Harmonic Generation by a Terahertz Pulse in a Thin Nonlinear Layer on a Metal Mirror

E.M. Buyanovskaya*, S.A. Kozlov*, A.A. Sukhorukov†
*ITMO University, St. Petersburg, Russia
Email: lee.buyanovskaya@niuitmo.ru
†Nonlinear Physics Centre, Research School of Physics and Engineering,
Australian National University, Canberra, ACT 2601, Australia.

***Abstract*—We theoretically analyze the reflection of a terahertz pulse from a mirror with a nonlinear dielectric layer, and show that the layer thickness can be chosen to either suppress or enhance high harmonic generation.**

I. Introduction

RECENT development of powerful single cycle waves in terahertz (THz) range generation systems [1], [2] has brought immediate interest to the effects of media nonlinearity on their propagation. Here we investigate the high harmonic generation by THz pulse in a thin layer of nonlinear dielectric media on top of a metal mirror, as schematically shown in Fig. 1a. Due to the lack of destruction of optical media in the field of intense pulse such generation can be significant and lead to practical application such as integrated optical circuits and sum-frequency generation spectroscopy [3], [4].

II. Analytical study

We perform theoretical analysis based on a second order wave equation formulated directly for the electric field of a few cycle electro-magnetic pulse with a broad spectrum [5]:

$$\frac{\partial^2 E}{\partial z^2} - \frac{{N_0}^2}{c^2}\frac{\partial^2 E}{\partial t^2} + \frac{2N_0}{c}a\frac{\partial^4 E}{\partial t^4} - \frac{2N_0}{c}bE - \frac{2N_0}{c}g\frac{\partial^2 E^3}{\partial t^2} = 0, \tag{1}$$

where E is the density of electrical field, z is the propagation direction, t is the time, N_0, a, b are the parameters that characterize the typical nonresonant dependence of refraction index of dielectric media in its transparency range

$$n^2 = {N_0}^2 + 2cN_0 a\omega^2 - 2cN_0\frac{b}{\omega^2} \tag{2}$$

from frequency ω [6], $g = 2n_2/c$ describes nonlinearity of media polarization response n_2 - nonlinear coefficient of the media refractive index, c is the light velocity in vacuum.

We assume the pulse spectrum lies in the transparency range of nonlinear dielectric media. We apply method of successive approximations and derive asymptotic expression for the field of the wave reflected from metal mirror with nonlinear dielectric layer, in the absence of dispersion in the following form:

$$E_{\text{refl}}(0,t) = -E_{\text{in}}(t-2L) - \frac{L_{\text{wave}}}{L_{\text{nl}}}\left(\int_0^L \frac{\partial}{\partial t}\left[\left(E^{(0)}(z', t-2L+z')\right)^3 - \left(E^{(0)}(z', t-z')\right)^3\right] dz'\right) \tag{3}$$

where

$$E^{(0)}(z,t) = E_{\text{in}}(t-z) - E_{\text{in}}(t+z-2L). \tag{4}$$

$E_{\text{in}}(t)$ is the input pulse.

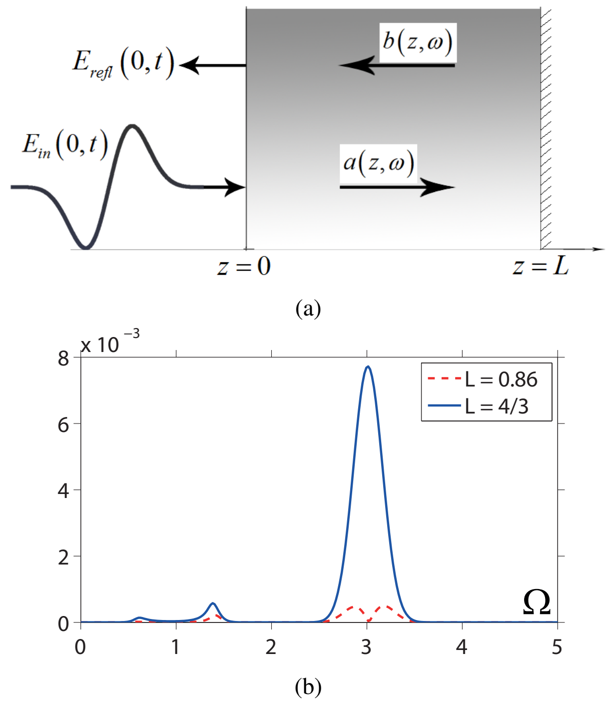

Fig. 1: (a) Schematic of few-cycle pulse reflection from a metal mirror coated with a nonlinear dielectric layer ($a(z,\omega)$ and $b(z,\omega)$ are interacting counter-propagating waves), (b) Spectrum changes kF due to effect of cubic nonlinearity for $\tilde{L} = 0.86$ (red dashed line) and $\tilde{L} = 4/3$ (blue solid line). Frequency Ω is normalized to the central frequency of incident pulse.

III. Numerical simulation of few-cycle pulse dynamics

We numerically simulate reflection of an incident single-cycle Gaussian pulse:

$$E_{\mathrm{in}}(t) = E^{(0)}(t) = E_0 \exp\left(-\frac{t^2}{\tau_0^2}\right) \sin\left(\frac{\pi t}{2}\right), \qquad (5)$$

where $\tau_0 = 4t_0/T_c$ is normalized pulse duration; t_0 is pulse duration in seconds; T_c is its central period; E_0 is pulse amplitude (see electric field profile in Fig. 1a).

We use experimental data for stoichiometric $\mathrm{MgO : LiNbO_3}$ crystal: $n_2 = 5.4 \cdot 10^{-12}\ cm^2/W$ [7] and characteristic field intensity $I = 10^8\ W/cm^2$.

In Fig. 1b we plot a difference between the spectra of reflected and incident pulses

$$kF = ||F_{\mathrm{refl}}| - |F_{\mathrm{in}}||$$

for dimensionless layer thicknesses $\tilde{L} = 0.86$ and $\tilde{L} = 4/3$, where $\tilde{L} = 4 \cdot L[m]/\lambda$ and λ is a vacuum wavelength at the central frequency of the input pulse. We observe enhanced generation of new frequencies around the third harmonic of the central pulse frequency for $\tilde{L} = 4/3$. On the other hand, third-harmonic generation is almost completely suppressed for $\tilde{L} = 0.86$.

IV. Conclusion

We have formulated a general asymptotic analytical solution to the problem of THz pulse reflection from a metal mirror covered with a nonlinear dielectric layer. Based on the analytical and numerical analysis we calculated the transformations of the pulse spectra for the case of dispersionless media. We find that self-action of a few cycle wave and its nonlinear interaction with counter-propagating wave can lead to either enhanced or suppressed third harmonic generation depending on the thickness of dielectric medium.

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