Guided-wave resonance and enhanced nonlinear-optical effects

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We show that the surface-plasmon resonance is not the only electromagnetic resonance which can lead to the enhancement of nonlinear-optical effects. In this Communication we consider another electromagnetic resonance, namely, the guided-wave resonance; we show that this electromagnetic resonance leads to a much greater enhancement than that due to the surface-plasmon resonance.

In a previous paper[1] (henceforth referred to as I) we pointed out that surface-plasmon (SP) resonance, which is associated with a TM incident wave, is not the only electromagnetic (EM) resonance leading to an enhancement of nonlinear-optical (NLO) processes.

In I, we considered the TE fundamental mode of a waveguide constituted by a dielectric medium deposited onto a metal surface and we showed that, for a suitable thickness and modulation of this structure, an incident TE plane wave gives rise to a resonant excitation of this normal mode. As the TM SP resonance, this TE guided-wave (GW) resonance can be used to enhance NLO effects.

In I, we calculated the associated electric field just above the modulated region and found that this TE GW resonance leads to an enhancement of second-harmonic generation (SHG) in this modulated structure which is seven times greater than in the case of a bare grating supporting SP.

This result was obtained by considering the diffracted EM field just above the modulated region. In this Communication, we report early results which show that, *inside* the modulated region, the enhancement associated with the GW resonance is much more than seven times greater than that associated with SP resonance.

The system under consideration is depicted in Fig. 1. A plane wave with frequency ω, angle of incidence θ, is incident on a grating (groove spacing d, groove depth δ) ruled on a medium with complex premittivity $\epsilon(\omega)$. This grating is covered by a dielectric medium (thickness e, permittivity ϵ_c). In the calculations reported here, the medium on which the grating is impressed is a metal.

The incident plane wave is diffracted by the modulated region (which extends from $y=0$ to $\delta+e$). All the diffracted orders are evanescent in region $y<0$, since we deal with a metallic medium. In region $y>\delta+e$ the diffracted orders are either propagating or evanescent, depending on the value of their longitudinal wave-vector component as compared to k_1 ($k_1^2c^2/\omega^2=\epsilon_1$, ϵ_1: permittivity of the region $y>\delta+e$). In the calculations, the periodicity d is chosen in such a way that the $l=1$ diffracted order is evanescent above the modulated region. Then this $l=1$ diffracted order can be resonantly excited,[1] which means that it exists a specific value Θ of θ, for which its intensity *inside* the modulated region is maximum. The peak value of the intensity of the $l=1$ diffracted order depends on x, y, and δ.

For each value of δ, we have looked for the point of coordinates (x_{opt}, y_{opt}) which leads to the greatest value I_M of the peak values of this intensity. This has been done for two metals (silver and gold) using

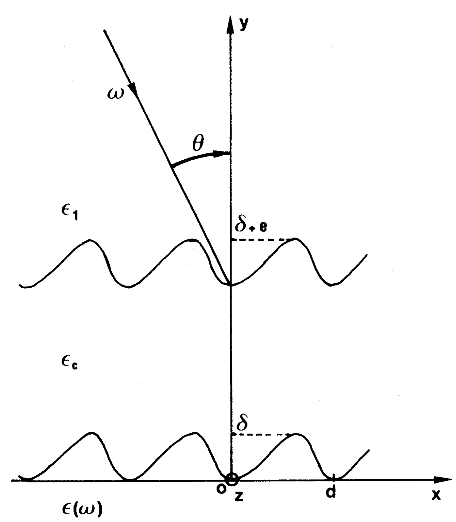

FIG. 1. Scattering geometry.

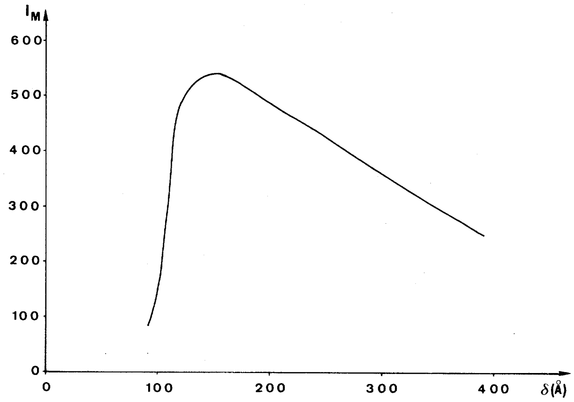

FIG. 2. I_M as a function of δ for a silver substrate $d=5556$ Å, $e=5900$ Å, and $\epsilon_c=2.22$. In this case, $\delta_{opt}=150$ Å. For this value of δ, $y_{opt}=0.366$ μm and $\Theta=-35.847°$.

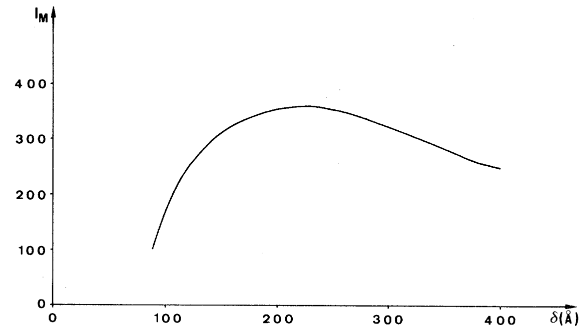

FIG. 3. Same as Fig. 2, except that we deal with a gold substrate $d=5556$ Å, $e=6008$ Å, and $\epsilon_c=2.22$. In this case, $\delta_{opt}=240$ Å, $y_{opt}=0.375$ μm, and $\Theta=-35.300°$.

the rigorous EM theory of gratings described in Ref. 2.

The corresponding results are reported in Figs. 2 and 3. In both cases (Ag, Au), for a given thickness e, it exists an optimum value δ_{opt} of δ for which I_M $(x_{opt}, y_{opt}, \Theta)$ is itself maximum. We get, for a Ag substrate: $I_{MM}=543$, $\delta_{opt}=150$ Å; for a Au substrate: $I_{MM}=361$, $\delta_{opt}=240$ Å (MM: maximum maximorum).

These results mean that when the optimization is achieved, the greatest value of the intensity of the $l=1$ diffracted order, inside the modulated region, is, respectively, 543 and 361 times greater than the unit intensity of the incident beam for silver and gold gratings.

In order to have a better feeling of the importance of this new EM resonance phenomenon, assume that the ω frequency beam acts as a pump for SHG in the structure of Fig. 1. Due to this GW resonance, the enhancement E of the square modulus of the nonlinear polarization at 2ω is equal to $E=E_{Ag}=19\,385$ for a Ag substrate, $E=E_{Au}=9025$ for a Au substrate; as compared to the case where a TM incident beam acts as a pump for SHG in a bare Ag or Au medium with flat interface.

In the same way, the comparison can be performed with respect to the case of SHG in the bulk dielectric medium ϵ_c with a flat entrance face. Then, using a TM pump beam, we get

$$E=E_d=174\,467 \; .$$

Notice that $\delta_{opt} \ll e$. Thus *a very shallow* modulation of the waveguide leads to a *strong* increase of the intensity of a given diffracted order.

Let us now compare E_{Ag} to the enhancement E' of SHG arising from the SP resonance contribution in an optimized bare Ag grating. We get[1] $E'=300$ for $\delta=\delta_{opt}=114$ Å and $d=5556$ Å.

And, consequently, the enhancement E_{Ag}, due to the TE GW resonance, is 64 times greater than the enhancement E' due to the TM SP resonance.

To conclude, the SP resonance is not the only EM resonance leading to an increase of NLO effects. In this Communication, we have studied another EM resonance, namely, the guided-wave resonance which occurs with a TE incident wave and not with a TM one as for the SP case. We have shown that this GW resonance leads to a much greater enhancement of the second-harmonic intensity than the SP resonance does. A forthcoming paper will be devoted to a detailed study of this new kind of EM resonance.

[1]R. Reinisch and M. Neviere (unpublished).
[2]*The Electromagnetic Theory of Gratings*, edited by R. Petit (Springer, Berlin, 1980), and references cited therein.