Ultrathin Corrugated Metallic Strips for Ultrawideband Surface Wave Trapping at Terahertz Frequencies

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***Abstract*—The finite element method has been used to simulate the dispersion properties of the ultrathin spoof slow-wave plasmonic waveguide on basis of different ultrathin metal strip grooves. We analyze the dispersion curves, electric intensity distribution and power flow distribution. To conclude, the most ideal slow-wave system is the arch-shape waveguide. Analysis of such an ultrathin arch-shape waveguide presents an ultrawideband performance for trapping surface waves, which permits broadband trapping of terahertz radiation.**

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

I. Introduction

Surface plasmon polaritons (SPPs) has attracted lots of interests for the potential for strong confinement of electromagnetic wave in the subwavelength scale over broadband. However, metal behaves like a perfect electric conductor (PEC) and cannot support in the terahertz (THz) frequencies [1]. Therefore, based on "spoof SPPs" we design some surface structures for overcoming the limit. Besides, various structures have been used to slow light at THz frequencies, such as graded metallic grating, graphene monolayer and corrugated wire [2-4]. But, such structures will result in the large size devices. So, an ultrathin corrugated metallic structure has been adopted to manufacture compact devices [5-7].

II. Device Structure

The four different spoof plasmonic waveguides structures are shown in Fig .1. In Fig. 1(a), the structure which is named "double grating" has a width d of 5 μm and gap a of 16 μm. The height b increases from 5 to 30 μm with a step of 1 μm. The distance h between two grating bottoms is 15 μm. The structure in Fig. 1(c) which is named "comb-shape" has a length f of 546 μm and a width w of 205 μm. As for Fig .1(b) and (d), the two structures which are named as "dumbbell-shape" and "arch-shape" structure both have variational radius r from 5 to 30 μm. The whole length g is 1326 μm. The height w and the distance h in Fig. 1(b) and (d) remain the same as those in Fig. 1(a) and (c).

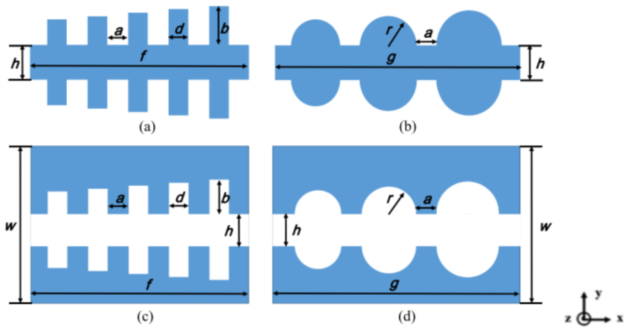

Fig. 1. Schematics of the spoof plasmonic waveguides with (a) double grating, (b) dumbbell shape, (c) comb-shape, and (d) arch-shape structures.

III. Results and Discussion

The dispersion relations of SPPs are shown in Fig. 2. It is obvious that the dispersion curves of SPPs of two rectangular shapes are much higher than semi-circle shapes. And at the first Brillouin zone boundary, the frequency of the arch-shape structure is 1.71 THz, which is the minimum value. The arch-shape structure shows more deviation compared light line for its wave vectors of SPPs are larger compared to others.

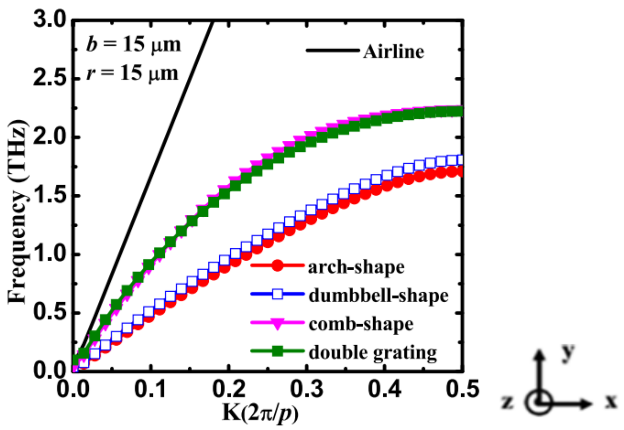

Fig. 2. Dispersion relations of SPPs in one unit of the four different structures for b = 15 μm and r = 15 μm.

To better understand the dispersion properties of SPPs, the electrical field intensity distributions are analyzed in Fig. 3. As we can see, the highest electric field intensity is usually appeared at the upper and bottom of metal strip in the two structures in Fig. 3(a) and (b) and middle area in Fig. 3(c) and (d). The comb-shape and arch-shape structures have higher propagation efficiency than other two structures for their two opposite strips structures. As a result, we can conclude that the dispersion properties not only depend on the dimension of the waveguide structures but also the propagation path of the different waveguides.

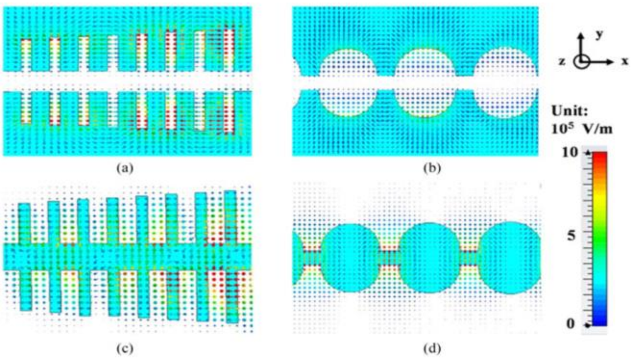

Fig. 3. Electric field intensity distributions on the four kinds of slow-wave waveguides at 1 THz with (a) double grating, (b) dumbbell-shape, (c) comb-shape, and (d) arch-shape structure.

To verify the conclusion of Fig. 3, the power flow distributions for the four structures are plotted in Fig. 4. The attenuation coefficients α can be calculated by $ln(P_1/P_2)/(2f)$, where P_1 and P_2 are defined as the power of the face at 0 μm and 546 μm in the x direction, respectively. From Fig. 4, it is obvious that the attenuation coefficients α of the double grating and dumbbell-shape structures are much larger than other two, which indicates shorter propagation length. The power along the comb-shape waveguide decays firstly and then increases to peak value. As for the arch-shape structure, the electric field intensity presents periodic oscillatory in Fig .4, which indicates the controllability of slow-wave system. Therefore, we choose arch-shape waveguide as the ideal structure.

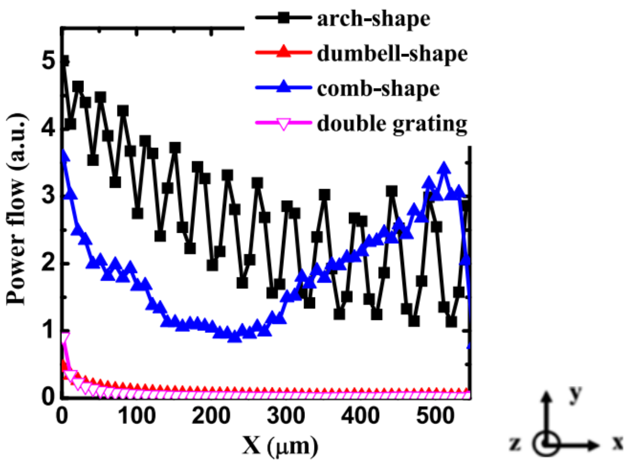

Fig. 4. Power flow distributions along the central line at 1 THz for the structures in Fig. 3.

In order to analyze the propagation properties of the arch-shape waveguide shown in Fig. 5(a), we design some grooves with different disk radii varying from 5 μm to 30 μm and the dispersion curves of SPPs are plotted in Fig. 5(b). We can see that as the radius of the disk increasing, the dispersion curve decreases and the difference in sizes has less influence on the confinement ability, especially when the radius is larger than 25 μm. Besides, the range of radius from 5 to 30 μm corresponds to the range of frequency from 1 to 3.5 THz, which indicates an ultra-wideband capability.

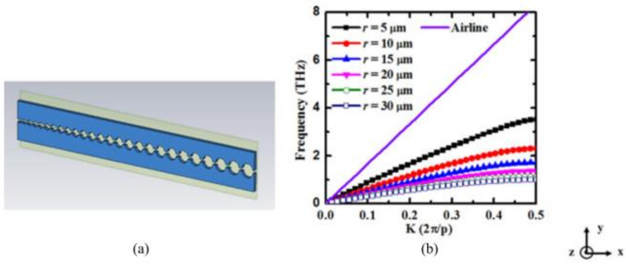

Fig. 5. (a) Three-dimensional schematic of the arch-shape waveguide with gradient radii. (b) Dispersion curves of one unit of the designed arch-shape waveguide with different radii varying from 5 μm to 30 μm at a step of 5 μm. The purple line is the airline.

IV. Conclusion

In summary, the finite element method has been used to analyze the characteristics of dispersion for the spoof SPPs on basis of different corrugated metal groove structures. Based on the conclusion of comparison, the arch shape slow-wave plasmonic waveguide was chosen to be the ideal structure and its dispersion relation and propagation characteristics have been observed. And this gradient corrugated plasmonic waveguide can be demonstrated as controlling slow light with elaborate designing, which can contribute to realizing compact plasmonic function devices at THz frequencies.

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