Academic Journal of Emerging Technologies
ISSN Print: 3104-4417
ISSN Online: 3104-4425
CD ISSN: 3104-4433
https://doi.org/10.63313/AJET.9031

Terahertz on-chip surface plasmon polaritons modulation devices

Yexin Xu*. Quan Li. Binqi Du. Huirong Wang and Xinxin Zhang
School of Electronic Engineering, Tianjin University of Technology and Education, Tianjin 300222, China
Email: 1309405803@qq.com

How to cite this paper: Xu, Y. X., Li, Q., Du, B. Q., Wang, H. R., & Zhang, X. X. (2025). Terahertz on-chip surface plasmon polaritons modulation devices. *Academic Journal of Emerging Technologies*, 2(1), 60–64. ISSN Print: 3104-4417; ISSN Online: 3104-4425.
https://doi.org/10.63313/AJET.9031
Published: 2025-12-31

Abstract

This Surface plasmon polaritons (SPPs) refer to a special electromagnetic wave mode that exists at the interface between a metal and a dielectric, holding significant application prospects in on-chip devices. However, relevant on-chip modulation devices are quite scarce, especially in the terahertz (THz) band. In this paper, by integrating metasurfaces with photoresist, a terahertz on-chip modulation device is designed, enabling the control of the propagation of surface plasmon polaritons. This terahertz on-chip modulator provides a reference for the design of novel surface plasmon polariton devices and exhibits broad application prospects in future photonic integrated chips.

Keywords

Surface plasmon polaritons; metasurface; terahertz; modulator

1. Introduction

Surface plasmon polaritons (SPPs) are a special electromagnetic wave mode that exists at the interface between a metal and a dielectric. Through the interaction between electromagnetic waves and electrons in the metal, the electromagnetic field is localized near the interface and propagates parallel to it [1,2]. Due to its two-dimensional planar propagation characteristics, it is also known as terahertz surface plasmonic wave (SPW). Developing terahertz SPP functional devices and subsequently constructing terahertz on-chip systems based on SPP links are considered an important approach to realizing compact terahertz systems, and have become a cutting-edge and hot research direction in the current terahertz field [3-5]. In addition, the rapid development of metasurfaces has transformed the design concepts of traditional optical devices and significantly advanced the field of meta-optics. In this paper, by combining the artificially designable characteristics of metasurfaces with the insulating properties of photoresist, a terahertz SPP modulation device is designed. This device is expected to meet the application requirements and offer unique prospects of terahertz on-chip systems, serving as one of the viable and effective options for the miniaturization and integration of terahertz systems.

2. Metasurface design

The basic structural unit design of the terahertz modulator mainly consists of two layers, as shown in Figure 1. The bottom layer (the green part) is a quartz substrate with a thickness of 100 μm, and the top layer (the yellow part) is an Electromagnetically Induced Transparency Slit (EITS) metal - structured layer [6]. The metal - structured layer is composed of a Bar Slit (BS) and a Split - Ring Slit (SRS), forming a complementary version similar to the classic Electromagnetically Induced Transparency (EIT) structure, denoted as EITS. Similar to the design of traditional free - space EIT, the BS serves as a bright - mode resonator, while the SRS acts as a dark - mode resonator. The specific dimensions of the metal structure are as follows: l = 180 μm, x = 60 μm, g = 8 μm, d = 5 μm, w = 10 μm, and P = 600 μm. The operating frequency of the entire metasurface is set at 0.5 THz. Under the incidence of a terahertz beam, the resonance of a single periodic structure can excite the propagation of local surface waves. We arrange the single periodic structures in an 8×8 pattern, and the field distribution of the entire surface wave is the result of the mutual interference of all periodic units. To investigate the surface - wave excitation characteristics of the proposed device, we use CST Microwave Studio to conduct three - dimensional full - wave time - domain numerical simulations. The specific simulation settings are as follows: Open boundary conditions are adopted in all directions, and the quartz substrate is assumed to be semi - infinite to avoid secondary reflections within the quartz substrate. The incident wave is set as a plane wave that vertically impinges on the metasurface from the substrate side, with the terahertz electric field direction along the x - direction. Both the quartz substrate and the quartz spacer layer are set as lossless dielectrics with a dielectric constant of εq = 3.76. Aluminum metal is set as a lossy metal with a conductivity of σm = 3.56 × 10^7 S/m.

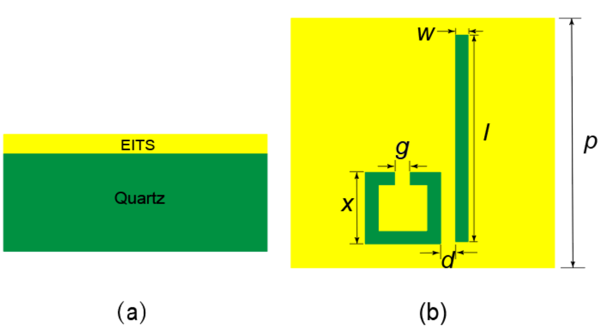

Figure 1. (a) Side view of the terahertz sensor structure; (b) Diagram of a single metal slit structure of the terahertz sensor

3. Results

The propagation of surface plasmon polaritons (SPPs) obtained from the simulation is shown in Figure 2(a). It can be observed that the surface waves on the left - hand side of the array are suppressed, exhibiting an overall asymmetric excitation characteristic. This is because the Split - Ring Slit (SRS) is located to the left of the Bar Slit (BS). As a result, the destructive interference effect mainly occurs on this side, and the resonance of the SRS significantly suppresses the excitation of the corresponding surface waves, leading to a substantial reduction in the surface waves excited by the BS on the SRS side. In addition, new surface - wave excitations appear at the top and bottom of the metasurface. This is due to the near - field coupling effect of the BS, which causes the excitation of the SRS.Since a significant destructive interference effect occurs on the left - hand side of the array, we detected the amplitude excitation spectrum at a point 3 mm away from the center of the sample and 100 μm above the sample surface (as indicated by the green dot in Figure 2(a)). The red curve in Figure 3 shows the detected spectrum. It can be seen that there is a distinct trough near 0.5 THz in the curve, which is caused by the destructive interference effect. This also corroborates the above - mentioned field distribution of the SPPs.

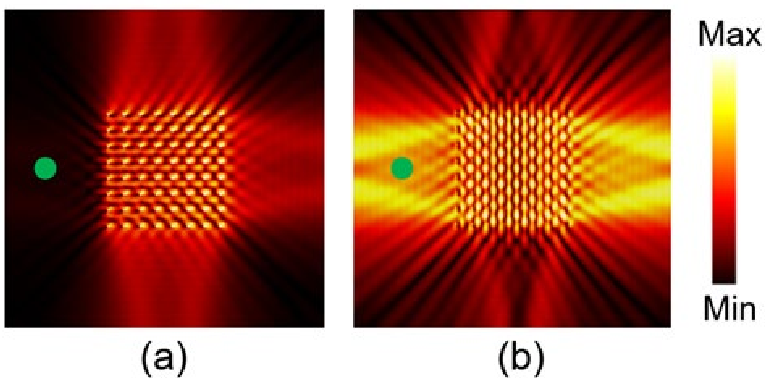

Figure 2. (a) Field distribution diagram of surface plasmon polaritons before coating with photoresist; (b) Field distribution diagram of surface plasmon polaritons after coating with photoresist

To verify the modulation characteristics of the terahertz sensor, we coated a layer of photoresist material with a thickness of 50 μm on the sample surface, which has a refractive index of n = 1.6. As can be seen from Figure 2(b), after coating with the photoresist material, the field distribution of surface plasmon polaritons (SPPs) undergoes significant changes: the intensity of the overall surface waves is enhanced; the enhancement of surface waves on the left - hand side of the array is particularly evident; while the surface waves at the top and bottom are slightly weakened. This is because, on one hand, the photoresist coated on the sensor surface can act to confine the SPPs; on the other hand, it acts on the dark - mode Split - Ring Slit (SRS) gap, thereby weakening the function of the dark mode and further reducing the destructive interference effect between the bright and dark modes. This weakening effect is more clearly observed from the changes in the amplitude excitation curve. As shown in Figure 3, the spectrum after coating with the photoresist (the black curve) exhibits a very prominent resonance peak at 0.5 THz, instead of the resonance trough (the red curve) before coating with the photoresist. This also proves that the destructive interference effect has been disrupted. This indicates that the photoresist is highly sensitive in modulating the SPPs, as it can transform a resonance troughinto a resonance peak.

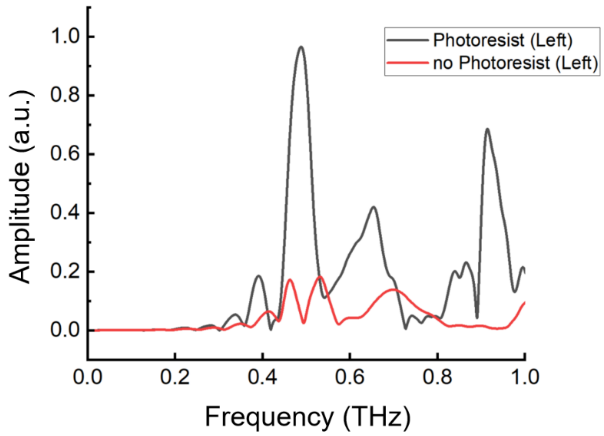

Figure 3. Amplitude excitation spectrum extracted from the left - hand Position

4. Conclusion

This paper proposes a terahertz surface plasmon polariton (SPP) modulation ap proach by integrating metasurfaces and photoresist. This method offers a valuable reference for the design of terahertz on - chip devices. Given its unique characteristics and advantages, it holds significant potential for applications in the field of integrated circuits and chips. By leveraging the interaction between the metasurface structure and the photoresist, we are able to achieve effective control and manipulation of SPPs, which is crucial for enhancing the performance and functionality of terahertz - based chip - level systems. The findings presented in this study pave the way for further exploration and development of advanced terahertz technologies in the chip domain, opening up new avenues for high - speed communication, high - precision sensing, modulation, and other related applications.

Acknowledgements

This work was supported by the Tianjin Municipal Undergraduate Innovation Training Program Project (Project Number: 202410066008).

References

[1] W. L. Barnes, A. Dereux, and T. W. Ebbesen, “Surface plasmon subwavelength optics,” Nature 424, 824-830 (2003).

[2] S. A. Maier, “Plasmonics: Fundamentals and Applications,” Springer, New York (2007).

[3] S. Ummethala, et al., “THz-to-optical conversion in wireless communications using an ultra-broadband plasmonic modulator,” Nat. Photonics 13, 519-524 (2019).

[4] Y. Salamin, et al., “Compact and ultra-efficient broadband plasmonic terahertz field detector,” Nat. Commun. 10, 5550 (2019).

[5] X. Zhang, et al., “Terahertz surface plasmonic waves: a review,” Adv. Photon. 2, 014001 (2020).

[6] Q. Li, et al., “Active control of terahertz surface plasmonic wave excitation using electromagnetically induced transparency based graphene metasurfaces,” Opt. Express 31, 37452-37463 (2023).