Terahertz wave modulator based on metamaterial

Li Jiu-sheng1,2, Zhao Xiao-li1
1Centre for THz Research, China Jiliang University, Hangzhou 310018, China
2College of Precision Instrument and Opto-Electronics Engineering, Institute of Laser and Optoelectronics, Tianjin University, Tianjin 300072, China

E-mail: jshli@126.com

Abstract. We demonstrated experimentally a terahertz wave modulator based on microstrip resonator structure. The signal modulation mechanism of the presented terahertz wave modulator is based on the resonance characteristic of resonator microstrip structure controlled by without or with light excitation. A modulated semiconductor laser with 808nm wavelength is employed to light the microstrip resonator structure. The experimental results show that the modulation speed and attenuation of the proposed terahertz modulator are of 0.1Kb/s and 25dB at frequency of 0.32THz, respectively.

1. Introduction
The terahertz (THz) frequency range 0.1–10 THz, located midway between microwaves and infrared light, presents a new frontier containing numerous technical applications and fundamental research problems. With the realization of the terahertz generator and detector, terahertz wave has attracted significant attention and has been extensively investigated. Due to their special properties, within the past few years, many potential applications of terahertz waves have been dramatically explored in many fields such as biomedical diagnostics, security screening, military detection, radio astronomy, atmospheric studies, high speed communication, quality control of packaged goods, and moisture analysis for agriculture [1]. With wide bandwidth and high data transmission bit rates, terahertz wave wireless communications have great potential in the future short range wireless communications [2]. As an important device in terahertz communication for signal processing, terahertz wave modulator has been attracted significant attention. In 2004, T.K.Ostmann [3] designed an electrically driven terahertz modulator. In 2007, using a one dimensional photonic crystal with a GaAs defect, L. Fekete et al. [4] demonstrated the possibility of ultrafast modulation of THz radiation. At this year, J. Li [5] analyzed a terahertz wave modulator using photonic crystals. However, there are still relatively undeveloped with only a few examples of cryogenically cooled and room temperature modulators. Quantitative studies on terahertz wave modulator are still very limited. Robust terahertz wave modulators are still needed that can be easily implemented and integrated into a chip-scale platform. Therefore, it is valuable to investigate the design of modulator in the terahertz range.

In this letter, we have proposed and demonstrated a novel terahertz wave modulator using microstrip resonator structure. The terahertz wave modulation mechanism of the proposed terahertz wave modulator is based on the resonance characteristic of resonator microstrip structure which is controlled by using a modulated laser. Experimental results show that the presented terahertz wave modulator has modulation speed of 0.1Kb/s, extinction ratio of 25dB, and simplicity.
2. Device fabrication

The resonator microstrip structure unit are optimized and obtained through simulation using commercial CST software. We transferred resonator microstrip structure pattern to mask. 210nm of aluminum on a 400µm-thick intrinsic silicon wafer was deposited by radio frequency magnetron sputtering method. About 1µm AZ-601 photoresist be coated on the wafer by GKF-411 gluing purifying machine. To evaporate the solvent and densify the AZ-601 film, put the wafers in hotplate at 70ºC persistence 5 minutes, and cool the wafer for 5 minutes. Mount the mask and the wafer onto the mask aligner, the AZ-601 film be exposed by URE-2000S deep ultraviolet lithography exposure plane. Bake the AZ-601 on a hotplate at 70ºC persistence 5 minutes for acid-initiated, thermally driven epoxy cross-linking. Develop with RZX-3038 positive photoresists developer with agitation until the pattern is clear, rinse with deionized water. To evaporate deionized water and densify the AZ-601 film, put the wafers in hotplate at 70ºC persistence 5 minutes, following with 120ºC oven 10 min, and cool the wafer for 15 minutes. The wafer is etched by MNL/DIII reactive ion etcher, rinse with deionized water and bake with 120ºC oven 10 minutes. Strip photoresist with ORNIII5532 plasma stripping photoresist system. The sample is evaluated by optical microscope and shown in figure 1.

![Figure 1. Photography of the modulator](image)

3. Experiment results

A backward-wave oscillator (BWO) system is used to test the terahertz-wave modulator which is placed at the focal point of the terahertz radiation. Both excitation and terahertz wave spot sizes while the carrier versus terahertz spot size overlap was determined by sweeping the optical excitation. The backward-wave oscillator is set to be 0.32THz and used as the continuous terahertz wave source. A modulated semiconductor laser at 808 nm with incident optical intensities 100mW is employed to light the microstrip resonator structure based on intrinsic silicon. The resonance of the microstrip resonator structure is controlled by the photo-excited carriers. Measured terahertz wave transmittance characteristic of the novel terahertz wave modulator with the modulated laser shows in Figure 2. Applied square wave signal with 0.1Kb/s for laser modulation is shown in Figure 2 (a). Figure 2 (b) shows the detected signal from terahertz wave pyroelectric detector with 0.1Kb/s. From figure, it can be noted that a better than 25dB attenuation of the novel terahertz wave modulator is obtained at terahertz frequency of 0.32THz. The modulation speed of the proposed modulator is of 0.1Kb/s. Being the modulation speed is limited by the response time of the detector, and further studies will be conducted with a rapid response terahertz detector.
4. Conclusion
We experimentally demonstrated that the terahertz wave modulator based on microstrip resonator structure is able to achieve terahertz wave signal modulation. The terahertz wave modulator presented here, is based on the modulated semiconductor laser excitation at 100mW average power at 808nm to light the microstrip resonator structure, demonstrating terahertz wave transmission modulation that has a modulation speed of 0.1Kb/s. The extinction ratio of the presented terahertz wave modulator is more than 25dB at frequency of 0.32THz.

Acknowledgments
This research was partially supported by the National Natural Science Foundation of China (No.60971027).

References
[1] Li J and Li X 2009 Chem. Phys. Lett. 476 92
[2] Piesiewicz R, Ostmann T K, Krumbholz N, Mittleman D and Koch M 2007 IEEE Antennas and Propag. Mag. 49 24
[3] Ostmann T K, Pierz K, Hein G, Dawson P and Koch M 2004 Electron. Lett. 40 124
[4] Fekete L, Kadlec F, Kužel P and N’emec H 2007 Opt.Lett. 32 680
[5] Li J 2007 Optics Commun. 269 98