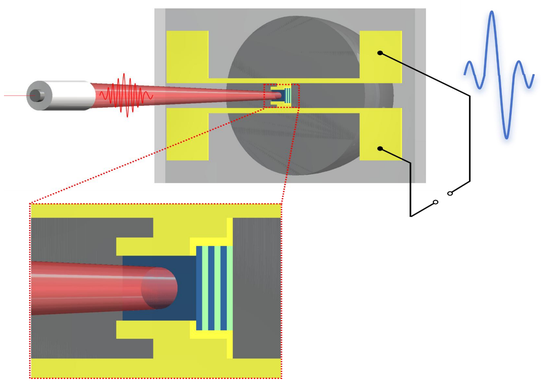


Simulation Modeling and High-Frequency Characteristics Optimization of Terahertz Photoconductive Antenna

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Abstract

Terahertz photoconductive antenna (PCA) is a mature terahertz technology that combines the radiation and detection functions of terahertz waves. In this work, a simulation model of terahertz wave radiation by a photoconductive antenna was established based on the semiconductor module and time-domain electromagnetic module of COMSOL. Based on this model, feasible schemes for optimizing the high-frequency characteristics of PCA were proposed.

Simulation methods

➢ Equation of ewfd model

The distribution of pump laser in photoconductive material satisfies the wave equation, which can be calculated in the frequency-domain:

$$\nabla \times (\nabla \times \boldsymbol{E}) - k_0^2 \left(\epsilon_r' + \frac{i\sigma}{\omega\epsilon_0}\right)\boldsymbol{E} = 0$$

$$\boldsymbol{E_0}(\boldsymbol{x},\boldsymbol{y},\boldsymbol{z}) = \sqrt{\frac{8P_o\eta_0}{f_p D_x D_y D_t}}\left(-\frac{\ln(0.5)}{\pi}\right)^{\frac{3}{4}} \exp\left(2\ln(0.5)\left(\frac{(x-x_0)^2}{D_x^2} + \frac{(y-y_0)^2}{D_y^2}\right)\right)\hat{\boldsymbol{e}}$$

➢ Equation of semiconductor model

The physical process of carriers in the photoconductive material include drift, diffusion, generation and recombination of the carriers, which can be described by the following equations[1]:

$$\epsilon_0 \nabla \cdot (\epsilon_r \nabla V) = q(n - p - N_D + N_A)$$

$$\frac{\partial n}{\partial t} = -\frac{1}{q}\nabla \cdot \left\{-\mu_n q \nabla(V + \chi)n + \mu_n k_B T G\left(\frac{n}{Nc}\right)\nabla n\right\} - r(x,y,z) + g(x,y,z,t)$$

$$\frac{\partial p}{\partial t} = \frac{1}{q}\nabla \cdot \left\{-\mu_p q \nabla\left(V + \chi + E_g\right)p + \mu_p k_B T G\left(\frac{p}{Nv}\right)\nabla p\right\} - r(x,y,z) + g(x,y,z,t)$$

➢ Equation of temw model

The time-dependent electromagnetic wave model satisfies the wave equation, in which the terminal current of the lumped port is calculated in the semiconductor model[2].

$$\nabla \times \mu_r^{-1}(\nabla \times \mathbf{A}) + \mu_0 \sigma \frac{\partial \mathbf{A}}{\partial t} + \mu_0 \frac{\partial}{\partial t}\left(\epsilon_0 \epsilon_r \frac{\partial \mathbf{A}}{\partial t}\right) = 0$$

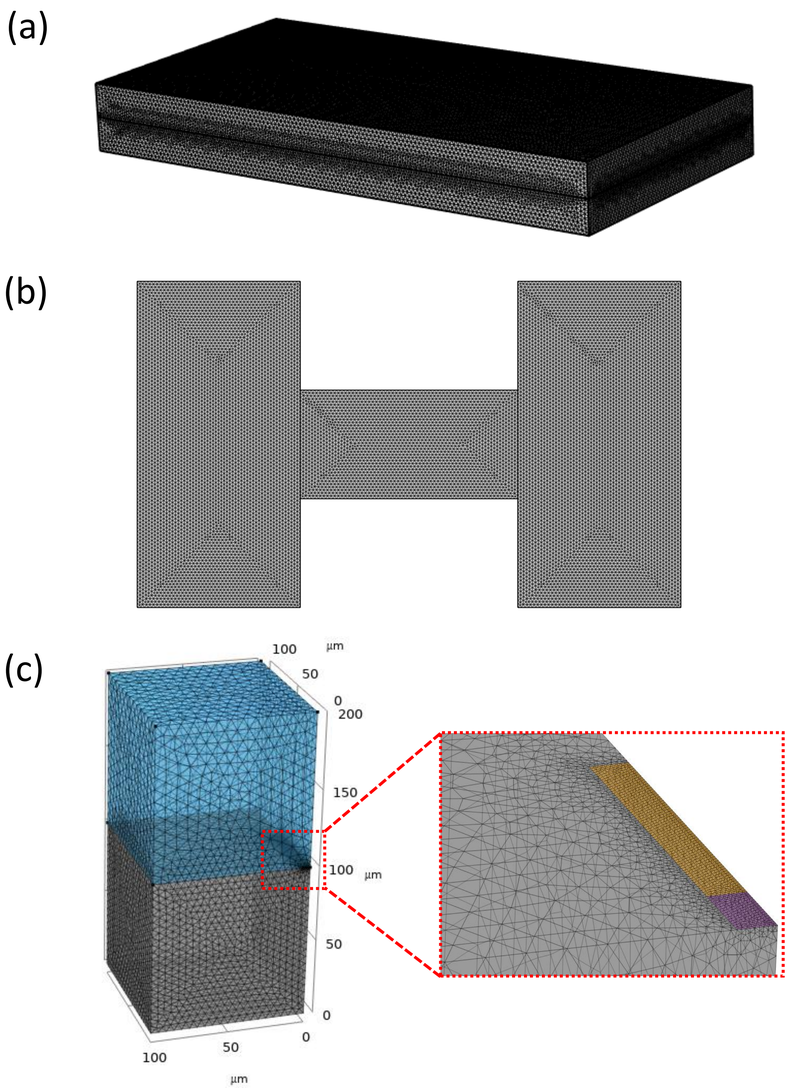


Figure. 1. (a) Mesh of the ewfd model. (b) Mesh of the semi model. (c) Mesha of the temw model

[1] Burford N et.al. Computational modeling of plasmonic thin-film terahertz photoconductive antennas[J]. Journal of the Optical Society of America B, 33(4): 748-759(2016).
[2] Batista J S, Churchill H O H, El-Shenawee M. Black phosphorus photoconductive terahertz antenna: 3D modeling and experimental reference comparison[J]. Journal of the Optical Society of America B, 2021, 38(4): 1367-1379.

Results

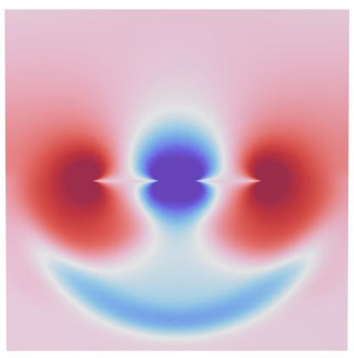


Figure. 2. THz wave radiation

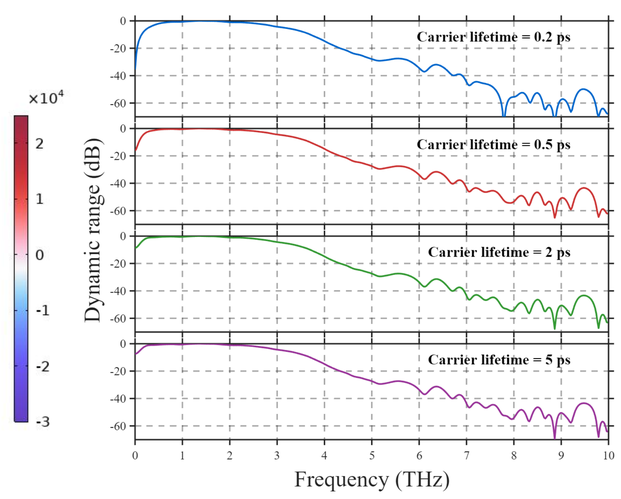


Figure. 3. THz spectrum with carrier lifetime

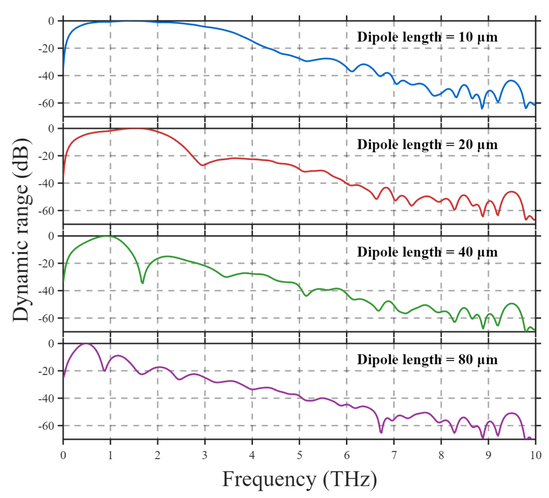


Figure. 4. THz spectrum with dipole length

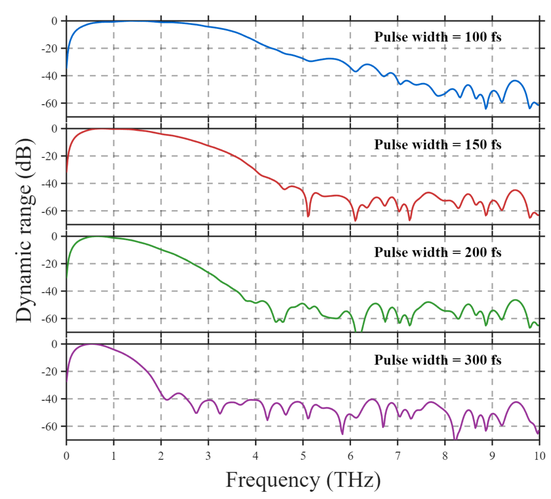


Figure. 5. THz spectrum with pulse width

- **The carrier lifetime of photoconductive material has little effect on the THz spectral characteristics, with the carrier lifetime becomes longer, the SNR of the THz signal between 0-100 GHz increases.**
- **With the dipole length of PCA becomes longer, the antenna operating bandwidth decreases slightly, and the spectrum shows low-frequency non-resonant suppression and dip bands, which worsened the high-frequency characteristics of PCA device.**
- **The pulse width of the pump laser has the greatest impact on the high-frequency characteristics of the PCA, with the pulse width increases from 100 fs to 300 fs, the operating bandwidth of PCA device drops from above 7 THz to roughly 2.5 THz.**

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