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Phase resonances in obliquely illuminated compound gratings

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Abstract

The existence of phase resonances in obliquely illuminated, perfectly conducting compound gratings is investigated. The diffraction problem of a p-polarized plane wave impinging on the structure is solved using the modal approach. The results show that even under oblique illumination, where no symmetry is imposed by the incident field, there are resonant wavelengths that are clearly associated with a certain degree of symmetry in the phase distribution of the magnetic field inside the cavities. New configurations of this phase distribution take place, that were not allowed under normal incidence conditions. It was found that the interior field is intensified in the resonances, and the specularly reflected efficiency is maximized. In particular, this efficiency is optimized for Littrow mount.

Keywords: Resonances; Diffraction gratings; Symmetry

1. Introduction

It is well known that different kinds of resonances can be found in metallic corrugated structures: surface plasmon polariton excitations (SPPs), surface shape resonances (SSRs) and phase resonances (PRs). SPPs are excited in infinite metallic gratings when illuminated by p-polarized light [1]. This excitation is accompanied by a significant power absorption [2,3], and consequently it produces a sudden change in the efficiency curves of the reflected orders. For a given period and material of the grating, and for a fixed angle of incidence, the excitation of a SPP is produced for a particular wavelength at which one of the diffracted orders propagates parallel to the surface, and therefore, the electric field near the surface is intensified. This phenomenon is particularly important when the corrugations are shallow. The SSRs, on the other hand, appear when the depth of the grooves is increased: the eigenmodes of each cavity can be excited, producing interesting resonant effects such as field enhancement inside the corrugations [4–6]. Contrary to the SPP excitations, these resonances are associated with the particular shape of each groove and can also be excited by s-polarized incident light [7–10], but are independent of the period of the grating and the incidence angle. Experimental evidence of the SSR excitations was given by López-Rios et al. [11], for lamellar gratings.

Another kind of resonances that might appear in structures with embedded cavities are the PRs. These resonances have been first reported in connection with structures comprising a finite number of cavities [12–16]. These structures can be regarded as passive antennas,

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which exhibit superdirectivity [17] for particular incidence conditions. When a bunch of cavities is illuminated by a p-polarized plane wave of a certain resonant wavelength, the far field pattern is narrowed while the field inside the cavities is enhanced and the phase difference between the magnetic field at adjacent grooves is 0 or π rad [16]. This particular phase distribution, which is automatically generated by the resonant wavelength, produces a superdirective pattern [13,14,16].

PRs are not allowed in infinite periodic simple gratings (gratings with a single groove in the period), since the pseudoperiodicity condition does not permit the field inside the cavities to have different phases. However, PRs in compound gratings under normal illumination have already been reported [18]. In this case, the specular efficiency is maximized, the interior field is intensified, and the phase distribution of the field inside the grooves takes forms analogous to those of finite gratings. The dependence of these resonances on the different parameters of the grating was studied in [19]. The existence of PRs in metallic gratings with ohmic losses have also been investigated recently [20]. Other works on resonant excitations due to dual-period gratings include the paper by Hibbins et al. [21], where the authors study the excitation of surface plasmons in metallic structures in the microwave region.

To deal with infinite metallic gratings of particular profiles (rectangular, triangular, semicircular), several modal approaches have been developed during the last 4 decades [7,9,22–27]. More recently, those modal methods have been generalized to arbitrary shapes of the corrugations, and numerical tools have been applied to enhance their performance [28–32]. To solve the diffraction problem from a perfectly conducting compound grating with rectangular grooves we applied the formulation proposed by Andrewartha et al. for simple gratings [7], and extended it to compound gratings [18]. This method is particularly suitable for rectangular profiles, and enables us to analyze the electromagnetic response in terms of eigenmodes, which is convenient for studying resonances.

In this paper, we investigate the excitation of PRs in compound gratings under oblique illumination. We show that the occurrence of such resonances is intimately connected with the phase distribution of the magnetic field inside the cavities. Particular attention is paid to the symmetry of the phase configurations that are automatically generated by the resonant wavelengths. The diffraction problem and the modal method are briefly described in Section 2. Numerical results that evidence the existence of PRs for non-normal incidence are given in Section 3, where we show efficiency curves as well as the amplitude and phase of the interior field as a function of the wavelength for a fixed angle of incidence, and for the order -1 and -2 Littrow mounts. The most significant conclusions are summarized in Section 4.

2. Configuration and method of resolution

We consider a p-polarized plane wave of wavelength λ that illuminates a perfectly conducting compound diffraction grating comprising several rectangular grooves in each period, as shown in Fig. 1. The structure parameters are the period (d), the number of grooves in each period (N), the width (a) and the depth (h) of each groove, and the distance between grooves (b). The wave vector $\vec{k}$ of the incident plane wave forms an angle θ_0 with the y-axis.

A comment on the validity of the ideal model of a perfectly conducting structure is pertinent here. At a first sight, one should think that for studying resonances it is basic to consider a real metallic surface. This is true if we are interested in surface plasmon excitations, or if we are in the region of the spectrum where these excitations are relevant. However, the purpose of this paper is to study the excitation of PRs, which are independent from surface plasmon excitations, and arise from a particular distribution of the field inside the cavities. The resonant wavelength is not mainly related with the refraction index of the metal, but with the particular arrangement of the phase of the electromagnetic field inside the rectangular corrugations.

The method of resolution is the modal method, which consists in expanding the fields inside the grooves in their own eigenfunctions satisfying the boundary conditions at the lateral walls and at the bottom of each cavity. A complete and detailed description of the modal method applied to the diffraction problem from compound gratings can be found in Ref. [18]. This method is very suitable for the rectangular profile of the cavities considered here. In this case, it takes a very simple form and it permits us to study the dependence of the PRs by varying independently the geometrical parameters of the groove. It has also been shown to be efficient for the calculation of the electromagnetic response of very deep gratings [33].

For the sake of completeness, we summarize the modal method applied to the present grating. The

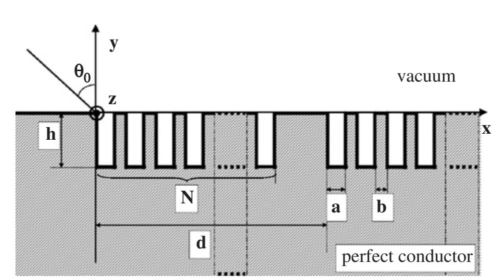

Fig. 1. Configuration of the problem.