Exotic optical elements generating 2D surface waves

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Summary

We introduce exotic optical elements for 2D surface wave systems hosting Bloch surface waves (BSWs). First, we will study a 2D non-diffracting beam, second, a 2D array of the optical bottle beam via the Talbot effect and third, tight light confinement like a photonic nanojet. Investigations are carried out using a well-established BSW platform.

Introduction

Routine optical tasks of transforming and directing light beams are commonly done with lenses and mirrors. They are the workhorses in conventional systems, even for micro-optical systems. More sophisticated designs have brought novel and exotic functions, e.g., non-diffracting character via a Bessel beam [1], a dark spot via an optical bottle beam [2], and sub-λ confinement via a photonic nanojet [3]. They had been profoundly studied in theory and in experiments for 3D systems. However, in new domains like nano-photonics and 2D surface wave systems, such performances are often difficult to be realized. The goal of this study is to bring such exotic functionalities into a 2D surface wave system, which hosts BSWs.

BSW platform

The schematic of the BSW platform is shown in Fig. 1, where three elements will be investigated for the proposed exotic performances. The operation wavelength is 1.55 µm. Six periods of Si_3N_4 (t = 283 nm) and SiO_2 (t = 472 nm) are alternately deposited on a glass substrate by chemical vapor deposition. For the top layer, an additional 50-nm-thick layer of Si_3N_4 is deposited. On the top of the platform, 60 nm thick TiO_2 structures will be patterned as the optical elements. Here, the effective refractive index contrast Δn between the structure layer (n_{eff1} = 1.26) and the top layer (n_{eff2} = 1.11) equals 0.15. More details of the multilayer parameters employed in the current BSW platform are reported elsewhere [4].

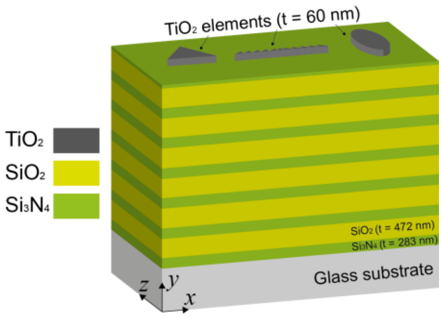

Fig. 1 Schematic of the BSW platform, which consists of a truncated multilayer and a TiO_2 structure layer on the top.

Results

Numerical studies and optimizations are carried out using a commercial finite-difference time-domain (FDTD) simulation tool (CST microwave studio). To generate a non-diffracting beam, we illuminate a 2D axicon with a BSW. The axicon is in this study an isosceles triangle as shown on the left (top layer) of Fig. 1. The base and height of the triangle are 50 µm and 25 µm, respectively. A long non-diverging beam is generated similar to the 3D axicon operation. The FDTD result is shown in Fig. 2(a). The propagation length without significant divergence reaches approximately 150 µm. For the dark spot, we employ a Fresnel axicon (Fraxicon) concept [5]. Such an implementation resembles the grating structures shown on the center of the platform in Fig. 1. Consequently, the Talbot effect produces multiple bright spots with regular periods in the lateral and axial directions, as shown in Fig. 2(b). Each bright spot is surrounded by dark spots, and *vice versa*, where the dark spot surrounded by bright spots is the analogy of the optical bottle beam. Those spots appear in a 2D array mainly due to the Talbot effect. For the last one, the PNJ-like tight spots, the critical parameters are the size of the element and the refractive index contrast between the surrounding medium and the element material. For the current BSW platform, the Δn is 0.15, which is too low to produce the PNJ with conventional circular geometry. Therefore, we need to adapt our design concept to find equivalent performance. We vary the shape of the elements, e.g., ellipse (shown in Fig. 2(c)), rhombus (not shown here), and triangle (shown in Fig. 2(d)). Among them, the isosceles triangle of base = 10 μm and height = 14 μm, shown in Fig. 2(d), leads to the smallest spot, whose FWHM size reaches 0.62λ.

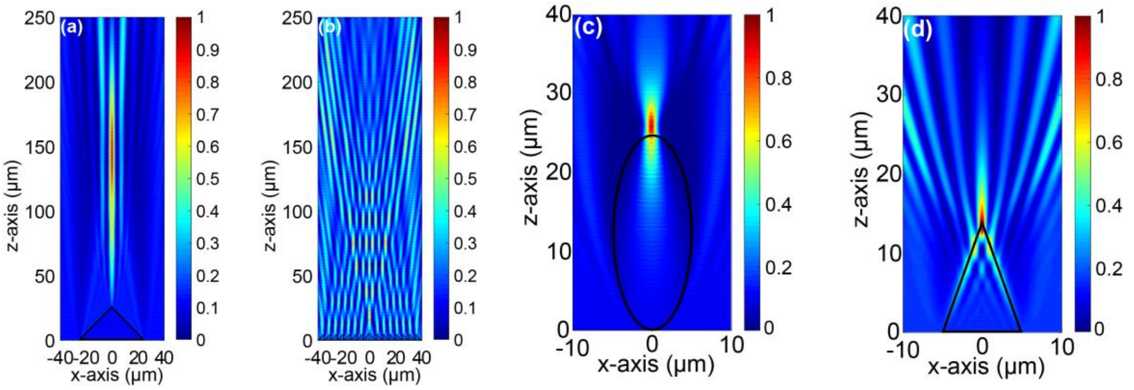

Fig. 2 Intensity distributions in the *x-z* plane obtained by FDTD simulations: (a) 2D Bessel-like beam, (b) an array of optical bottle beams via the Talbot effect, and (c)-(d) PNJ-like tight spots. The intensity is normalized. The element shape is drawn by dark solid lines in each intensity figures.

The optimized TiO_2 elements will be fabricated on the BSW platform, by electron beam lithography and a lift-off technique. Scanning near-field optical microscopy (SNOM) will measure near-field amplitude and phase distributions on each element.

Conclusions

Exotic optical functionalities for 2D Bloch surface wave systems have been demonstrated, such as a 2D Bessel-like beam, an array of optical bottle beams, and PNJ-like tight spots. They all show the predicted original properties, and in addition distinctive characteristics compared to 3D systems. In the conference, we will discuss the difference between 3D and 2D systems for each case, and the SNOM measurements will be presented, too.

Acknowledgement

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