Vortex-Beam Emitter Based on Spoof Surface Plasmon Polaritons

Jia Yuan Yin and Li-Xin Guo
School of Physics and Optoelectronic Engineering
Xidian University
Xi’an, Shaanxi, China
jyyin@xidian.edu.cn, lxguo@xidian.edu.cn

***Abstract*—A novel method to generate vortex beams by spoof surface plasmon polaritons (SPP) is proposed. The looped double-layer spoof SPP waveguide is applied to realize the transmission of electromagnetic waves. Beam emitting is accomplished through a series of circular patches, whose role is not only the radiation units but also resonators giving rise to the phase shifts required by the vortex beam. The proposed method is validated by both numerical simulation and experiment. The measured results show that vortex beams carrying different OAM modes are observed at different frequencies.**

Keywords—spoof surface plasmon polaritons; vortex beam; orbital angular momentum

I. INTRODUCTION

Since the fact that photons in optical vortices carry orbital angular momentum (OAM) was discovered, OAM modes have been investigated intensively in the field of optical [1] and to solve the problem in wireless communications as a new method [2]. Up to now, there have been many methods to generate OAM [3]-[5]. One issue that should be noted for the available methods is that most ones are achieved by bulky structure, making the system has big volume. This issue can be neglected for optical systems, but not for low frequency systems. In recent years, spoof surface plasmon polaritons (SPP) have been investigated to produce compact microwave components to enhance the performance of information systems [6]-[7]. The proposed SPP-based vortex beam emitter is one of the attempts.

In this paper, a novel method is proposed to generate vortex beams based on spoof SPP. A looped double-layer spoof SPP waveguide is applied to construct the transmission route of the EM waves, while a series of circular patches is set beside the spoof SPP waveguide for beam emitting. Such circular patches also function as resonators modulating the phase of radiation beam. It is shown that vortex beams with different OAM modes are generated at different frequencies without any changes in structure. High purity of the expected mode can be observed clearly at every resonant frequencies.

II. OPERATING PRINCIPLES

Since the vortex beam owns helical phase fronts and azimuthal component of wave vector, the key to generate vortex beam is the rotated phase distribution and radiation. Fig. 1(a) illustrates a prototype of the proposed structure, in which a single-side corrugated metallic strip is used to form the spoof SPP waveguide. Because of the loop structure, the spoof SPP waveguide is designed on both sides of the dielectric substrate in order to avoid the overlap. The top and bottom SPP waveguides are connected by a metallic via, as shown in Fig. 1(b). F4B is chosen as the substrate material in this particular design with a height of 3 mm. The spoof SPP waveguide is made to be a loop with radius of 80 mm, for the purpose to form the whole length as an integer times of wavelength at the expected radiation central frequency (6 GHz). Here, a series of circular metal patches is used as radiators. When the circular patches are placed around the spoof SPP waveguide, it has been demonstrated that the SPP waves are easily coupled to the patches for efficient radiations [8]. The radius of the circular patch is set as 8 mm for the same sake, so that the single-pass phase shift after a circular resonator can achieve 2π, which will be explained later.

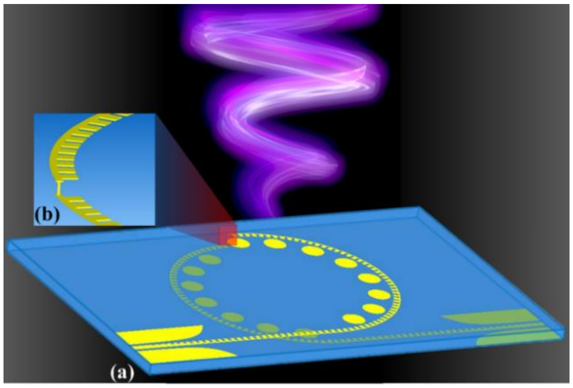

Fig. 1. (a) Prototype of the vortex beam emitter, in which the yellow part is modeled as copper and the blue part is the dielectric substrate. Particularly, the lighter yellow denotes the structure on the top of substrate, while the darker yellow represents the structure on the bottom of substrate. (b) Detailed illustration of the connection between the top and bottom structures.

Spoof SPP waveguide owns different propagating constants (k) at different frequencies. That is, when the EM waves propagate along the spoof SPP waveguide for the same physical distance, the phase shift varies at different frequencies. If the spoof SPP waveguide is made to be a loop, the rotated phase distribution will be achieved along the spoof SPP waveguide and a phase gradient along the azimuth direction will be obtained. According to the principle of OAM mode index, the mode index of the traveling-wave loop structure can

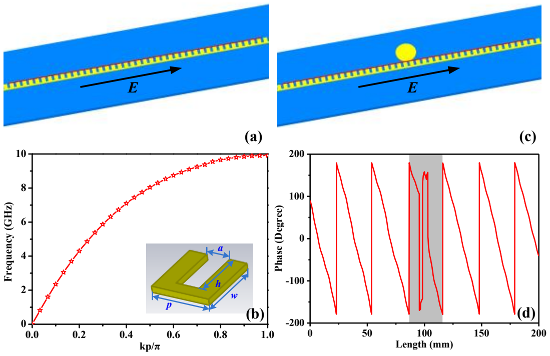

Fig. 2. (a) Spoof SPP waveguide without the circular patch. (b) Dispersion curve of the unit cell on the spoof SPP waveguide. (c) Phase change along the spoof SPP waveguide without the circular patch. (d) Phase change along the spoof SPP waveguide with the circular patch.

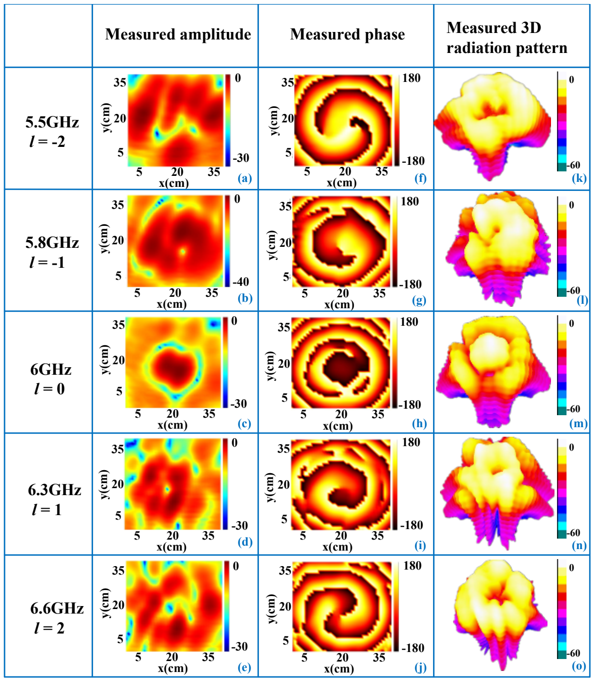

Fig. 3. (a)-(e) Measured normalized amplitudes of the OAM modes under different orders. (f)-(j) Measured normalized amplitudes of the OAM modes under different orders. (k)-(o) Measured normalized far-field radiation patterns of the OAM modes under different orders.

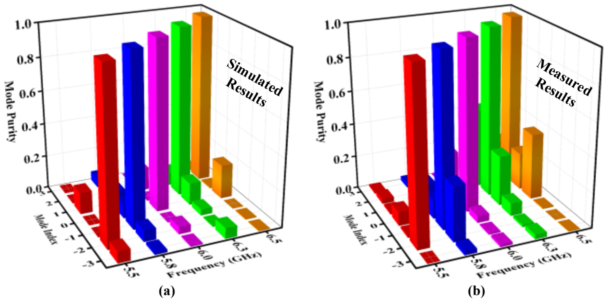

Fig. 4. Normalized mode purity of the beam emitted from the proposed design. (a) Modal content calculated through simulated phase data. (b) Modal content calculated through measured phase data.

be calculated. When the circular patches are put beside the spoof SPP waveguide, a phase lag appears along with the energy coupling. If the single-pass phase shift after the circular resonator is made to be 2π, then the effective phase-shift achieves 2π as shown in Fig. 2(d). Therefore, the final radiation phase is a combination of the phase from the spoof SPP waveguide and the phase lag brought from the circular metal patches. As a consequence, if the total phase shift around the loop is l times of 2π, then the OAM mode number is l.

III. RESULTS

The measured results are presented in Fig. 3, in which Figs. 3(a)-(e) and 3(f)-(j) give the amplitude and phase distributions, respectively, Figs. 3(k)-(o) are the normalized 3-D radiation patterns. With reference to the figures, the mode number of OAM beam is conspicuous. We can get $l = -2, -1, 0, 1, 2$ at 5.5, 5.8, 6.0, 6.3, and 6.6 GHz.

Modal purity is also an indicator of the characteristic of the vortex beam emitter. The normalized modal content at each resonant frequency is calculated through both simulated and measured phase data, as shown in Fig. 4. From this figure, it is clearly that at certain frequencies, the expected modes appear to these points, and the other modes are in very small amounts, implying little effects on the final emitted beam. The good agreement between simulated and measured results can be regarded as another success of the proposed design.

IV. CONCLUSION

A novel and simple method is proposed to generate vortex beams by spoof SPP. The transmission route of EM waves was formed by a looped double-layer spoof SPP waveguide. Circular patches are used not only for the radiation units, but also for resonators to produce the phase shift. The proposed method was verified by both numerical calculation and experiments. Vortex beams with different OAM modes are observed at different frequencies. The high purity of the expected mode implying the success of the proposed design.

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