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Transmission and directionality control of light emission from a nanoslit in metallic film flanked by periodic gratings

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Abstract

We investigate the transmission and directional properties of light emission from a nanoslit film flanked by periodic gratings, formed on a silver film, embedded in a high index dielectric medium. Using FDTD calculations it is demonstrated that the transmission has strong dependence on dimension of the dielectric film. The directional property of the emitted beam is controlled by tapering height of output grating elements and this effect is explained by standard theory of antenna array. We propose and examine the potential of such slit grating structure as a Plasmonic antenna in axial injection of light from single mode fiber to photonic crystal waveguide.

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1. Introduction

The directional beaming properties of subwavelength metallic aperture patterned with periodic corrugation make them interesting candidates for variety of optical devices. Due to excitation of surface Plasmon [1], the light flux per unit area through the aperture is 5–10 times greater than the flux per unit area of the incident beam [2–7]. However the total transmittance of the reported structures is poor [8]. It is thus important to enhance their transmittance and improve directionality for efficient utilization in light emitting devices such as surface plasmon based optical antenna [9,10].

In the present research we use FDTD method to study the transmission and directional properties of a nanoslit surrounded by periodic gratings, formed on a silver film, embedded in a high index dielectric medium. It is found that the transmission of slit grating (SG) structure has strong dependence on the dimension of dielectric film embedding it and for certain specific dimensions of the dielectric film transmission is resonantly high. For controlling the directionality of emitted beam idea of tapered grating is proposed. It is demonstrated that with appropriate taper profile the side lobes in the output beam can be suppressed. This phenomenon has been explained by standard theory of antenna array. To our knowledge, this is the first theoretical study on the effects of dielectric film dimension and grating taper, on the transmission and directionality of such plasmonic structures.

In addition, it is shown that the use of dielectric surface grating on the input side of the SG structure enhances transmission. We implement the SG structure on a thin silver circular film and calculate its transmission using 3D FDTD method, the transmission

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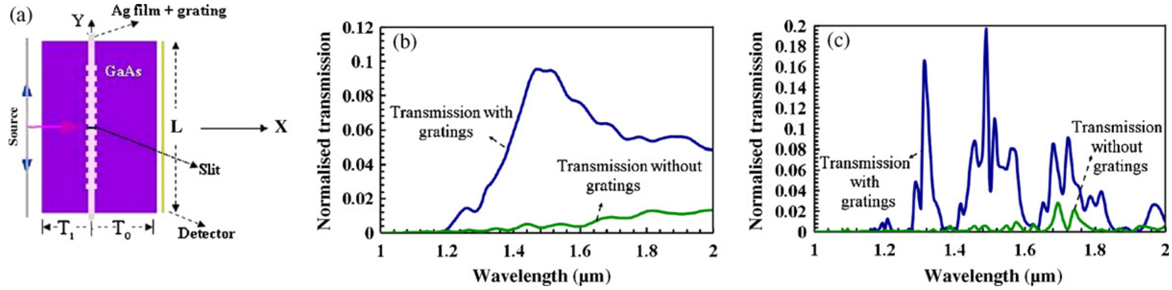

Fig. 1. (a) SG structure embedded in GaAs medium. Calculated transmission spectra in (b) infinite dielectric medium (c) finite dielectric film, blue and green curves represent transmission of the structure with and without gratings. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

is nearly 47%. The transmission of the structure may further enhance by optimization of dielectric film dimension. Based on the results of SG structure, we propose a surface plasmon (SP) antenna which could be employed for axial injection of light from single mode (SM) fiber to an air bridge type two-dimensional photonic crystal waveguide (2DPC-WG).

2. Analysis and simulations

2.1. Transmission properties

We are interested in analyzing the transmission properties of the system depicted in Fig. 1a: a single slit flanked by surface gratings formed on a silver film, embedded in a high index dielectric medium (GaAs). The important parameters used are: silver film thickness 0.18 μm, slit width 40 nm, grating periodicity $\Lambda = 0.3$ μm, grating depth $h = 0.06$ μm, refractive index of dielectric medium 3.45, etc. The SG structure is illuminated normally by a *p*-polarized broadband source and its transmission is calculated, in spectral range λ = 1–2 μm, by 2D FDTD method [11]. In the simulation, the dispersion model used for silver is derived from the experimental data provided by Johnson and Christy [12]. Two different cases are considered: (1) when the dielectric medium has infinite extent in XY plane and (2) when it is finite, rectangular, having length $L = 4.8$ μm and thicknesses $T_i = 1.4$ μm and $T_o = 1.8$ μm from the slit center; the source and detectors being outside the dielectric medium as shown.

However the following differences in their transmission are worth noting: (i) single transmission peak is observed in first case whereas multiple peaks are present in second case (ii) transmission near $\lambda = 1.5$ μm, in second case is almost double. Further it was observed that, in the first case, the peak transmission wavelength varies almost linearly with grating period, being $\lambda = 1.44$, 1.46 and 1.54 μm, respectively for periodicity $\Lambda = 0.28$, 0.30 and 0.32 μm (Fig. 2a) but with similar variation the peak positions do not change appreciably in the second case (Fig. 2b). However the variation in dimension of dielectric film greatly affects the peak transmissions due to resonance effects, as for example when the length of GaAs film is reduced by 0.2 μm (ΔL) transmission near wavelength 1.3 μm goes down by 50%, whereas if the thickness of input film is increased by 0.1 μm (ΔT_i) no transmission peak is observed near wavelength 1.3 μm. The results are plotted in Fig. 2c.

Transmission in the second case is found more sensitive to the dimension of dielectric film but less sensitive to grating periodicity.

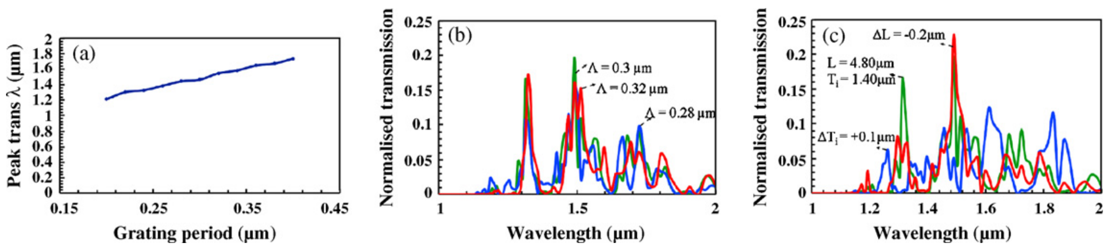

Fig. 2. SG structure in (a) dielectric medium of infinite extent, peak transmission wavelength varies almost linearly with grating period (b) dielectric film, the transmission peaks do not shift appreciably with small variation in grating periodicity. (c) Transmission of SG is very sensitive to dielectric film dimension.