Commercial graphene nanoplatelets-based tunable attenuator

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A commercial graphene nanoplatelets-based tunable attenuator is proposed. The attenuator comprises of a couple of microstrip lines connected through a gap where the commercial graphene nanoplatelets are drop casted. The transmitted signal through the microstrip line can be varied by an applied DC bias voltage that alters the graphene resistance. The DC resistance of commercially acquired graphene is higher than lab-grown graphene and so is the resulting minimum attenuation of the transmitted signal. The proposed structure is designed to reduce both the minimum graphene resistance and the transmission. The resultant dynamic range of attenuation is more than twice as compared to other series attenuators designed with lab grown graphene nanoplatelets. The operating frequency of the attenuator is from 1 to 5 GHz with maximum dynamic range of attenuation almost 10 dB.

Introduction: In the search for novel materials, carbon-based materials are one of the most sought-after materials due to their interesting properties. Graphene is one of the most important carbon-based materials. It has particularly useful electronic, mechanical and thermal properties [1]. In modern electrical systems, graphene is deployed in a number of areas including active devices [2, 3] and absorbing materials [4].

Modern communication systems require electronic tuning of key components. Graphene has the capability to vary its electron mobility upon the application of a DC voltage [1]. The electronic tuning of graphene's resistance is valid through a wideband going from DC to millimetre waves covering an important part of the frequency spectrum [5]. The tunable conductivity of graphene is valid for multi-layered graphene [6]. Carbon materials including multi-layered graphene are deployed in a number of microwave applications including, antennas [7–9], phase shifters [10] and attenuators [6, 11–13]. For tuning applications, drop-casting multi-layered graphene is the most convenient since it is the least complicated and the most cost-effective [6].

For mass-scale production and further simplification of the fabrication of tunable microwave components, it is highly desirable to deploy commercial graphene nanoplatelets instead of lab-grown graphene nanoplatelets. In order to verify the tunable conductive properties of commercial graphene nanoplatelets and to check their functionality at microwave frequency a simple design of a series attenuator needed to be deployed.

In this Letter, a series tunable microwave attenuator is designed, its prototype is fabricated and its functionality verified through measurements. As shown in Fig. 1, the tunable attenuator is composed of two microstrip lines of 50 Ω. The microstrip lines are separated from each other by a gap. Commercial graphene nanoplatelets are deposited in the gap unlike lab-grown graphene nanoplatelets [6]. Since commercial graphene nanoplatelets possess higher sheet resistance, the dimensions of the gap are redesigned to lower the resistance of the graphene nanoplatelets and to lower the resultant minimum attenuation. As a result, the acquired dynamic range of the attenuation of this design is almost twice that of a similar design based on lab-grown graphene nanoplatelets [6].

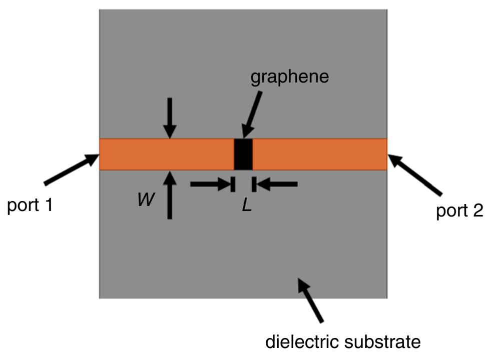

Fig. 1 *Design of the graphene-based series attenuator with indicated dimensions*

Design of the attenuator: The tunable graphene attenuator works with an applied DC voltage. When a DC bias voltage is applied to the commercial graphene nanoplatelets, the resistance of graphene nanoplatelets drops and the attenuation of the signal on the microstrip line is reduced. This makes the attenuator electronically tunable.

The structure of the tunable attenuator is simulated by the help of Ansys HFSS. Since the commercial graphene nanoplatelets are resistive, therefore they are modelled as a thin resistive sheet. For simulations, the range of the resistance in Ω/sq. is kept in the range of the estimated resistance of the commercial graphene nanoplatelets. The substrate on which the attenuator is designed is the Rogers 4350 B with thickness, $h = 0.786$ mm, dielectric constant, $\varepsilon_r = 3.66$ and loss tangent, tan-$\delta = 0.004$. The microstrip lines have width $W = 1.66$ mm, which corresponds to a characteristic impedance of 50 Ω. The length of the gap with graphene is given by L. The optimum value of L has been chosen by a parametric analysis as shown in Fig. 2, where AR is the aspect ratio of the gap given by AR = L/W. Since the minimum sheet resistance of commercial graphene nanoplatelets is high, therefore an AR = 1 gives a very low transmission (less than − 12 dB). The transmission can be increased to more than − 3 dB with an AR = 0.1. However, with this value of AR, the dynamic range of the transmission is drastically reduced to less than 10 dB. An intermediate value of AR = 0.5 is chosen in order to provide a transmission of almost − 6 dB with a dynamic range greater than 15 dB.

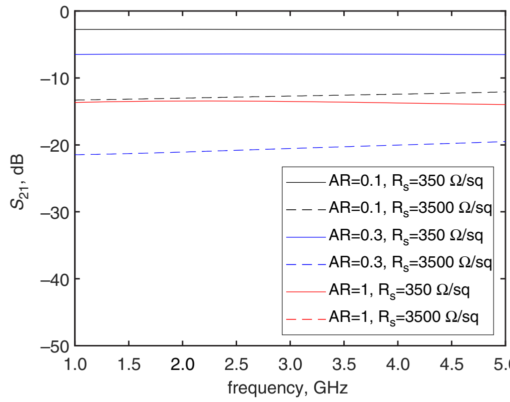

Fig. 2 *Transmission scattering values for minimum and maximum sheet resistance with different aspect ratio*

Simulation results as depicted in Fig. 3 show that with a decrease in graphene sheet resistance, the attenuation reduces. For a graphene sheet resistance value of 350 Ω/sq., the transmission is around − 21 dB, which increases to − 6 dB for a sheet resistance value of 350 Ω/sq.

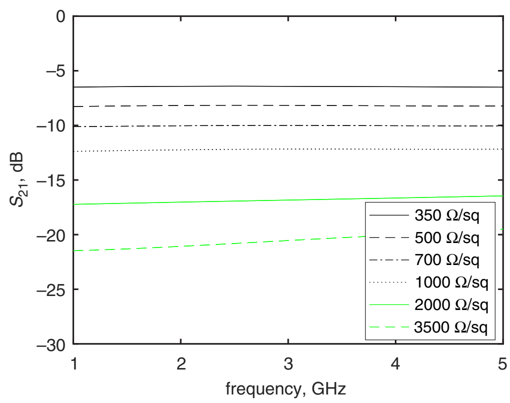

Fig. 3 *Simulated transmission scattering parameter (S_{21}) for different values of graphene sheet resistance*

Materials and fabrication: The commercial graphene nanoplatelets deployed in this work are provided by Nanoinnova. A standard procedure of mixing these nanoplatelets in isopropyl alcohol is adopted. The solution is then dropcasted in a gap on the substrate. Isopropyl alcohol evaporates leaving behind the commercial graphene nanoplatelets in the gap. The substrate is fabricated by applying a photoresist on the two-line sections and etching copper from the remaining portion of the substrate. Raman spectrum of the commercial graphene used measured from 500 to 4000 cm^{-1}, is illustrated in Fig. 4. The ratios of the peaks are $I_D/I_G = 0.15$, $I_D/I_{2D} = 0.27$ and $I_G = I_{2D} = 1.81$. This behaviour is coherent with standard Raman spectra of multilayer graphene consisting less than five layers [14].

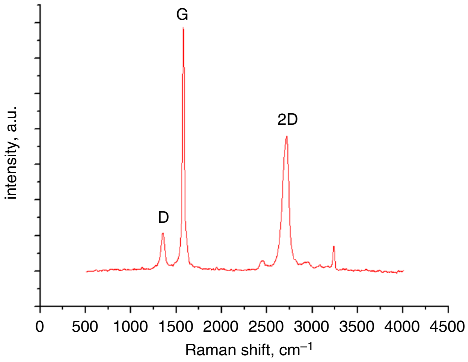

Fig. 4 *Raman spectroscopy of the commercial graphene nanoplatelets*

Measured results: Measurements of scattering parameters of the tunable graphene attenuator require a vector network analyser (VNA), a pair of broadband bias-tees and a DC voltage supply as shown in Fig. 5*a*. The two ports of the VNA are connected to the RF end of the bias-tees, which are in turn connected to the tunable graphene attenuator ends as shown in Fig. 5*b*. Scattering parameters are measured for various applied DC voltage values. Initially without the application of a DC voltage, the graphene nanoplatelets bear high sheet resistance. Upon increasing the DC voltage the graphene resistance is reduced increasing the transmission of the signal through the microstrip line.

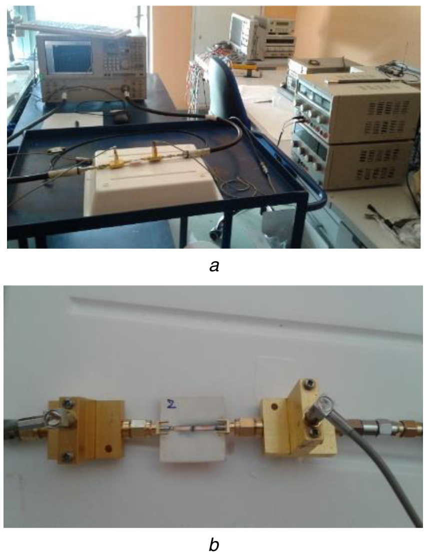

Fig. 5 *Tunable attenuator prototype*

a Measurement setup with the prototype connected to VNA and bias-tees
b Tunable attenuator connected to bias-tees with graphene drop casted on the gap

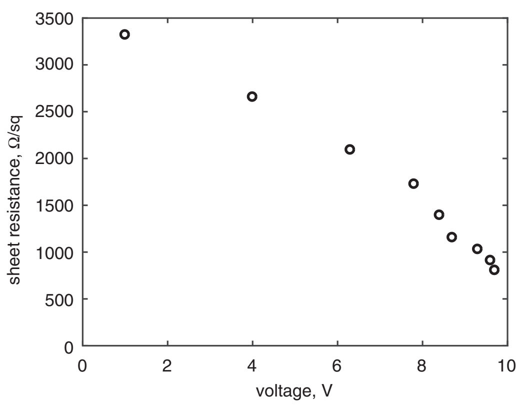

Fig. 6 *Variation of the sheet resistance of the tunable graphene attenuator*

The DC resistance values are calculated from the current drawn for each applied DC voltage, $R = V/I$. From the measured value of the resistance, the corresponding sheet resistance is calculated by $Rs = R\ W/L$. The values of the graphene sheet resistance for each value of applied DC voltage are shown in Fig. 6. The sheet resistance of commercial graphene nanoplatelets reduces with increasing DC bias voltage. In Fig. 7, the measured S_{21} values for different DC applied voltage are shown. The values of applied voltages can be related to their respective sheet resistance values via Fig. 6. The measured results of S_{21} are comparable to the simulated values. It can be seen that the minimum value of S_{21} is −18 dB for an applied DC bias voltage of 1 V while the maximum value of S_{21} is −8 dB for a maximum applied DC bias voltage of 10.5 V. The maximum dynamic range of attenuation is almost 10 dB.

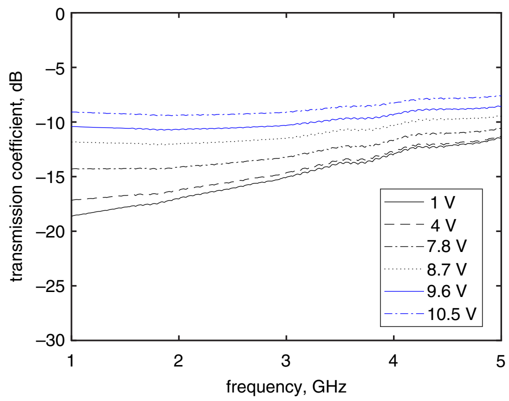

Fig. 7 *Measured transmission scattering at different applied bias voltages*

Conclusion: The functionality of a tunable graphene attenuator based on commercial graphene nanoplatelets is demonstrated with simulated and measured results. The attenuator is composed of two line sections of a microstrip line connected through a gap where commercial graphene nanoplatelets are deposited. Commercial graphene nanoplatelets bear higher sheet resistance as compared to lab grown graphene. The gap is custom designed to reduce the minimum sheet resistance of commercial graphene. This enables a lower minimum value of attenuation of the tunable microstrip attenuator. The attenuator works in the frequency band of 1 to 5 GHz with a maximum tunable dynamic range of the attenuation of up to 10 dB, which is almost twice that of comparable designs.

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One or more of the Figures in this Letter are available in colour online.

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