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RF Transmission Line Characteristics of Graphenes

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1. Introduction

Recently, the radio-frequency (RF) characteristics [1],[2] and applications [3],[4] of graphene have been received a lot of attraction since it showed the excellent electronic properties, e.g. low scattering rates, low defect densities, and high mobilities and so on, at direct current (DC) level. In these previous RF studies, the graphene separated from highly oriented pyrolytic graphite (HOPG) by the mechanical exfoliation method was usually utilized. Although the sample has clearly excellent properties due to reduction of impurities, this approach has a few drawbacks such as inefficient method, small area, time-consuming and so on. Also the RF characteristics of a very short graphene were mainly investigated so that capacitance components of the metallic electrode itself were predominant. In this work, we present the RF transmission line characteristics of the long single-and multi-layer graphenes grown by chemical vapor deposition (CVD) at high frequencies.

2. Fabrication and Measurement

Each single-and multi-layer graphene was synthesized on copper (Cu) and on nickel (Ni) film by the CVD method using a mixture of methane (CH_4) and argon (Ar) as the carbon source for 15 mins at 950 ^{o}C. Next, the samples were transferred on the SiO2/Si (300 nm/300 μm). The Si-substrate with a high-resistivity (≥13 kΩcm) was used for minimizing dielectric loss at high frequencies. After the thermal evaporation and lift-off process, the coplanar waveguide (CPW) electrode with graphene was fabricated. The fabricated sample is shown in the Fig. 1.

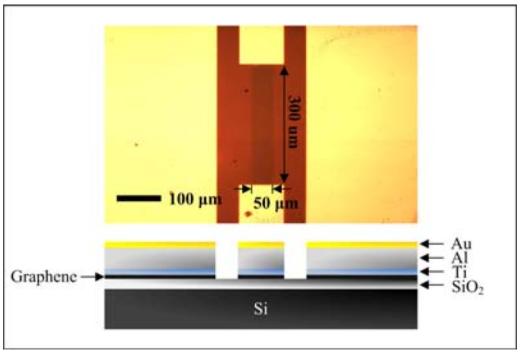

Fig. 1 Geometry and cross-section view of the CPW electrode with a graphene

The electrode was comprised of tri-layer with Au/Al/Ti (40 nm/ 300 nm/ 10 nm), as shown in the Fig. 1. Dimensions of the sample are as follows: the width and length of the CPW electrode ground are 300 μm and 360 um, respectively. The area of the square CPW IN/OUT electrode is 100 μm^2. The effective length and width of the graphene are 300 μm and 100 μm, respectively. For the multi-layer graphene, we confirmed that the thickness of the graphene is about 3 nm, i.e. about 10 graphene layers, by atomic force microscope (AFM).

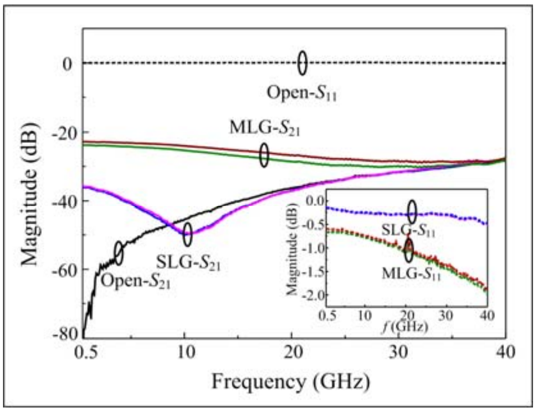

Fig. 2 Magnitude of S-parameters for a single- and a multi-layer graphene

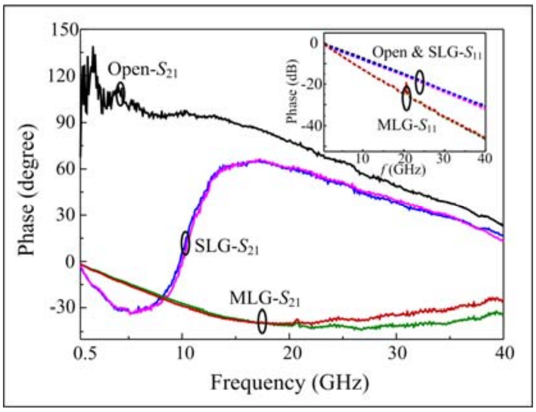

Fig. 3 Phase of S-parameters for a single- and a multi-layer graphene

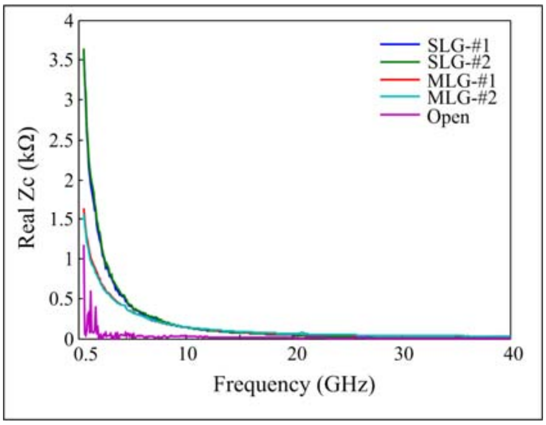

Fig. 4 Real Z_c for three configurations: the single- and multi-layer graphenes and open

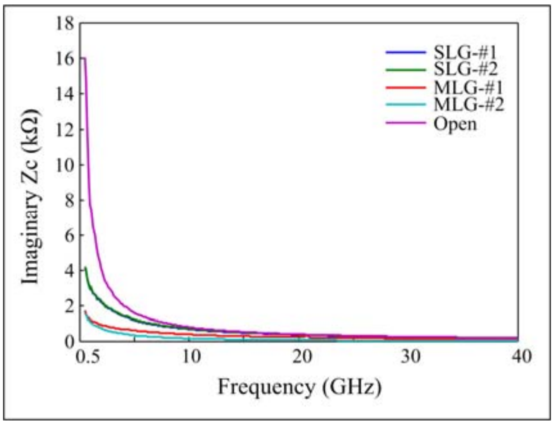

Fig. 5 Imaginary Z_c for three configurations: the single- and multi-layer graphenes and open

In order to measure the RF characteristics of the graphene, the RF measurement system including G-S-G probe was calibrated by the standard full 2-port method using open, short, load, and thru, i.e. OSLT, configuration. From the 2-port vector network analyzer, magnitude and phase of S-parameters for the graphene and open configuration could be obtained, as shown in Fig. 2 and Fig. 3.

3. Results and Analysis

In the Fig. 2, the S_{21}, i.e. transmission coefficient, of the single-layer graphene (SG) behaviors along the open configuration as frequency increases. Especially, it shows the weak resonance near 10 GHz. This is due to the parallel resonance of inductance component (L) of the graphene itself and capacitance component (C) between the graphene and the ground in configuration of the CPW electrode with a single-layer graphene. In the case of the multi-layer graphene (MG), although the S_{21} is much lower characteristic compared to that of conventional transmission line, e.g. copper or gold transmission line, it exhibits the typical transmission line characteristic that gradually decreases the S_{21} level as frequency increases.

In the Fig. 3, the S_{21} phase of the single-layer graphene, the resonance point that changes the phase characteristic can be clearly observed. It is also found that the S_{21} phase of the multi-layer graphene behaviors like as a thru line until 20 GHz and more and more approaches the open configuration after 20 GHz. Meanwhile, the characteristic impedance (Z_c) of RF transmission line is given by

$$Z_c = \sqrt{\frac{R + j\omega L}{G + j\omega C}}. \qquad (1)$$

Mathematically manipulating the equation (1), the real and imaginary part of Z_c are expressed as

$$|Z_c|^2 = \frac{RG + \omega^2 LC}{G^2 + (\omega C)^2} + j\frac{\omega(LG - RC)}{G^2 + (\omega C)^2}. \qquad (2)$$

The real and imaginary components of Z_c of the equation (2) are plotted, as shown in the Fig. 4 and Fig. 5. It is found that the characteristic impedance of the multi-layer graphene is lower than that of the single-layer graphene. As a result, we can reason that the optimized thickness of graphene should be considered for utilizing as the RF transmission line.

4. Conclusions

We have observed the RF transmission line characteristic of the long single- and multi-layer graphene in the range from 0.5 GHz to 40 GHz. It was confirmed that although the transmission level of the multi-layer graphene has much lower than that of a conventional transmission line, it shows the potential as a RF transmission line if the optimized thickness is secured and its conductivity is improved.

Acknowledgements

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