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# ELECTRIC FIELD ENHANCEMENT OF GOLD TIP OPTICAL ANTENNA WITH SPECIAL GEOMETRY

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This paper provides a new design for a gold tip optical antenna based on a specific geometry, and then, the change of electric field enhancement for plane wave laser excitation with 400 to 700 nm in the vicinity of optical antenna are simulated. Progressions of geometry incorporate the change of period of circular grating from 200–300 nm, on the shaft of antenna. In addition, the distribution of enhancement of the electric field in a plane perpendicular to the shaft has been acquired. Finally, the optimal value for the maximum enhancement at the period of 208.843 nm is calculated.

**Keywords:** optical antenna, tapered gold tip, field enhancement, surface plasmon.

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## 1. Introduction

An optical antenna is a device which is designed to efficiently convert free-propagating optical radiation to localized energy, and vice versa [1]. They can enhance the coupling between free-space propagating light and the localized excitation of nanoscopic light emitters or receivers, thus forming the basis for many nanophotonic applications. Additionally, they can enhance the interaction between light and matter by several orders of magnitude and localize the energy of electromagnetic radiation in the subwavelength region. With the assistance of optical antennas, the diffraction Abbe limit can be overcome, leading to new opportunities in advanced optical spectroscopy and microscopy in the subwavelength range. Because of these properties, a subwavelength optical antenna would allow the detection of high frequency spatial features and the analysis of the electronic and vibrational structure for nanoscale objects. Properties of localized plasmons critically depend on the shape of the nanoparticles, which allows selective "tuning" of the system resonances to an effective interaction between light and matter.

This has potential for an extensive range of novel photonic applications, including chemical [2,3] and thermal sensors [4], near-field microscopy [5,6], nanoscale photodetectors [7], and plasmonic devices [8,9]. By utilizing optical antenna, it is possible to concentrate the energy of the laser in a little scale zone such as nanometer. The gold tip is one of the most popular optical antennas in the recent years. One advantage of this antenna, is the breaking of the diffraction limit. The enhancement in the electrical field around the gold tip as a result of the plasmon resonance, which is dependent on the antenna geometry and the impact of lightning rod effect [10]. Direct irradiation of the tip apex, in the near-field optical scanning microscope (NSOM) prompted the creation of a foundation signal and suppression of the efficiency of the antenna and thus, numerous explorations have been carried out to reduce this issue. Adiabatic nanofocusing along conical metal tapers describes a coherent transport of optical excitations in the form of surface plasmon polariton (SPP) waves over several tens of $\mu$m and the concentration of this energy into a nanometric volume at the taper apex. In the adiabatic limit, i.e., if the waveguide cross section variation is slow and relative changes of the SPP wave vector are small, on the scale of the SPP wavelength, radiative and reflective losses are minimized and energy transport to the apex is expected to be particularly efficient [3]. From an application perspective, adiabatic nanofocusing results in the creation of a single, dipole-like emitter, spatially localized to a few nm and with an intense optical near field. Such an emitter holds a high potential for, e.g., ultrahigh resolution optical microscopy, tip-enhanced Raman spectroscopy, or extreme ultraviolet (EUV) generation.

Raschke Et al [11] proposed the concept of adiabatic nanofocusing, in this method by reducing the size of the region in which enhancement of electric field occurs, the background might be greatly diminished. In the adiabatic nanofocusing method, first, the surface plasmon of the shaft is energized, then the surface plasmon travels to the apex of tip and is finally converted to the localized plasmon in the apex. In this paper, the geometry of the ordinary gold tip has been changed. Moreover, circular gratings with a period of 200, 250 and 300 nm have been included. Maxwell equations with FDTD simulation numerical software have been utilized to obtain the results. Using this geometry, a different peak, resulting from grating surface plasmon excitation, was obtained.

## 2. Methodology

The finite-difference time-domain (FDTD) approach is a reliable method for solving Maxwell's equations with complex geometries [14]. FDTD provides time domain information, offering insight into the electrodynamics of a system [15]. In FDTD, the electromagnetic field and structural materials of interest are described on a discrete mesh composed of so-called Yee cells.

Maxwell's equations are solved discretely in time, where the time step used is related to the mesh size through the stability criterion. This technique is an exact representation of Maxwell's equations in the limit that the mesh spacing goes to zero. All the calculated and reported intensities are normalized with respect to the intensity of the incident light. In side illumination, the light is linearly polarized along the tip axis. The software lumerical, based on the FDTD method, is utilized. The FDTD approach has rapidly become to one of the most important computational methods in Electromagnetics since Yee proposed it in 1966 [16]. The FDTD method involves the discretization of Maxwell's equations in both the time and the space domain in order to find the E and H fields at different positions and at different time-steps. The FDTD method can conveniently be applied to simulating the electromagnetic scattering and radiation from a target of complex shape as well as non-uniform dielectric objects by simply adjusting the number, size and material properties of the Yee cell [17].

Only the electric field component is chosen to evaluate the enhancement. The light intensity is presented by the square of the electric field intensity, which has the same tendency with the light intensity.

To generate a strong field enhancement at the tip, the electric field of the exciting laser beam needs to be polarized along the tip axis. The influence of tip shape and material on the field enhancement has been discussed in a series of publications with the aim of discovering the optimum tip [18, 19].

The electric field around the optical antenna is calculated and simulated based on Maxwell's equations:

$$E(r) = E_0 + i\omega\mu\mu_0 \int_v \bar{G}(r, r')j(r')dV', \tag{1}$$

and

$$H(r) = H_0 + \int_v [\nabla \times \bar{G}(r, r')]j(r')dV', \tag{2}$$

where $\bar{G}$ is the dyadic Green's function and $\mathrm{E}_0$ represents the initial electric field for the plane wave laser.

## 3. Simulation results

In this work, we investigated the influence of tip shape on the field enhancement. We assumed a golden tip, a 10 – nm radius of apex and a 30°. Cone angle and three proposed period of grating which are 200, 250 and 300 nm. The laser beam is considered as a plane wave with the wavelength of 400–700 nm. The considered model and the simulation results for the considering grating period are shown in following figures.

Figure 1 illustrates the shape of proposed optical antenna with 200 nm period grating.

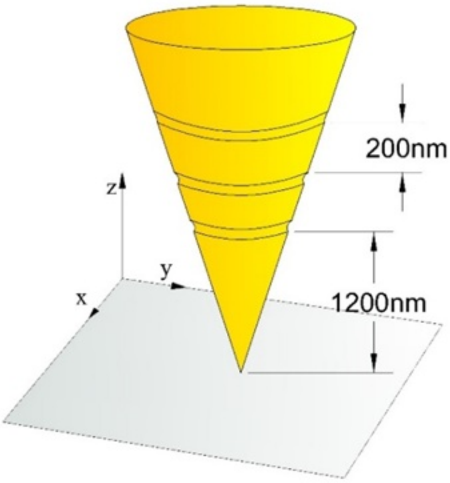


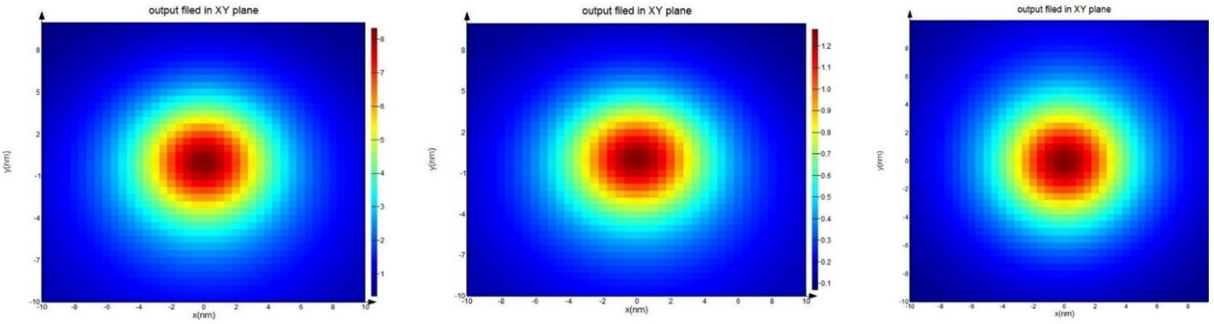
FIG. 1. Considered shape for optical antenna

Figures 2 show the intensity distribution for three proposed period of grating with 90 degree laser incident angle in X and Y axis.

These figures confirm that there are no significant changes in the intensity distribution in the plane of X–Y where Z = 0 nm.

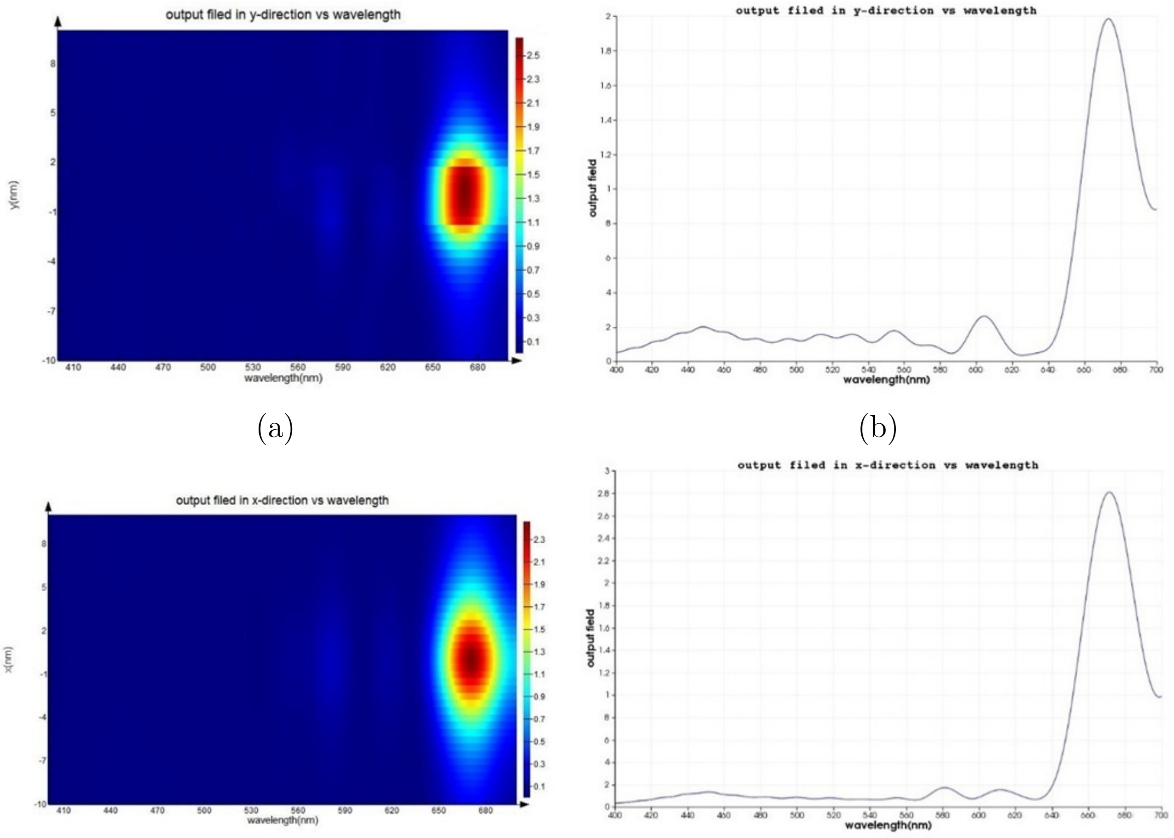
Figures 3 to 5 represent the distribution intensity in X and Y directions for three proposed grating periods. Moreover, the curves of enhancement for the X and Y component of electric field versus their wavelength are depicted.

According to the simulation results, it can be concluded that by changing the grating period on the shaft, the resonance can be shifted, which results in changing the distribution of the electric field enhancement.



(a) (b) (c)

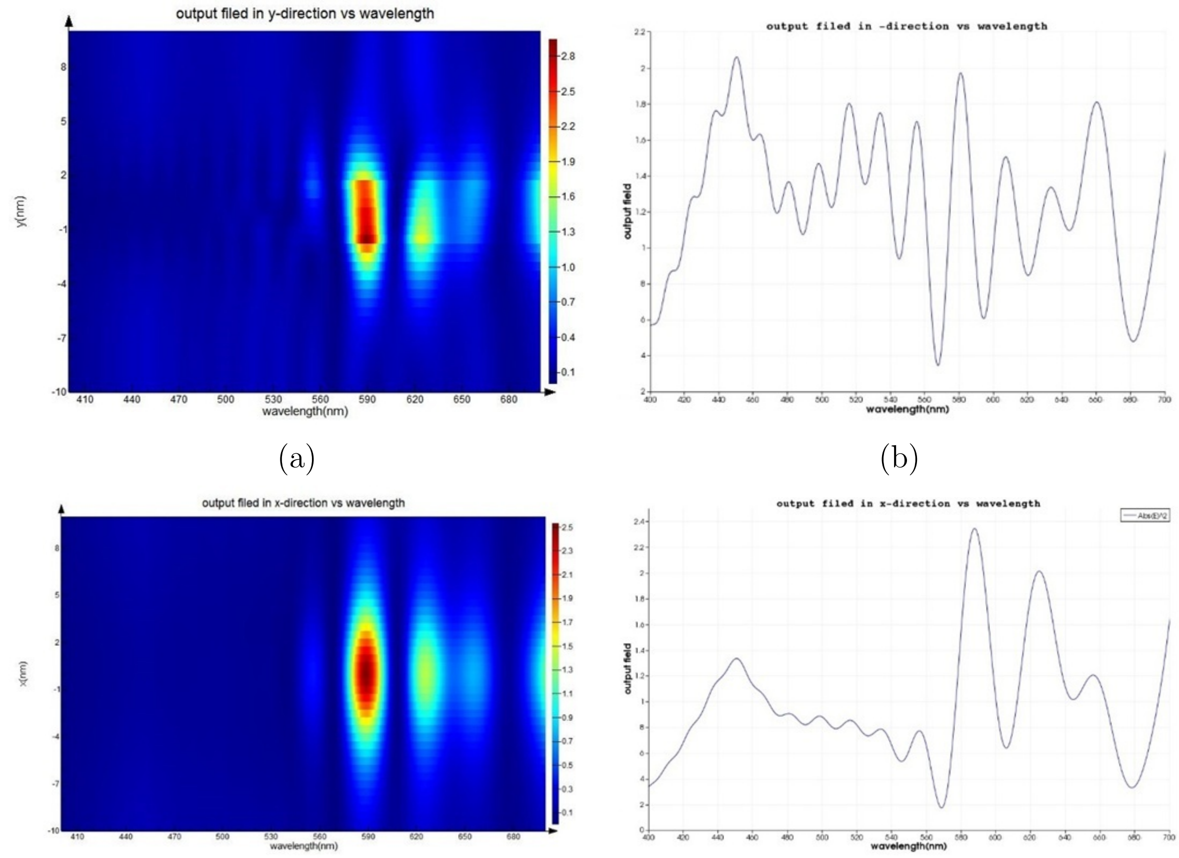
Fig. 2. (a) Intensity distribution with 200 nm period grating. (b) Intensity distribution with 250 nm period grating. (c) Intensity distribution with 300 nm period grating



(a) (b)

(c) (d)

Fig. 3. Results with 200 nm period grating: (a) the distribution intensity with y on the line of x=0, z=0 (b) the curve of enhancement of y component of electric field in y=0 versus wavelength (c) the intensity distribution intensity with an x on the line of y=0, z=0 (d) the curve of enhancement of the x component of electric field in x=0 versus wavelength



(a) (b)

(c) (d)

Fig. 4. Results with 250 nm period grating: (a) the distribution intensity with y on the line of x=0, z=0 (b) the curve of enhancement of y component of electric field in y=0 versus wavelength (c) the intensity distribution intensity with an x on the line of y=0, z=0 (d) the curve of enhancement of the x component of electric field in x=0 versus wavelength

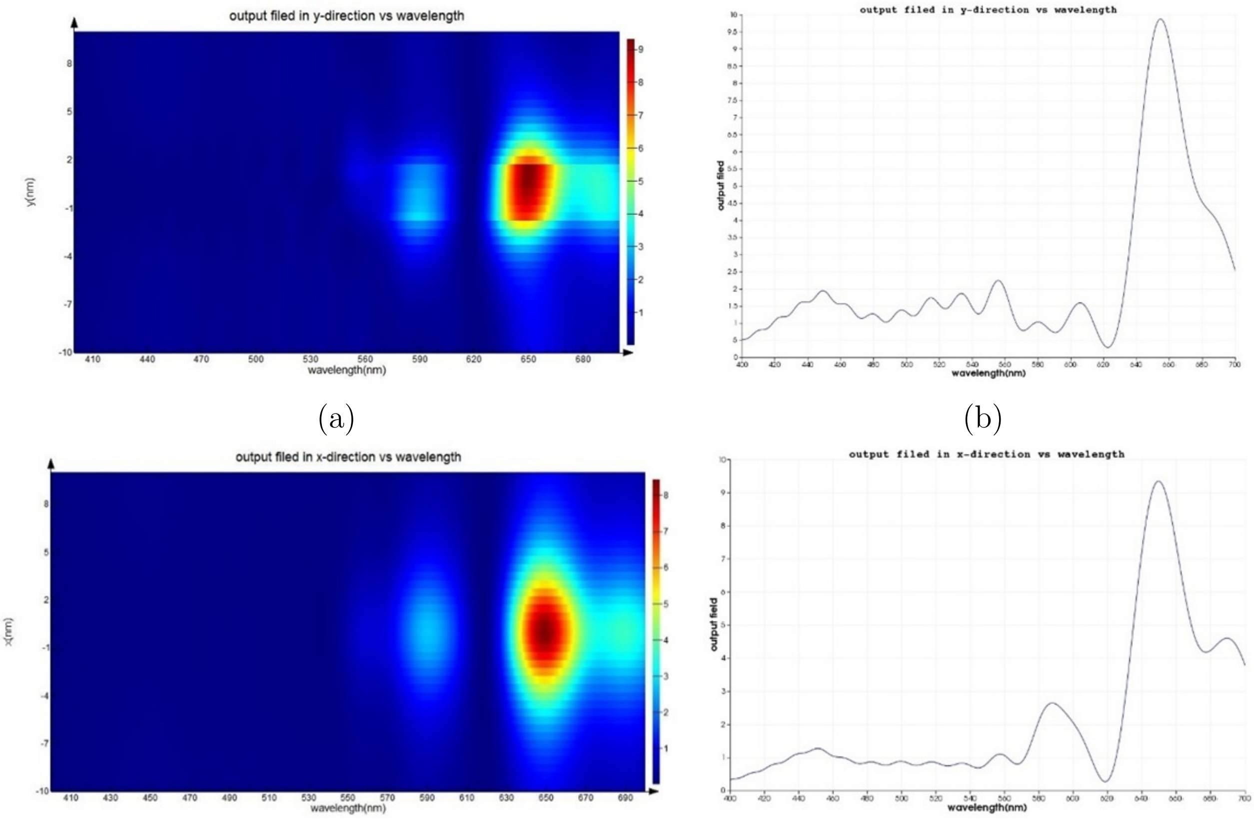
## 4. Maximize the electric field enhancement

Obtaining the maximum enhancement in an electric field is an important fact and can be utilized for the optimum design of an antenna. The optimized value for the grating period, based on the maximum electric field enhancement, is 208.843 nm.

The results of the optimization and maximum enhancement of the electric field for the new period of grating are illustrated in figure 6.

## 5. Conclusion

In this work, to calculate the enhancement of electric field intensity in the near – field area, the FDTD algorithm was applied. To summarize, the enhancement of the near-field using an apertureless probe system has been verified. The proposed gold tip optical antenna has a special geometry, a series of concentric circular gratings added to the shaft. The simulated model shows that by changing the grating period on the shaft, the resonance can be shifted, leading to a change in the distribution of the electric field enhancement. Changes of geometry include a change in the circular grating period from 200–300 nm, on the shaft of



(a) (b)

(c) (d)

Fig. 5. Results with 300 nm period of the grating: (a) the distribution intensity with y on the line of x=0, z=0 (b) the curve of enhancement of y component of electric field in y=0 versus wavelength (c) the intensity distribution intensity with an x on the line of y=0, z=0 (d) the curve of enhancement of the x component of electric field in x=0 versus wavelength

the antenna. The distribution of the electric field enhancement in a plane perpendicular to the shaft for the three samples has been analyzed. In addition, investigation revealed that the maximum electric field enhancement occurs at a period of 208.843 nm.

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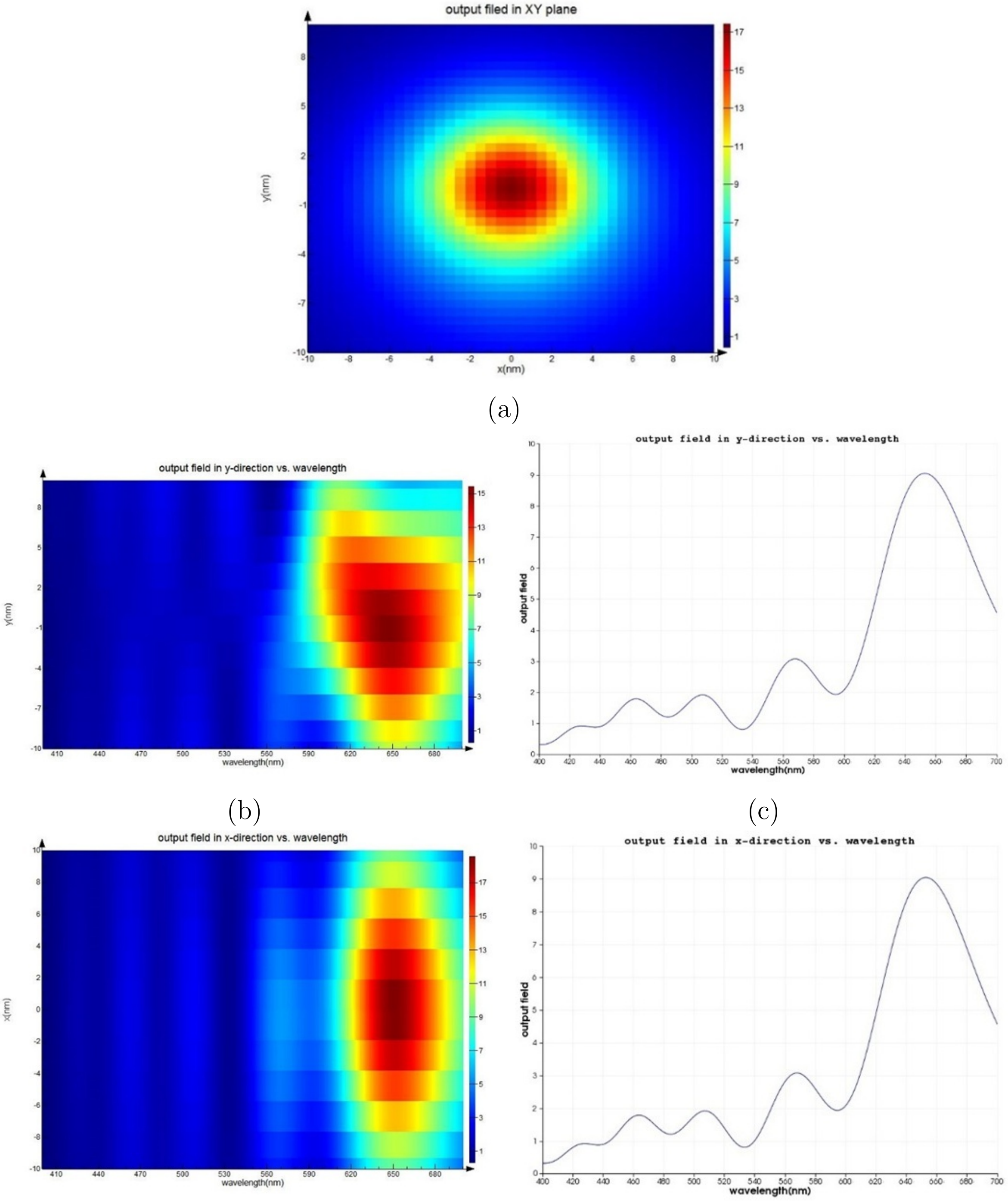

(a)

(b) (c)

(d) (e)

Fig. 6. Intensity distribution in simulation result when the grating period is 208.843 nm (optimized) with 90 degree laser incident angle. (a) the intensity distribution in the plane of x-y (z = 0 nm), (b) the distribution intensity with y on the line of x=0, z=0 (c) the curve of enhancement of y component of electric field in y=0 versus wavelength (d) the intensity distribution intensity with an x on the line of y=0, z=0 (e) the curve of enhancement of the x component of electric field in x=0 versus wavelength

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