Theoretical investigations of THz subwavelength metamaterials polarization insensitive modulators

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Abstract: The polarization response of THz wavelength metamaterials modulators were studied, and two special modulators structures were proposed and simulated: the center cross structure and twins split ring structure. Compared with the traditional split ring resonator modulators which were all polarization sensitive, the new two structures had properties of polarization insensitive. The center cross structure was a completely symmetrical metal structure and had the perfect characteristics of the polarization insensitive. For the twins split ring structure, they didn't achieve polarization insensitive completely, but the difference of THz polarization transmittance curves could be negligible. The surface current distribution of twins split ring structure was aslo simulated, and two main transmission mechanisms for the generation of two resonant absorption valleys were presented.

Key words: THz modulator; SRR structure; polarization insensitive

CLC number: TN215 **Document code**: A **Article ID**: 1007-2276(2014)11-3849-05

基于太赫兹亚波长超材料的偏振不敏感调制器的理论研究

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摘 要:对太赫兹波超材料调制器的偏振响应进行了研究。提出并计算仿真了两种特殊结构的调制器,包括中心十字结构和双开口环结构。传统的开口环结构的调制器是偏振敏感的,而所研究的两种结构都是偏振不敏感的。中心十字结构是一个完全对称的金属结构,并具有完美的偏振不敏感特性。对于双开口环结构,它没有达到完全的偏振不敏感,但从太赫兹偏振透射率曲线来看,这种差别可以忽略不计。此外还模拟了双开口环的表面电流分布,并提出了产生两个谐振吸收波谷的主要机制。

关键词:太赫兹调制器; 开口谐振环; 偏振不敏感

收稿日期:2014-03-09; **修订日期**:2014-04-13

基金项目:北京市教育委员会科技计划面上项目(KM20120028009);北京市自然科学基金和北京市教育委员会科技计划重点项目(KZ201310028032)

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0 Introduction

Metamaterials with subwavelength structural features show unique electromagnetic responses that are unattainable in natural materials [1-3]. Terahertz subwavelength metallic structures, also called terahertz metamaterials have attracted much attention in recent years because those metamaterials with subwavelength structural features show unique electromagnetic responses and potential applications in biological fingerprinting, security imaging, remote sensing, and high-frequency wireless communications in the terahertz region[4-6]. Due to the application of high-speed wireless communications, terahertz communication technology has become a research hotspot in many countries. In the terahertz communications technology solution, some different modulation methods have been researched, such as: the inner modulation based on the photoconductive antenna, the external modulation with photonic crystal or metamaterials, electrical mixer modulation technique, optical modulation based on ROF technology[7-10]. Among these modulation schemes, the terahertz communications external modulator based on metamaterial shows better performance and development prospects.

Split ring resonator (SRR) THz metamaterials is the basic form of external metamaterial modulator. Since 1999, Pendry proposed the split ring resonator concept [11], the research in this area has been rapidly developing. Chen Hou-Tong, who published a paper in Nature about controllable metamaterials for terahertz modulator in 2006. This article gives a comprehensive description of the electrically controlled terahertz modulator. By an external signal, depletion layer is formed in the semiconductor substrate, then the metal structure capacitance changes which effects equivalent LC circuit, so the transmittance of the THz waves has been changed at the LC resonant frequency[12]. Ranjan Singh, who reported a light-controlled high-temperature superconducting THz metamaterials ultrafast dynamics research paper in 2009. With increasing of the pump power, the resonance frequency reduces and frequency red shift phenomenon are found [13]. In 2010, Li Jiusheng of China Institute of Metrology used 808 nm and 100 mW optical excitation radiation on THz metamaterials modulator, using BWO THz sources and detectors for experimental measurements, at 0.32 THz resonant frequency, the measured modulation depth of 57% and the modulation rate of 0.1 kb/s have been achieved [14]. In 2011, our group characterized the ultrafast dynamical properties of split ring resonators by utilizing optical pump-terahertz probe spectroscopy on a sub-picosecond timescale[15].

From the above articles there is a common problem for all metamaterial modulators: the metamaterial THz modulators are the polarization-sensitive. Modulators' transmission of different polarization incident THz wave are not the same values. So this issue will restrict the application in THz communications. These metamaterial SRRs modulators are all asymmetry structures which are main reason for polarization-sensitive. Especially the metal structure of the opening in asymmetry is the main reason to produce the polarization-sensitive.

In this letter, we designed the symmetrical metal structure to achieve modulator polarization insensitive properties. All samples were simulated using a 1 μm thick gold layer on a 700 μm thick high-resistivity silicon substrate. The designed structures are just THz resonators, but it's easy to work as modulators when extra electric field or light applied. We investigated the physical mechanism of transmission spectrum through these structures and used the finite-difference time-domain (FDTD) to simulate polarization performance accurately. These metamaterials structures provide a new method to produce polarization insensitive terahertz modulator for high-speed terahertz communication.

1 Polarization insensitive modulator structures

1.1 Center cross structure

To achieve polarization insensitive modulator, the

SRR symmetry opening structure must be considered to design the polarization insensitive modulator. We proposed a center cross structure(Fig.1), and simulated using FDTD method.

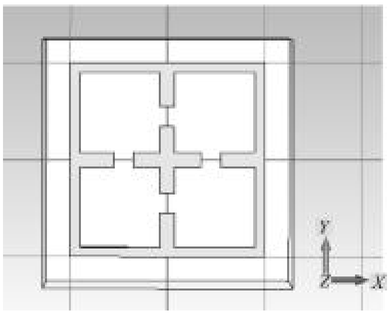

Fig.1 Center cross structure

This metal structure is composed of a square structure and a cross structure added at the center, which makes four opening gap in the whole structure. The overall structure can be realized axisymmetric (**X** axis, **Y** axis) and a central symmetry. The transmittance spectrum simulation result of this structure is shown in Fig.2.

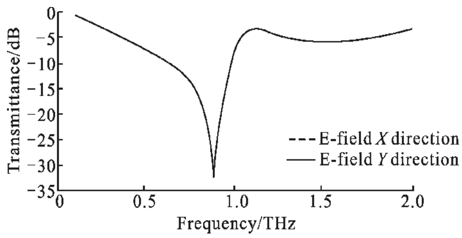

Fig.2 Cross structure THz transmittance

From the Fig.2, we can see clearly that the **X**-direction and **Y**-direction polarization transmittance curves completely coincide. That's because this metal structure is designed a completely symmetrical structure. So its transmittance of the THz wave shows the characteristic of the polarization insensitive.

In order to illustrate the fully symmetrical structure and the polarization insensitive characteristic, we put the cross structure "split" into horizontal and vertical openings stitch structure shown in Fig.3, transmission simulation results are shown in Fig.4.

We compared the frequency corresponding to transmission valley of Fig.2 and Fig.4, the transmittance function of the cross structure is an interaction of horizontal opening structure in **X**-direction and vertical opening structure in **Y**-direction. When the electric field paralleling to the direction of the opening stitch, the opening stitch response to the electric field maximally. When the open position is completely symmetrical, metamaterials THz field modulator **X**, **Y** direction is identical to the response.

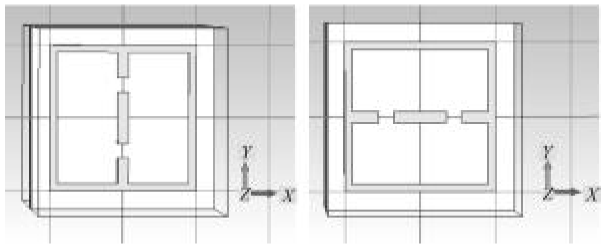

Fig.3 Vertical split structure and horizontal split structure

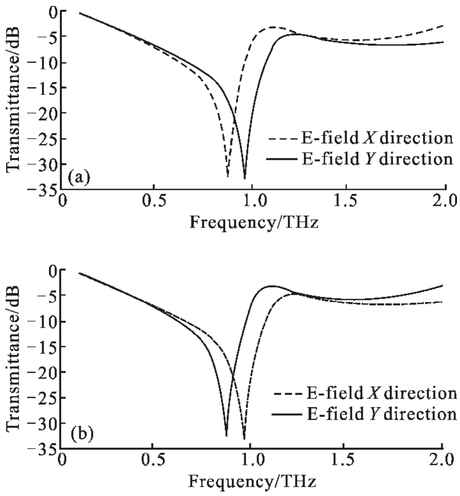

Fig.4 Polarization electric field transmission curves of vertical split structure and horizontal split structure

1.2 Twins split ring structure

The cross structure SRR is designed to meet our goal of polarization insensitive. However, as using the equivalent circuit theory to analysis this structure, the equivalent circuit is too complicated, it's hard to calculate the resonant absorption frequency point by physical mechanism. Then we have designed a twins split ring structure, the structure is shown in Fig.5, and its transmittance simulation results are shown in Fig.6.

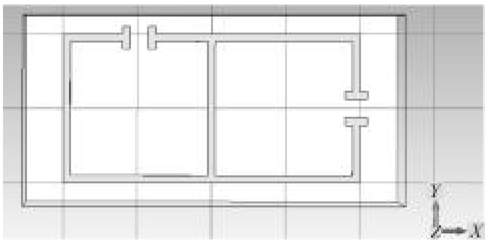

Fig.5 Schematic of twins split ring structure

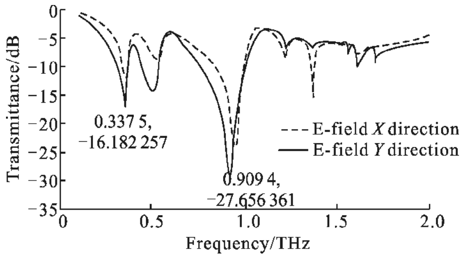

Fig.6 Transmittance of twins split ring structure

From Fig.6, the **X**-direction and **Y**-direction polarization THz wave transmittance values of this structure are not quite same. This is due to twins split ring structure has not completely symmetrical opening position. However, for the two electric field polarization directions, the difference of transmittance curves is very small and can be neglected. As shown in Fig.6, The transmittance and position values of first and third absorption valley have been labeled respectively. We analyzed the resonant absorption mechanism by the surface current distribution. The surface current distribution is shown in Fig.7.

When THz wave incidents to the twins split ring structure, it will induce current in the metal. We simulated the current distribution at resonant absorption wavelengths. From Fig.7(a), we can see clearly the current in left split ring structure form a loop current flows. In this case, the left split ring can be considered a RLC equivalent circuit, and the resonant frequency of this RLC circuit is exactly 0.337 5 THz which is the first absorption valley. But in Fig.7 (b), the surface current distribution in theupper and lower metal arms are in the same direction, and the metal split ring at the left can't form a loop current. So the 3rd absorption valley at 0.909 4 THz is not caused by RLC circuit resonant absorption, it's due to metal strips resonant absorption in this structure.

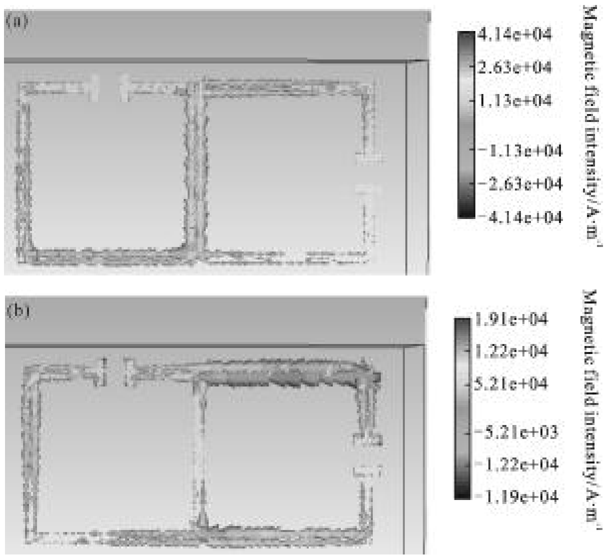

Fig.7 Current distribution at 0.337 5 THz and current distribution at 0.909 4 THz

2 Conclusion

In this paper, the polarization response of THz metamaterials SRR modulators have been researched. Two polarization insensitive SRR structures are proposed and simulated: the center cross structure and twins split ring structure. For the center cross structure, the metal structure is completely symmetrical structure. So its transmittance of the THz wave shows the perfect characteristics of the polarization insensitive. For the twins split ring structure, it don't completely realize polarization insensitive, but the transmittance curves especially the resonant absorption points coincide quite well and the difference can be neglected, meanwhile we used the surface current distribution simulation of both spit ring of the modulator to explain the transmission function generating mechanism, and gave two main transmission mechanisms for generation of two resonant absorption valleys.

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