Terahertz Fabry-Perot interferometer constructed by metallic meshes with micrometer period and high ratio of linewidth/period

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Abstract

The possibility of constructing terahertz Fabry-Perot interferometer using metallic meshes with micrometer period and high ratio of linewidth/period is investigated, and the effectivity of traditional equivalent circuit method is verified by FDTD method. Simulation shows that the reflectance and transmittance of this kind of meshes calculated by equivalent circuit method have considerable deviation from those obtained by vector analysis of FDTD, so equivalent circuit method can be used to roughly evaluate the properties of this kind of metallic meshes. By using a metallic mesh with the period of 5 micrometers and the ratio of linewidth/period of 0.8, a finesse larger than 1100 can be achieved while the peak transmittance is still larger than 0.2 for a Fabry-Perot interferometer. It is therefore concluded that a high-quality terahertz Fabry-Perot interferometer can be constructed by using metallic meshes with micrometer period and high ratio of linewidth/period.

Keywords: Fabry-Perot interferometer, metallic mesh, terahertz, FDTD

1. Introduction

In recent years, terahertz technologies attract more and more attention in science and industry. Terahertz filters and terahertz Fabry-Perot interferometers (FPI) are important instruments and widely used in many terahertz applications [1-9]. Metallic meshes are especially preferred as reflectors of this kind of filters and Fabry-Perot interferometers for their high reflectance, low absorbance, compact size, and no restriction on spectral range [4-7].

High reflectance of metallic meshes is needed to achieve high finesse and high resolution for this kind of filters or FPI [2, 5, 9]. However, traditional metallic meshes with period from several decades to several thousands of micrometers fail to achieve high reflectance at terahertz frequencies, because the period is not far less than the applied wavelengths. Fortunately, with the development of micro-fabrication technologies such as laser direct writing and electron beam writing, metallic meshes with period of several micrometers and high ratio of linewidth/period can be fabricated, which makes it possible to provide high reflectance at terahertz frequencies. In this paper, the possibility of constructing terahertz FPI using metallic meshes with micrometer period and high ratio of linewidth/period is investigated, and the structural parameters of metallic meshes are optimized.

The accurate calculation of reflectance of a single metallic mesh is very important because the reflectance is a key factor to decide the transmission function and finesse of an FPI. The typical method for calculating the reflectance of a single metallic mesh is equivalent circuit method [7, 10], which is successfully used for metallic meshes with period from several decades to several thousands of micrometers. However, to the best of our knowledge, for a metallic mesh with period of several micrometers and high ratio of linewidth/period, the effectivity of traditional equivalent circuit method has not been verified yet. Therefore in this paper, the finite difference time domain (FDTD) method is used to calculate the reflectance and transmittance of this kind of metallic meshes at terahertz frequencies, and the simulated results are compared with those obtained by equivalent circuit method.

2. Theory of Fabry-Perot interferometer

For an FPI composed of two parallel metallic meshes, its transmission function can be obtained by Airy formula and expressed as follows [2, 6]:

$$T_{FPI} = \left(1 + \frac{A_m}{T_m}\right)^{-2} \left[1 + \frac{4R_m}{\left(1 - R_m\right)^2} \left(\sin\frac{\delta}{2}\right)^2\right]^{-1}, \tag{1}$$

where T_{FPI} is the spectral transmittance of FPI, T_m, R_m, and A_m are the spectral transmittance, reflectance and absorbance respectively for a single metallic mesh, δ is the phase difference of two interference beams for a Fabry-Perot cavity with thickness d and refractive index n, and expressed as [2, 6]:

$$\delta = \frac{2\pi}{\lambda} 2nd + 2\Phi, \tag{2}$$

where λ is the incident wavelength in vacuum and Φ is the phase-shift for the reflection on one mesh. The finesse of an FPI can be obtained by using the reflectance of single metallic mesh R_m and can be simplified as follows when R_m is larger than 0.6 [6]:

$$F = \frac{\pi\sqrt{R}}{1 - R}, \tag{3}$$

3. Optimization of structural parameters of metallic meshes for an FPI at THz

According to equation (1), T_{FPI} of the FPI at different R_m and A_m can be shown in Fig. 1. As briefly described in [r7], it can be seen from Fig.1 that higher R_m leads to high finesse but decreases the peak value of T_{FPI}, smaller A_m leads to high peak value of T_{FPI} and has slightly effect on finesse. Therefore smaller A_m and higher R_m are appreciated in the design of metallic mesh used in FPI.

For an inductive metallic mesh with better conductivity, its absorbance at terahertz frequency can be calculated by using equivalent circuit method and expressed as [7, 10]:

$$A_m = 2R_m \frac{R_0}{Z_s} = 2R_m \sqrt{\frac{\pi\varepsilon_0}{\lambda\sigma}} \frac{g}{2a}, \tag{4}$$

where ε_0 is the permittivity of free space, ε_0 is the bulk dc conductivity of the metallic mesh, g is the period and $2a$ is the linewidth of the metallic mesh, $R_0/Z_S$is the normalized loss resistance of single metallic mesh.It can be seen from Fig. 2 that smaller R_0/Z_S can be obtained by larger ratio of linewideth/period, and $R_0/Z_S$is smaller than 0.0025 and 0.0008 at 10 THz and 1 THz respectively when the ratio of linewideth/period is larger than 0.8.

Fig. 3 shows the peak values of T_{FPI} and finesse of an FPI at different R_m. For a metallic mesh with the ratio of linewideth/period of 0.8, A_m is about 0.005 at 10 THz according to equation (4), and the largest finesse is 350 when the peak values of T_{FPI} are larger than 0.2; while A_m is about 0.0015 at 1 THz, the largest finesse is larger than 1100 when the peak values of T_{FPI} are still larger than 0.2. So the performance of an FPI composed of two metallic meshes at low frequency is better than that at high frequency, and high reflectance is especially worth pursuing at low frequency (0.1~2THz) to improve the performance of an FPI.

According to the equivalent circuit theory, the transmittance T_m of a single metallic mesh can be approximately obtained by the following equation at the condition of λ □ g [6]:

$$T_m \approx \left[\frac{2g}{\lambda} \lg\left(\sin \frac{\pi a}{g} \right) \right]^2 , \tag{5}$$

Then combining equation (4), the reflectance of the single metallic mesh is:

$$R_m = \left(1 - T_m\right)\left(1 + \frac{2R_0}{Z_s}\right)^{-1} . \tag{6}$$

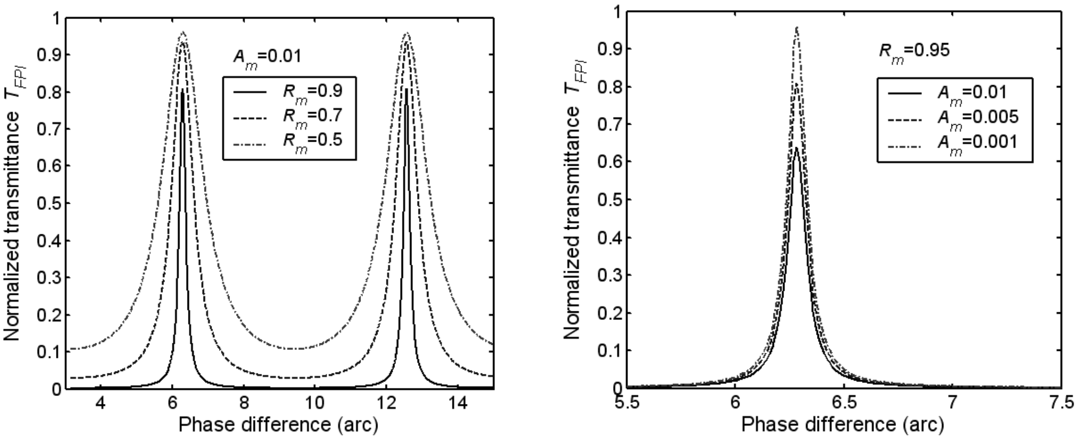

Fig. 1. The normalized transmittance T_{FPI} at different R_m and A_m.

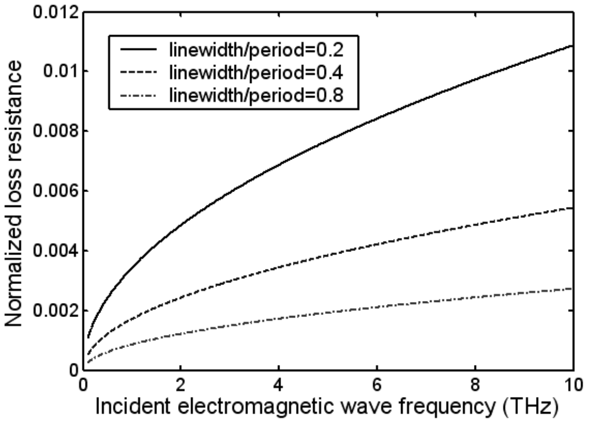

Fig. 2. The normalized loss resistance of single metallic mesh calculated by equation (4).

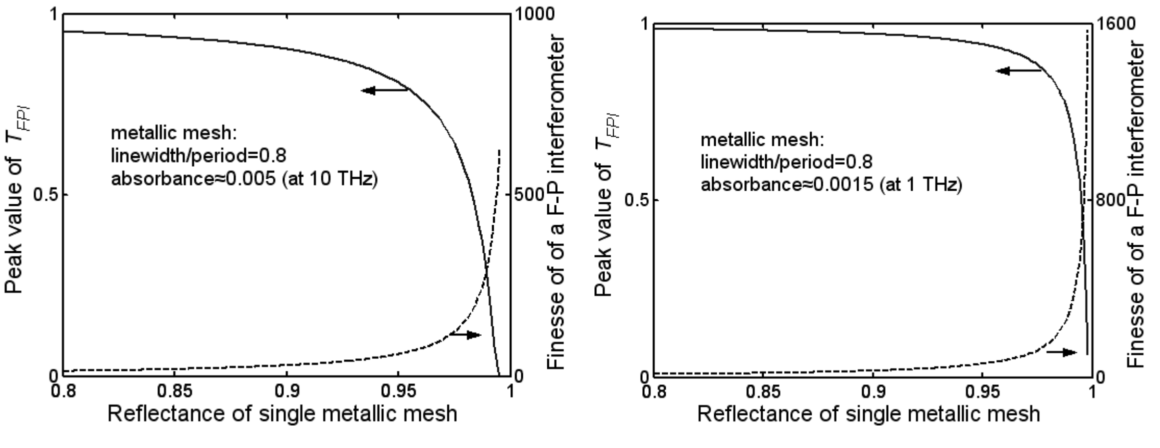

Fig. 3. The peak values of T_{FPI} and finesse of a Fabry-Perot interferometer at different R_m.

According to equation (6), the reflectance of single metallic mesh at fixed ratio of linewidth/period and different *g* can be shown in Fig. 4. It can be seen that a smaller period *g* can result in a higher reflectance at a fixed ratio of linewidth/period. It is therefore anticipated that good reflectance at terahertz frequency can be achieved with a small period of several micrometers. However, the equivalent circuit method is usually suitable for the analysis of transmission properties of metallic mesh with period from decades to thousands of micrometers and the not very high ratio of linewidth/period. For the metallic mesh with period of several micrometers and high ratio of linewidth/period, which is appreciated for the application of Terahertz FPI, the reflective properties of this kind of metallic meshes should be analyzed and the effectivity of traditional equivalent circuit method should be verified.

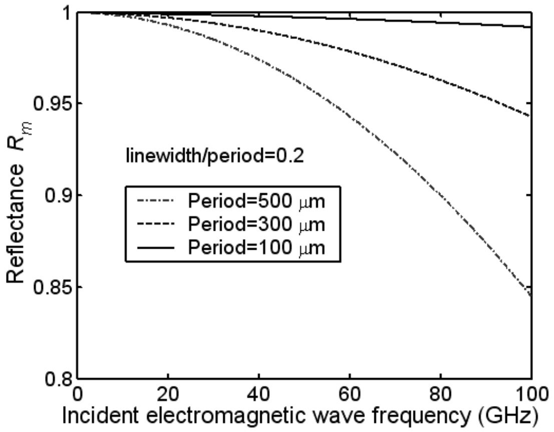

Fig. 4. The reflectance R_m of a single metallic mesh at different periods.

4. Reflective properties of metallic mesh with period of several micrometers

R. Sauleau et al proposed an FDTD model for the transmission analysis of Fabry-Perot cavity at 60 GHz [11]. Here we use this model to analyze the reflectance and transmittance of a single-layer metallic mesh with period of several micrometers and high ratio of linewidth/period at THz. Fig. 5 is the transmittance and reflectance of a metallic mesh with the period of 5 micrometers and the ratio of linewidth/period of 0.8, both the ideal linewidth and the effective linewidth are used in equivalent circuit method [6, 7].

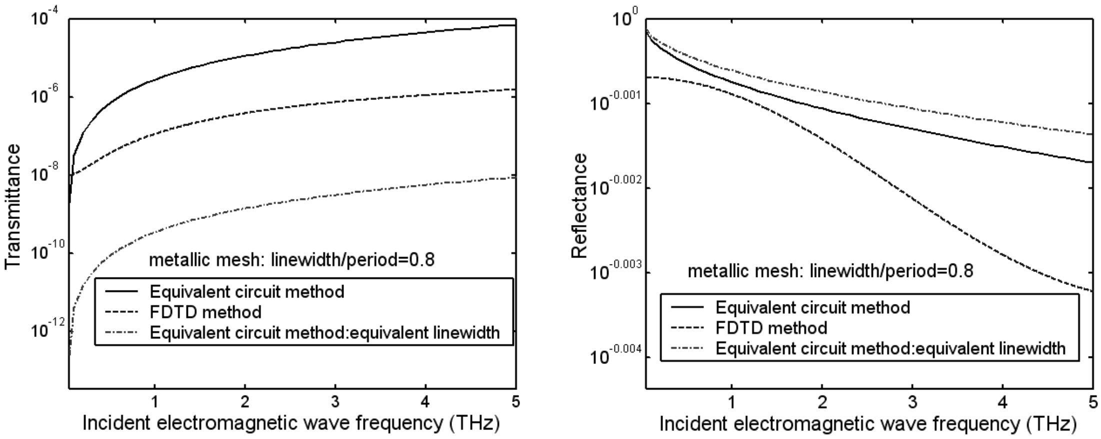

Fig. 5. The transmittance and reflectance of a single metallic mesh with the period of 5 micrometers.

It can be seen from Fig. 5 that, the transmittance or reflectance curves calculated by different methods have the same trend along the frequency axis. However, the calculated results of equivalent circuit method have considerable deviation from vector analysis results of FDTD, which indicates that the traditional equivalent circuit method is not accurate for analyzing the properties of meshes with period of several micrometers and high ratio of linewidth/period at THz, but it can be used to roughly evaluate the properties of this kind of meshes. Fig.5 also shows that, at terahertz frequency, this kind of meshes can achieve high reflectance and low transmittance, for example, a reflectance of 0.9985 and a transmittance of 10^{-8} at 1 THz. It means that a finesse larger than 1100 can be obtained when the peak values of T_{FPI} are still larger than 0.2 according to Fig. 3.

5. Conclusion

In this paper, the possibility of constructing a terahertz Fabry-Perot interferometer using metallic meshes with period of several micrometers and high ratio of linewidth/period is disscussed. Simulation result shows that using a metallic mesh with the period of 5 micrometers and the ratio of linewidth/period of 0.8, a finesse larger than 1100 can be achieved for a Fabry-Perot interferometer when the peak values of T_{FPI} are still larger than 0.2.

It has been shown that the reflectance and transmittance of a metallic mesh with the period of several micrometers and high ratio of linewidth/period calculated by traditional equivalent circuit method have considerable deviation from those obtained by vector analysis of FDTD, but it can be used to roughly evaluate the properties of this kind of metallic meshes.

6. Acknowledgements

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