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Log-periodic Circular Tooth Antenna Enhancing Terahertz Absorption for Graphene Detector

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Abstract

Log-periodic circular tooth antenna is modeled and simulated to enhance absorption for graphene detector in terahertz frequency. S parameter is primarily extracted from isolated antenna, showing a uniform radiation feature. A frequency-dependent voltage collected by a monitor set over graphene sheet under terahertz illumination is detected and compared with that of the condition without an antenna. Voltage curve versus frequency matches the corresponding S parameter of the log-periodic circular tooth antenna over a wide range from 0.2THz to 1THz, conforming the absorption assistance effect of the antenna.

1. Introduction

Graphene, an one-atomic-layer thick material, has been widely investigated in optics since its discovery[1]. Versatile devices utilizing graphene were designed and implemented in visible[2] and infrared optics[3] while the low absorption[4] restricts graphene [5]in photodetectors especially for terahertz waveband. Several methods including photogating effect[6], plasmonic excitation[7, 8], Salisbury screen[9] were introduced to enhance the absorption of graphene.

Log-periodic antenna, serving as a wide waveband antenna in communication field[10], can achieve uniform absorption over a wide frequency range. Terahertz science generally refers to electromagnetics between 0.1THz and 10THz. Characteristic length for an antenna ranges from hundreds of micrometers to a few millimeters when the working frequency is in terahertz waveband.

Integration of log-periodic circular tooth antenna and graphene layer is simulated through CST studio suite. CST software exploits finite integration time-domain method(FITD) in time domain solver[11]. S parameter is first extracted from paired Log-periodic antenna, showing its radiation feature. Graphene sheet without antenna is illuminated by terahertz light. The isolated graphene shows negligible response to polarized terahertz plane wave. Then, stacking antenna with graphene enhances electric field in graphene as well as absorption.

2.Setup and Result

Log-periodic antenna refers to a multi-element array arranged in predefined ratio. Investigation and design of log-periodic antenna is matured and the antenna is easily modeled in simulation[12, 13]. Parameters are to be determined to define unique structure. Among these, R_n refers to nth radius and $d_n = R_{n+1} - R_n$ is the distance between adjacent arms. The outmost arm R_1 is set to 332um in this simulation. T is defined as the ratio between adjacent arm given by following equation:

$$\mathrm{T} = \frac{R_{n+1}}{R_n} < 1$$

Solid angle $\phi = 30.9^{\circ}$ is the angle around the tip and tooth angle $\theta = 60.3^{\circ}$ is the arm angle. The outmost radius is calculated as $L_1 = R_1\phi = 179um$.

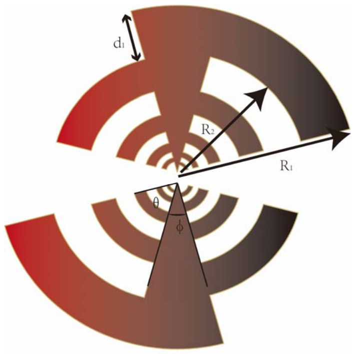

Figure1. Log-periodic circular tooth antenna schematic.d_1,R_1 ,R_2 ,θ and ϕ are illustrated.

Paired log-periodic gold antenna is placed far from each other and runs to a discrete port by means of long leads, thus makes room and eliminates edge effect for graphene. Substrate is set to lossless silicon possessing a relative dielectric constant of 11.9. S parameter is first extracted from simulation. Uniform curve conforms with the theory and practice[14] while certain peaks at 0.35THz, 0.46THz, 0.66THz and 0.73THz are also obvious, as illustrated in figure3 (a) . The highest radiation rate locates at 0.46THz with a minimum S parameter of -35dB, a radiation power of 22% and a gain of 4.94dBi. Direction graph shows x plane radiation dominates. Polarization performance can be summarized from simulation results. Electromagnetic wave paralleled to tooth arm inclines to interact with the antenna and is used to stimulate graphene sheet and integrated device in subsequent steps.

Graphene is a two-dimensional Dirac semimetal material and its electromagnetic behavior can be represented by surface optical conductivity deduced from Kubo formula[15]. Surface conductivity can be simply written as Drude model[16] where intraband transition absorption dominates with a weak photon energy of a few meV, as given by following equation:

$$\sigma_g = \frac{ie^2\mu_c}{\pi\hbar^2(\omega + i\tau^{-1})}$$

Where ω is the angular frequency of the incident light. Chemical potential μ_c is set to 0.5eV and carrier relaxation time τ adopts 0.1ps, defining a uniform real part and parabolic like curve for imaginary part in terahertz frequency.

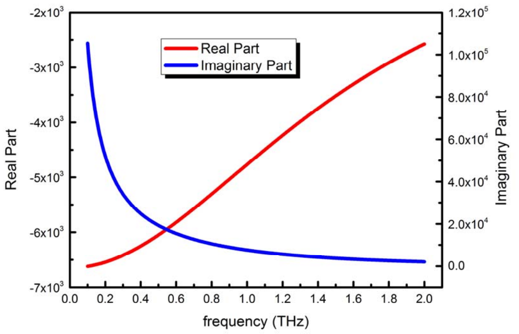

Figure2. Dielectric constant of graphene versus frequency.

Dielectric constant is evaluated as $\epsilon_r = 1 + i\sigma_g\eta_0/(k_0\Delta)$, where $k_0 = 2\pi/\lambda$ and $\eta_0 \approx 377\Omega$. Graphene layer is described by a $\Delta = 10$nm thick square with a 20um side length.

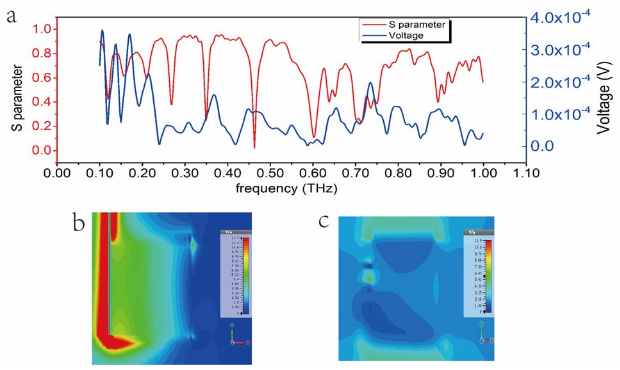

Figure3. S parameter of log-periodic antenna, voltage over graphene and electric distribution on graphene plane. (a) S parameter of isolated log-periodic antenna and voltage across graphene along x axis in (b), (b) Electric field distribution on the graphene plane assisted by antenna, (c) Electric field distribution on isolated graphene sheet with a same scale bar.

Graphene on a 50um silicon substrate is illuminated by terahertz light. A voltage monitor is set along the polarization direction and electric information is collected. Negligible absorption is observed in pristine graphene.

Then, log-periodic antenna is stacked on graphene layer and the calculation is again performed. Voltage monitors set and electric field on the graphene plane before and after imposing the antenna conforms the enhancement effect of the antenna. Time and frequency domain simulation shows similar electromagnetic distribution around graphene. The field distribution around graphene sheet changes in sinusoidal format. Maximum value of electric field is illustrated in Figure3(b) and (c). Several response peaks can be drawn from voltage spectral. The peaks locate at 0.35THz, 0.46THz, 0.66THz and 0.73THz, coincided with S parameter of the antenna.

3. Conclusion

Limitation in photo detection applying due to low absorption of graphene to terahertz light can be relieved by integrating with a log-periodic antenna. Specially designed antenna from a wide frequency range from 0.2THz to 1THz can achieve much higher electrical response, conformed by voltage monitor results before and after imposing the antenna. Problems such as contact between graphene, gate effect and substrate reflection still need investigating further in order to make the discussed model closer to reality.

4. Acknowledgements

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5.References

1 Novoselov, K.S., Geim, A.K., Morozov, S.V., Jiang, D., Zhang, Y., Dubonos, S.V., Grigorieva, I.V., and Firsov, A.A., ''Electric field effect in atomically thin carbon films'', Science, 306, (5696), 2004, pp. 666-669, doi:10.1126/science.1102896
2 Nikitskiy, I., Goossens, S., Kufer, D., Lasanta, T., Navickaite, G., Koppens, F.H., and Konstantatos, G., ''Integrating an electrically active colloidal quantum dot photodiode with a graphene phototransistor'', Nature communications, 7, 2016, pp. 11954, doi:10.1038/ncomms11954
3 Youngblood, N., Chen, C., Koester, S.J., and Li, M., ''Waveguide-integrated black phosphorus photodetector with high responsivity and low dark current'', Nat. Photonics, 2015, doi:10.1038/nphoton.2015.23
4 Bonaccorso, F., Sun, Z., Hasan, T., and Ferrari, A.C., ''Graphene photonics and optoelectronics'', Nat. Photonics, 4, (9), 2010, pp. 611-622, doi:10.1038/nphoton.2010.186
5 Yeung, K.Y., Chee, J., Yoon, H., Song, Y., Kong, J., and Ham, D., ''Far-infrared graphene plasmonic crystals for

plasmonic band engineering'', Nano Lett, 14, (5), 2014, pp. 2479-2484, doi:10.1021/nl500158y
6 Tao, L., Chen, Z., Li, X., Yan, K., and Xu, J.-B., ''Hybrid graphene tunneling photoconductor with interface engineering towards fast photoresponse and high responsivity'', npj 2D Materials and Applications, 1, (1), 2017, doi:10.1038/s41699-017-0016-4
7 Yeung, K.Y., Chee, J., Song, Y., Kong, J., and Ham, D., ''Symmetry Engineering of Graphene Plasmonic Crystals'', Nano Lett, 15, (8), 2015, pp. 5001-5009, doi:10.1021/acs.nanolett.5b00970
8 Echtermeyer, T.J., Britnell, L., Jasnos, P.K., Lombardo, A., Gorbachev, R.V., Grigorenko, A.N., Geim, A.K., Ferrari, A.C., and Novoselov, K.S., ''Strong plasmonic enhancement of photovoltage in graphene'', Nature communications, 2, 2011, pp. 458, doi:10.1038/ncomms1464
9 Ying, X., Pu, Y., Luo, Y., Peng, H., Li, Z., Jiang, Y., Xu, J., and Liu, Z., ''Enhanced universal absorption of graphene in a Salisbury screen'', J. Appl. Phys., 121, (2), 2017, pp. 023110, doi:10.1063/1.4973898
10 Lazaridis, P.I., Zaharis, Z.D., Skeberis, C., Xenos, T., Tziris, E., and Gallion, P.: 'Optimal design of UHF TV band log-periodic antenna using invasive weed optimization', in Editor : 'Book Optimal design of UHF TV band log-periodic antenna using invasive weed optimization' 2014, edn, pp. 1-5
11 Xiao, B., Kong, S., Chen, J., and Gu, M., ''A microwave power divider based on spoof surface plasmon polaritons'', Optical and Quantum Electronics, 48, (3), 2016, doi:10.1007/s11082-016-0456-7
12 Engargiola, G.: 'Non-planar log-periodic antenna feed for integration with a cryogenic microwave amplifier',: 'Book Non-planar log-periodic antenna feed for integration with a cryogenic microwave amplifier' 2002, pp. 140-143 vol.144
13 Pantoja, R., Sapienza, A., and Filho, F.M., ''A microwave printed planar log-periodic dipole array antenna'', IEEE T. Antenn. Propagp., 35, (10), 1987, pp. 1176-1178, doi:10.1109/TAP.1987.1143990
14 Joardar, S., and Bhattacharya, A.B., ''Two New Ultra Wideband Dual Polarized Antenna-Feeds Using Planar Log Periodic Antenna and Innovative Frequency Independent Reflectors'', Journal of Electromagnetic Waves and Applications, 20, (11), 2006, pp. 1465-1479, doi:10.1163/156939306779274318
15 Sharapov, S.G., Gusynin, V.P., and Beck, H., ''Magnetic oscillations in planar systems with the Dirac-like spectrum of quasiparticle excitations'', Phys. Rev. B,, 69, (7), 2004, doi:10.1103/PhysRevB.69.075104
16 Li, H.-J., Wang, L.-L., Zhang, H., Huang, Z.-R., Sun, B., Zhai, X., and Wen, S.-C., ''Graphene-based mid-infrared, tunable, electrically controlled plasmonic filter'', Appl. Phys. Express., 7, (2), 2014, pp. 024301, doi:10.7567/apex.7.024301