Rainbow trapping and releasing in InSb graded grating strip at the terahertz range

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***Abstract*—In this paper, we demonstrate the feasibility of exciting surface plasmon polaritons (SPPs) using intrinsic indium antimonide (InSb) graded grating structure, which exhibits extraordinary properties of trapping and releasing electromagnetic waves in terahertz range. The dispersive properties of the gradient-corrugate InSb grating structure is characterized using the computer simulation technology (CST). Furthermore, the propagation characteristics of the InSb grating grooves are thorough analyzed by the dispersive relation curves, electron field magnitude distribution. It is proved that the graded grating grooves based on intrinsic InSb are capable of exciting SPPs. The electric field magnitude distributions of the grating waveguide in fixed frequency at different temperatures are compared, which demonstrates the InSb grating structure is an excellent candidate for trapping and releasing SPPs at terahertz (THz). The thermo-optic property of InSb gives rise to the meaningful application for future compact communication devices.**

Keywords*— Spoof surface plasmon polaritons (SPPs); simeconductor grooves

I. INTRODUCTION

Surface plasmon polaritons (SPPs) are electromagnetic wave bounding to the interface between two different media [1, 2]. And these different media have opposite permittivities such as conductor and dielectric. The strong field confinement to the surface gives SPPs the ability to wide applications including optical buffers, filters, and enhanced light-matter interactions [3,4]. Comparing to existing researches which focus on rainbow trapping of electromagnetic waves by various approaches [5,6], there is less concern about releasing the trapping SPPs mode [7]. For better controlling the speed of surface waves, it is important to study the releasing of electromagnetic waves. In this paper, the dispersive characteristics of the gradient grating waveguide along the intrinsic indium antimonide (InSb) surface in the THz frequency are investigated. The trapping and releasing properties of InSb graded grating structure are thoroughly compared by tuning the temperature parameters. Such structure based on thermo-optic material InSb exhibits excellent trapping and releasing capabilities, which is significant for future optical application.

II. DEVICE STRUCTURE

To investigate the SPPs property of intrinsic InSb gradient-corrugated grating waveguide thoroughly, the structure we used is exhibited in Fig. 1. And we examine the dispersive relation by the eigenmode solver of commercial software technology (CST) Microwave Studio. In this system, the thickness of the intrinsic InSb strip along the z direction t is 65 μm, the period *p* is 215 μm, the depth of the groove is represented by *h*, the groove width *d* is 65 μm, and the width of the space bar *a* is 150 μm. The groove size is defined by *a* and *d*. The height for the whole graded grating waveguide *H* is set to be 600 μm. The groove depth *h* changes gradually along the *y* direction, which increases from 100 to 500 μm. Therefore, the whole length of the strip *W* is 8965 μm including 41 periods.

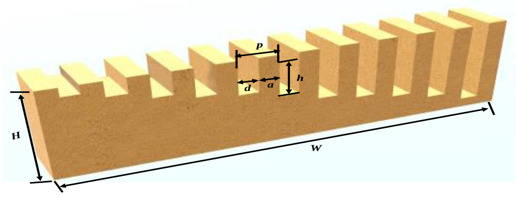

Fig. 1. 3D schematic of the designed plasmonic graded grating waveguide with intrinsic InSb.

III. RESULTS AND DISCUSSION

In order to analyze the SPPs dispersion characteristics of the InSb plasmonic graded grating waveguide, the dispersive curves are demonstrated in Fig. 2. As we can see, the upward trend of the dispersive curve gradually slows until it disappears, and the cutoff frequency of the curve is corresponding to the point where the upward trend disappears. What's more, the cutoff frequency decreases along with the deeper groove due to stronger confinement of the SPPs waves. It can be seen that the minimum value of the cutoff frequency is 0.084 THz corresponding to the groove depths of 500 μm. And the maximum cutoff frequency is 0.326 THz, which is corresponding to the groove depth 100 μm.

To further interpret the dispersion characteristics of SPP mode in the graded grating waveguide for InSb, the electric field magnitude distribution of TM mode is extracted using COMSOL Multiphysics, which is demonstrated in Fig. 3. And we observe the simulated electric magnitude distribution on a plane that is 1 μm above the grating strip in the *z* direction. The length of the whole strip is 8965 μm with 41 periods and the depth of grooves changes gradually from 100 to 500 μm at a step of 10 μm. As we can see, the propagation distances of the SPPs waves are shortened step by step along with the increasing frequency, which is correspond to the dispersive relation shown in Fig. 2. What's more, the group velocity of the SPPs falls to nearly zero along the *x* direction at the position 7675 μm, 5805 μm, 4515 μm, 2795 μm, 1075 μm for the cutoff frequency 0.084 THz, 0.112 THz, 0.151 THz, 0.214 THz, 0.326 THz, respectively.

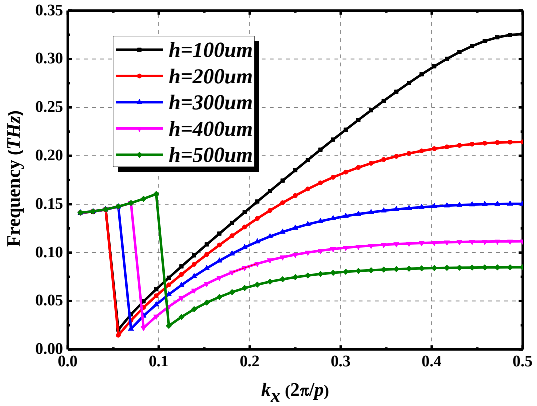

Fig. 2. The dispersion relations of SPPs in one unit of the designed spoof plasmonic graded grating waveguides with different groove depths.

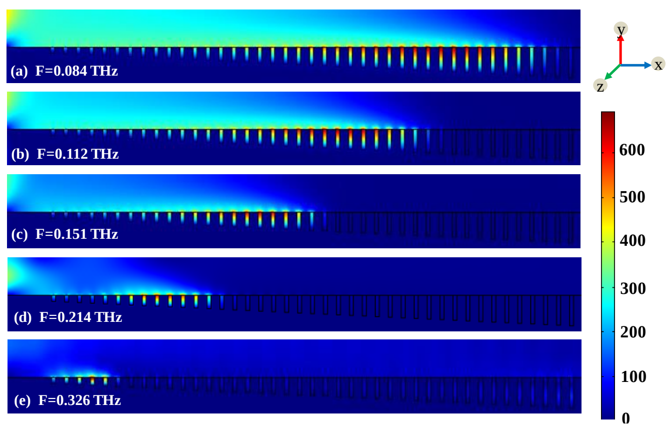

Fig. 3. 2D electric field magnitude distributions of the designed spoof plasmonic graded grating waveguides along intrinsic InSb at different frequencies.

The dispersive relations of intrinsic InSb in one unit of the designed gradient-corrugated grating waveguides with different groove depths are shown in Fig. 4. The parameters used in simulation are the same with those in Fig. 2. As can be seen from the Fig. 5, the cutoff frequency of the dispersive curves increases along with the increasing temperature.

To get a better picture of the thermo-optic property of InSb, 2D electric field distributions of the designed gradient-corrugated grating waveguides are simulated in Fig. 6. We observe them on the plane that is 1 μm above the grating structure along the *z* direction. For comparing the propagation properties of InSb at different temperatures, the frequency 0.214 THz is chosen for the convenience of covering all the temperature range. It can be seen that the propagation distances are shortened step by step along with the temperature increase. The trend that the cutoff frequencies increase with the increasing temperature is also observed in Fig.5 . The 2D electric field distributions clearly indicate that the rainbow could be released by tuning temperature at InSb graded grating structure.

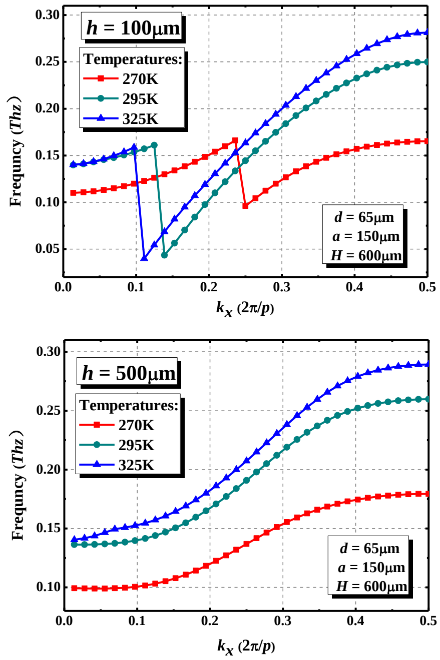

Fig. 4. The dispersion relations of SPPs in one unit of the designed spoof plasmonic graded grating waveguides with different groove depths at different temperature.

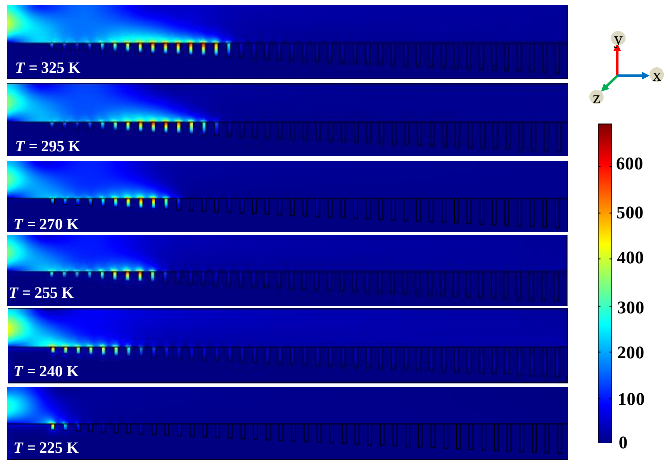

Fig. 5. 2D electric field magnitude distributions of the designed spoof plasmonic graded grating waveguides along intrinsic InSb at different temperature.

IV. Conclusion

In this work, SPPs propagating at the surface of grating grooves based on InSb achieve rainbow trapping and releasing in THz region succefully. The propagation characteristics of the InSb grating grooves are thorough analyzed by the dispersive relation curves, electron field magnitude distributions. Such thermo-optic property of InSb permits optical buffers, data synchronizers, broadband slow-light systems, and other future on-a-chip optical communications.

References

[1] J. Gómez Rivas, M. Kuttge, and H. Kurz, "Low-frequency active surface plasmon optics on semiconductors," Appl. Phys. Lett. 88(8), 082106 (2012).

[2] L.V. Hau, S. E. Harris, Z. Dutton, and C. H. Behroozi, "Light speed reduction to 17 metres per second in an ultracold atomic gas," Nature 397, 594–598 (1999).

[3] Fengnian Xia, Lidija Sekaric and Yurii Vlasov, "optical buffers on a silicon chip," Nature Photonics 1, 65–71 (2007).

[4] Joyce K.S. Poon, Lin Zhu, Guy A. DeRose, and Amnon Yariv, "Transmission and group delay of microring coupled-resonator optical waveguides," Opt. Lerr. 31, 456-458 (2006).

[5] B. C. Pan, Z. Liao, J. Zhao, and T. J. Cui, "Controlling rejections of spoof surface plasmon polaritons using metamaterial particles," Opt. Express 22(11), 13940–13950 (2014).

[6] Z. Liao, J. Zhao, B. C. Pan, X. P. Shen, and T. J. Cui, "Broadband transition between microstrip line and conformal surface plasmon waveguide," J. Phys. D. 47(31), 315103 (2014).

[7] Q. Gan, Y. J. Ding, and F. J. Bartoli, "Rainbow trapping and releasing at telecommunication wavelengths," Phys. Rev. Lett. 102(5), 056801 (2009).