Extended Abstracts of the 2013 International Conference on Solid State Devices and Materials, Fukuoka, 2013, pp444-445

Fabrication and Radio Frequency Characterization of Graphene Interconnect

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Abstract

In this study, large area of single, double, and multi-layer graphene Co Planar Waveguide (CPW) is fabricated using Atmospheric Pressure Chemical Vapor Deposition (APCVD) process. The intrinsic room temperature radio frequency characteristic is measured via direct contact to graphene surface with probe tip ranging from 0.1 GHz to 40 GHz. The physics based equivalent circuit model is designed which reproduce all the measured characteristics. Results show that multi-layer graphene could be a strong candidate for using the high frequency interconnect application in observed high frequency region.

1. Introduction

Graphene has attracted enormous research interest since its experimental discovery in 2004[1]. Since graphene based field effect transistors have been shown to be attractive characteristics for analog/RF devices [2], and graphene ribbons showed the outperformed results than conventional Cu interconnects [3], graphene has potentials of the strong candidate for realizing horizontal low loss interconnect materials that plays an important role in RF circuits. However current study in graphene interconnect, HOPG flake graphene was applied up to 10 μm area via mechanical exfoliation method and metal electrode were deposited for probing which caused low-carrier mobility and high contact resistance. Moreover de-embedding process was inevitable after its measurement to remove parasitic effect of metal electrode at high frequency region[4-7]. In this study, over 100 μm, large area graphene is synthesized via APCVD method and variable numbers of graphene layered CPW is tested. The intrinsic room temperature radio frequency characteristic is readily measured via new trial of direct contact of probe tip to graphene surface without metal electrode. This large-area CVD growth graphene and direct contact method showed comparable transmission performance with existing HOPG graphene interconnect devices [5-7]. Lumped element RLC equivalent circuit model is designed and the RF characteristics of fabricated graphene CPW are evaluated by simulation.

2. Device Fabrication

Using APCVD method, graphene layer is grown on the Cu foil with 75μm thickness. At first step, heat the chamber up to 1060 °C with Ar 1000 sccm and H2 200 sccm then maintain 20 minutes. For growth, inject Ar 1000 sccm, H2 10 sccm and methane 2 sccm for 5 minutes. After its growth, methane is removed and it is cooled down to room temperature. Pull out graphene growth Cu foil from APCVD and spin coat with PMMA. Remove Cu foil using Cu etchant and rinse PMMA/graphene in DI water. Transfer the floating PMMA/graphene on SiO_2/Si wafer and remove PMMA with aceton after drying. Repeat above step, few layers of graphene sample is fabricated. Conventional photolithography is used to pattern the graphene. Fig.1 shows structure of graphene CPW device for Ground Signal Ground (GSG) measurement.

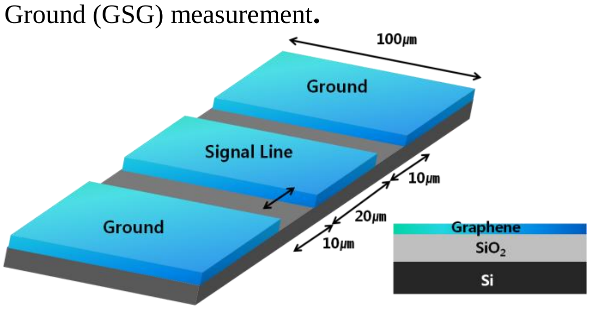

Fig.1 Fabricated devices for GSG measurements

3. Results and Discussions

Measurements of transmission and reflection characteristic along with laminating of manufactured device and simulation result of equivalent circuit are shown in Fig.2 (a). RF transmission characteristics are confirmed to be improved as the number of layers increases. S_{11} magnitude shows not much difference within magnitudes of few dB. As can be seen in Fig.2 (b), the Insertion Loss (eq.1) and Impedance Z (inset) increase as the number of layers decreases. Improved transmission performance and low loss characteristics of multi-layer graphene device seem to be the consequence of resistance lowering due to the increase of thickness effect.

$$\text{Insertion Loss} = -10\log\frac{|S_{21}|^2}{1-|S_{11}|^2} \quad \text{dB} \tag{1}$$

The frequency response of the graphene device in below 10 GHz region is determined by contact resistance of the surface, while little change in overall impedance character-

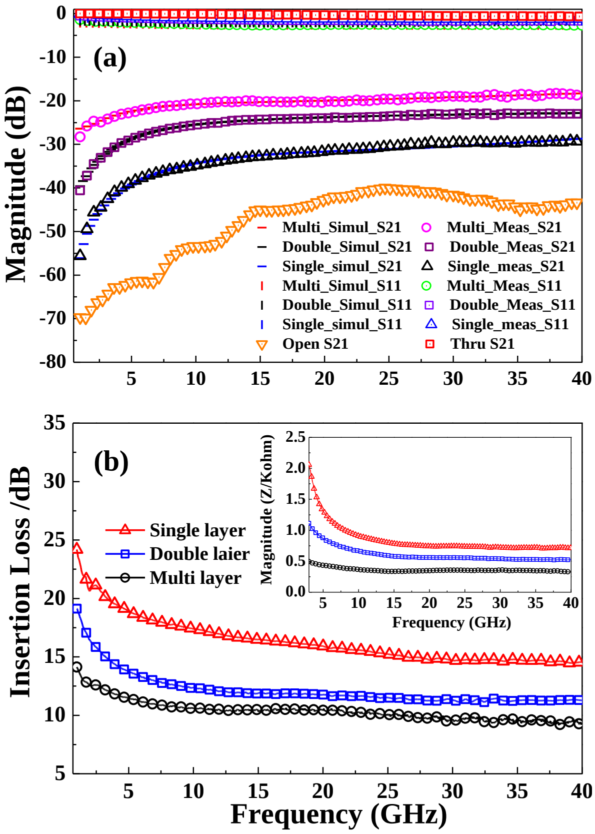

Fig. 2 (a) Magnitude comparison of S-parameters for measured and simulated values for various layers. (b) Insertion Loss and impedance for various layers.

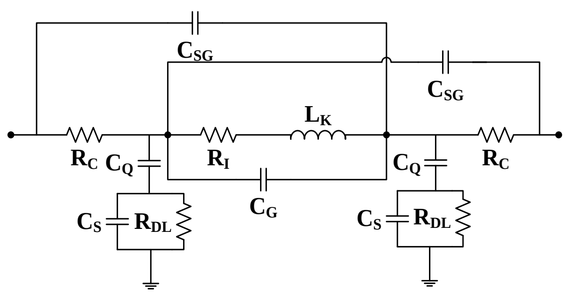

Fig. 3 Physics-based Equivalent circuit model

istics above 10 GHz is shown due to the absence of skin effect and low kinetic inductance of atomically thin properties of graphene layers [7,8]. The 400 nm thickness of Au thru component in RF calibration kit is as the reference device. The synthesized graphene layer has atomically thin thickness of few nanometers. Despite of this thin current path, S_{21} magnitude of the multi-layer sample is only about 20 dB lower than the sample with thru configuration and shows no distinctive change in overall characteristic over a wide frequency range from 10 GHz to 40 GHz. Table I describes components of lumped element equivalent circuit model of Fig. 3.

4. Conclusion

Large area graphene CPW device with direct contact with-

Table I Description of component in equivalent circuit

Component	Description
R_C	Contact resistance
R_{DL}	Substrate resistance(Dielectric loss)
R_I	Intrinsic resistance of graphene
L_K	Kinetic inductance of graphene
C_G	Capacitance of graphene
C_{SG}	Resistance between signal line and GND layer
C_S	Parasitic capacitance between graphene and substrate
C_Q	Quantum capacitance

out metal electrode is first fabricated and RF responses are measured. Even the tested area increased more than 10 times via APCVD, performance of device shows S_{21} within -20dB and insertion loss of 10dB which is comparable or even better than existing HOPG devices over 10 GHz range [4-7]. The transmission and reflection characteristics are well coincides with the proposed equivalent circuit model. The S_{21} of conventional Cu interconnect is typically superior to our results, but the thickness of Cu is dozens of μm. However that of fabricated graphene layers is just few nanometers which only 0.01% of the thickness of Cu. Thus application of graphene as interconnect component into multi-layer packages, chemical mechanical polishing (CMP) process will no longer need due to its ultra-thin properties.

By precisely controlling the thickness, defect density with large area uniformity of graphene by CVD growth, the transmission performance could be enhanced. Moreover the electrodeless measurement technique will reduce the parasitic effect in high frequency region with easy fabrication.

Acknowledgements

This work was supported by the National Research Foundation grant funded by the Korean Government (MEST, No. 2012 - 0001214).

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