Optics Communications 339 (2015) 216–221

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Realization of enhanced light directional beaming via a Bull's eye structure composited with circular disk and conical tip

Qing Zhang [a,b], Pidong Hu [c], Chengpu Liu [a,*]

[a] State Key Laboratory of High Field Laser Physics, Shanghai Institute of Optics and Fine Mechanics, Shanghai 201800, China
[b] Department of Physics, College of Sciences, Shanghai University, Shanghai 200444, China
[c] Department of Physics, East China University of Science and Technology, Shanghai 200237, China

ARTICLE INFO

Article history:
Received 24 August 2014
Received in revised form
13 November 2014
Accepted 14 November 2014
Available online 20 November 2014

Keywords:
Surface plasmon polariton
Beaming efficiency
Subwavelength structure
Bull's eye structure

ABSTRACT

One new plasmonic light beaming structure aiming to improve beaming property, based on the basic Bull's eye pattern but with the central hole blocked by a metal circular disk at the input side and a conical tip added at the output side, is proposed. The FDTD simulation confirms that this composite structure provides an enhanced beaming efficiency of light not only in the signal intensity but also the angular distribution. Compared to that for Bull's eye structure, the far-field intensity can be enhanced by several times, due to the strong coupling between the circular disk and metal film forming a cavity-like antenna; simultaneously the far-field angular distribution is narrowed obviously, as a result of the focusing effect from the conical tip which significantly localizing the surface plasmon waves excited by the periodic ring grooves. Moreover, the near-field light transmission shows an oscillatory pattern versus circular disk's diameter, however as a whole, the competitive contributions from the collecting area and the metal loss of the circular disk, results in the existence of the optimal transmission.

1. Introduction

According to standard diffraction theory, when light transmits through an isolated sub-wavelength hole or slit in an opaque screen, the transmission is very weak and light diffracts to all directions [1]. The weak transmission and strong diffraction are considered as two basic constraints in manipulating light in a very small scale for technological purposes. On one hand, the second constraint is broken Since Ebbesen et al. has first reported that, when light transmits through a metallic subwavelength aperture, surrounded with periodic surface corrugations at the output side (that is the so-called Bull's eye structure), the radiation pattern will be compressed into a narrow beam instead of diffracting into all directions [2,3]. This plasmonic beaming phenomenon has attracted an explosion of interests in the interaction between light and subwavelength metallic structures [4–8]. On the other hand, numerical simulations have confirmed that covering a subwavelength slit by one metal nanostrip, a horizontal nanocavity antenna was formed, can significantly enhance the optical transmission [9], which is later confirmed experimentally by Li et al. using metal disks instead [10], therefore the first constraint could also be broken.

Here we combine the above two advantages, and propose a new far-field beaming scheme, based on a Bull's eye composite structure (BECs), which is from but different to the well-known Bull's eye structure [2]. A circular metal disk is added at the input side of the Bull's eye structure, the far-field intensity is enhanced significantly, but its angular distribution does not change. In addition, a conical tip is added above the central hole, which first guiding the surface plasmons (excited by the periodic ring grooves) into larger area, and then pushing some plasmons further to localize near to the conical tip's apex [11,12]. As a result, the conical tip provides a better focusing to the far-field angular distribution.

The new far-field beaming scheme can achieve improved light transmission and focusing efficiency obviously and simultaneously, which could find the roads to some multidisciplinary fields, such as near-field microscopy [13], high-density data storage [13], and light emitting diodes [14].

2. Nanostructure's design and simulation tools

Bull's eye composite structure is shown in Fig.1. Part I is a Bull's eye pattern which is etched from a free standing 300 nm thick silver layer: one central hole, and goes completely through the silver layer with a diameter of 300 nm; five 60 nm deep grooves surrounding the hole are etched at the output side of the layer

* Corresponding author.
E-mail address: chpliu@siom.ac.cn (C. Liu).

http://dx.doi.org/10.1016/j.optcom.2014.11.047

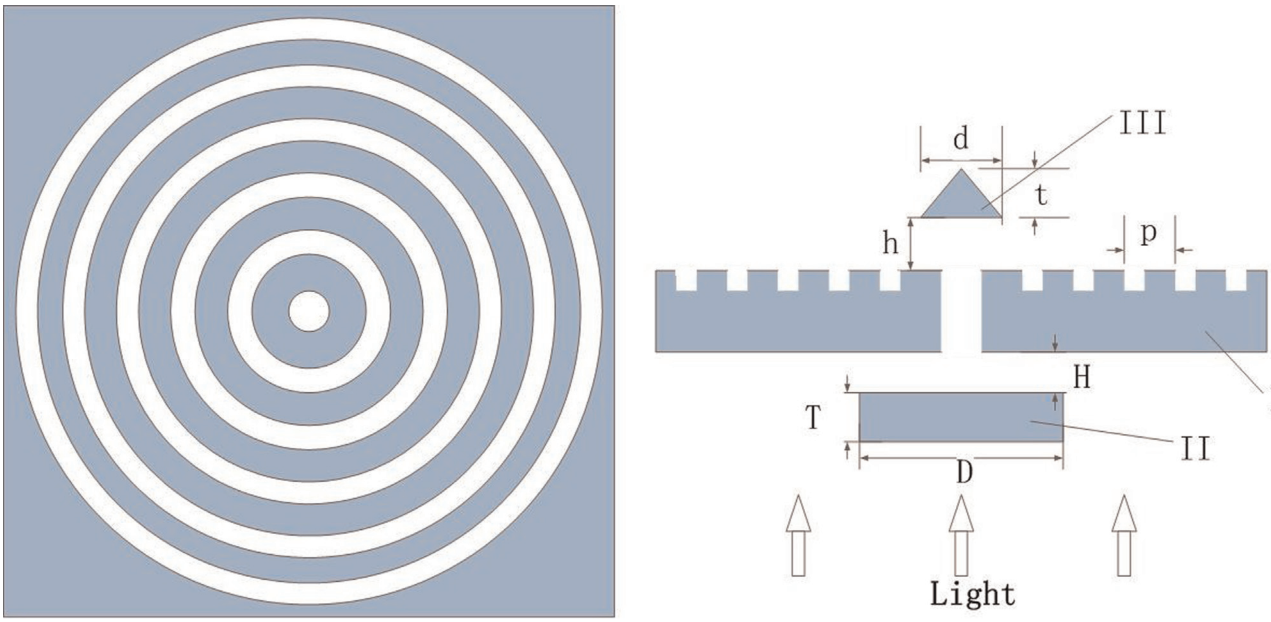

Fig. 1. Schematics of Bull's eye composite structure (BECs) (Right, side view), including three elements: Part I, the conventional Bull's eye structure, part II, a circular metal disk, and part III, a conical metal tip. The light is incident from the bottom vertically. Top view of the grooves in Part I is shown in the left.

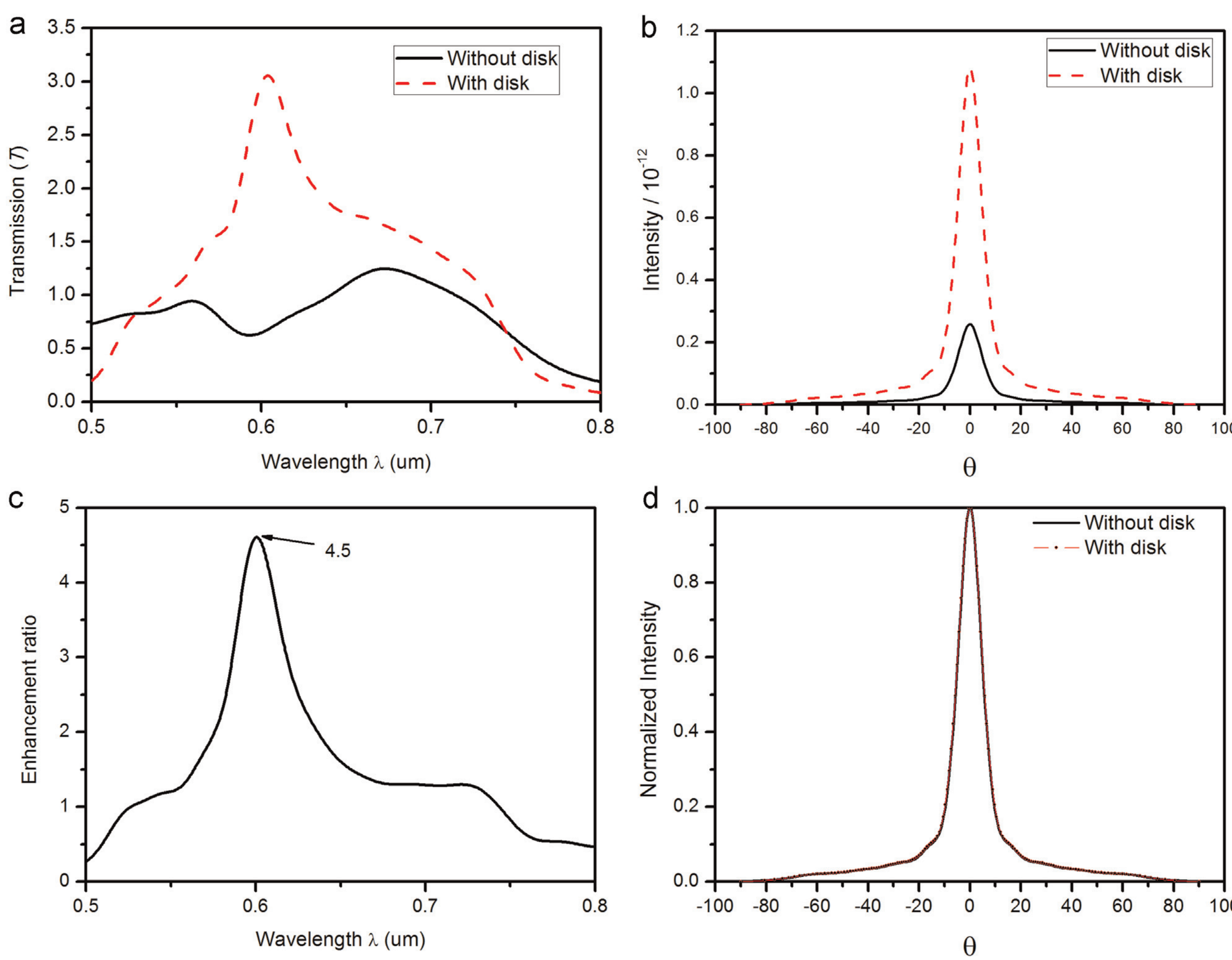

Fig. 2. Simulated transmission spectra (a) and the corresponding far-field intensity angular distributions (b) for Part I with (dashed line) or without (solid line) disk (Part II) plus. The transmission enhancement ratio between the above two cases versus the wavelength is show in (c). (d) is the normalized results to (b). The parameters are $T=200$ nm, $H=150$ nm and $D=2000$ nm.