single-layer graphene*, Nano Lett., vol. 8, no. 3, pp. 902–907, Mar. 2008.

[17] C. Xu, H. Li and K. Banerjee, *Graphene nanoribbon (GNR) interconnects: A genuine contender or a delusive dream?* IEEE International Electron Devices Meeting, IEDM 2008, pp. 1-4, 15-17 Dec 2008.

[18] C. Xu, H. Li, and K. Banerjee, *Modeling, analysis, and design of graphene nanoribbon Interconnects*, IEEE transactions on electron devices, vol. 56, no. 8, pp. 1567-1578, Aug. 2009.

[19] M. S. Sarto and A. Tamburrano, *Comparative analysis of TL models for multilayer graphene nanoribbon and multi wall carbon nanotube interconnects*, Int. Symp. EMC, pp. 212-217, 2010.

[20] D. Sarkar, C. Xu, H. Li, and K. Banerjee, *High-frequency behavior of graphene-based interconnects—Part II: Impedance analysis and implications for inductor design*, IEEE Trans. Electron Devices, vol. 58, no. 3, pp. 853–859, Mar. 2011.

[21] V. Kumar, S. Rakheja and A. Naeemi, *Modeling and optimization for multilayer graphene nanoribbon conductors*, IEEE International Technology Conference 2011 and Materials for advance metallization (IITC/MAM), pp. 1-3, 8-12 May 2011.

[22] S. Haji Nasiri, M. K. Moravvej-Farshi and R. Faez, *Time Domain Analysis of Graphene Nanoribbon Interconnects Based on Transmission Line Model*, Ira. Jour. of Elect. & Electro.Engi., Vol. 8, pp.37-44, Mar.2012.

[23] Y. Fang, W. Zhao, X. Wang, F. Jiang, and W. Yin, *Circuit modelling of multilayer graphene nanoribbon (MLGNR) interconnects*, in IEEE Conference (APEMC), 2012 Asia-Pacific Symposium, pp. 625 – 628, MAY 2012.

[24] M. K. Majumdar, N. Reddy K., B. K. Kaushik, and S. K. Manhas, *Comparison of propagation delay in single and multi-layer graphene nanoribbon interconnects 2012 5th International conference on computers and devices for communication (CODEC)*, pp. 1-4, 17-19 Dec. 2012.

[25] N. Reddy K., M. K. Majumdar, B. K. Kaushik, S. K. Manhas and B. Anand, *Dynamic crosstalk effect in multilayer graphene nanoribbon interconnects*, 2012 International conference on communication, devices and intelligent systems (CODIS), pp. 472-475, 28-29 Dec.2012.

[26] S. Rakheja, and A. Naeemi, *Graphene nanoribbon spin interconnects for nonlocal spin-torque circuits: comparison of performance and energy per bit with CMOS interconnects*, IEEE Transactions on Electron Devices, vol. 59, no. 1, pp. 51-59, Jan. 2012.

[27] J. P. Cui, W. S. Zhao, and W. Y. Yin, *Signal Transmission Analysis of Multilayer Graphene Nano-Ribbon (MLGNR) Interconnects*, IEEE Trans. Electromagnetic Compatibility, vol. 54, no. 1, pp.126-132, Feb. 2012.

[28] Behnam, *Transport in nanoribbon interconnects obtained from graphene grown by chemical vapor deposition*, Nano Lett. 12(9), pp. 4424–4430, 2012.

[29] S. Bhattacharya, S. Das, D. Das, *Analysis of Stability in Carbon Nanotube and Graphene nanoribbon Interconnects*, International Journal of Soft Computing and Engineering (IJSCE), vol. 2, no. 6, pp. 325-329, Jan. 2013.

[30] A. Maffucci, and G. Miano, *Number of Conducting Channels for Armchair and Zig-Zag Graphene Nanoribbon Interconnects*, IEEE Trans. Nanotechnology, vol.12,no.5,pp.817-823, Sep.2013

[31] S. Rakheja, V. Kumar, and A. Naeemi, *Evaluation of the potential performance of graphene nano-ribbons as on-chip interconnects*, contributed paper, proceedings of IEEE, vol. 101, no.7, pp. 1740-1765, July 2013.

[32] A. Hassan, T. Nandy, M.I. Abedin, A. Islam, and A. Dutta, *Resonant Frequency Analysis of Graphene Nanoribbon Based VLSI Interconnect System*, 8th International Conference on Electrical and Computer Engineering, pp.156-159, 20-22 Dec. 2014.

[33] I.F.P. Nesamani, R. P. Divakaran, V.L.Prabha, M.B.Sujith, *Source Drain Engineering in FinFET – A Review*, International Journal of Engineering Trends and Technology (IJETT), vol.8,no.9, Feb.2014.

[34] V.Sharma, and R. P. Agarwal, *MLGNR interconnects with finfet driver: optimized delay and power performance for technology beyond 16nm*, International Journal of Research in Engineering and Technology(IJRET), vol.3,no.9, pp.117-123, Sep.2014.