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# Numerical Analysis of Photorefractive Recording by Optical Pulses

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## ABSTRACT

A numerical simulation of the photorefractive recording in BSO using an illumination pulse and subjected to an external electric field has been made. New effects on time evolution of the space charge field and charge carrier density was obtained.

## SUMMARY

### 1. Introduction.

Photorefractive recording process is generally described within the frame of band transport model proposed by Kukhtarev *et al.* [1]. However, an analytical solution has not yet been found regarding this model. Usually some approximations are made in order to linearize and solve equations that defines it. Some numerical approaches assume truncated Fourier expansion for all pertinent physical magnitudes and validity of the obtained solution, depends on harmonic basis considered elsewhere [2-4]. These approaches describe various photorefractive recording aspects, but under pulsed illumination, is no longer adequate due to the unaccomplished quasi-steady state in this regime. Recently, it has been surveyed in the literature new and novel results by numerical simulations of the recording process in  $\text{Bi}_{12}\text{SiO}_{20}$  under continuous illumination [5].

Photorefractive recording using short pulses has been investigated, in a lesser extent, than previous recording processes using continuous illumination. However, it is important to study the process under a regime in which the illumination is applied during short periods but at high intensities [7,8]. Using these conditions, it is likely to obtain information to optimize photorefractive response rate. A fast response rate is required in some applications of photorefractive crystals in order to obtain similar results as those with conventional electronic devices [9]. This justifies the study of the photorefractive recording process with pulses.

The aim of this work is to simulate the photorefractive response under pulsed illumination at high nonlinear regime (modulation depth  $m = 1$ ). The method of lines using a finite element collocation procedure was used. From this approach, it was calculated the time evolution of the space charge field  $E_{sc}$  and the charge carrier density  $n$ . Amplitude of the space charge field showed damping mode oscillations which disappeared when power was increased.

### 2. Theoretical Model.

From the theoretical standpoint, it was assumed a light intensity pattern given by:

$$I(x,t) = I_0 [1 + m \cos(kx)] \quad (1)$$

where  $I_0 = I_S + I_R$  is the total intensity,  $m = 2(I_S I_R)^{1/2} / I_0$  is the modulation depth,  $k = 2\pi/\Lambda$  is the grating wave number and the intensities of writing beams are represented by  $I_S$  and  $I_R$ .

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The response of the photorefractive material with regard to illumination is well described by the band transport model [1], which assumes that photoexcited charge carriers migrate from bright to dark regions of the interference pattern leading to build up a charge density which induces a space charge field, according to Poisson law.

The model is described by a nonlinear set of differential equations:

$$\partial N_D^+ / \partial t = sI(N_D - N_D^+) - \gamma n N_D^+ \quad (2)$$

$$\partial n / \partial t = \partial N_D^+ / \partial t - \partial J / \partial x \quad (3)$$

$$J = e\mu n E + eD \partial n / \partial x \quad (4)$$

$$\partial (\epsilon \epsilon_0 E) / \partial x = e (N_D^+ - n - N_A) \quad (5)$$

where  $N_D$  is the donors density,  $n$  is the electrons density,  $N_D^+$  is the density of ionized donors,  $N_A$  is the density of acceptors and  $J$  is the current density. The total electric field is  $E$  and it includes both the external field  $E_0$  and the space charge field  $E_{sc}$ ,  $I$  is the laser intensity and  $\gamma$  is the recombination coefficient. The electron mobility is  $\mu$  and  $D$  is the diffusion coefficient. The dielectric constant is  $\epsilon$  and  $\epsilon_0$  is the permittivity of vacuum,  $s$  is the cross section of photoionization and  $e$  is the charge carrier.

Taking a derivative with respect to time, using the continuity equation and integrating with respect to variable  $x$ , the Poisson's equation can be rewritten as:

$$\partial (\epsilon \epsilon_0 E) / \partial t = -eD \partial n / \partial x - e\mu n E + J_0 \quad (6)$$

where  $J_0$  is an independent constant of the variable  $x$ , but it is a function of time.

The boundary condition corresponding to the application of a constant voltage on the edges of the crystal is formulated as follows:

$$1/L \int_0^L E(x,t) dx = V/L = E_0 \quad (7)$$

where  $E(x,t) = E_{sc}(x,t) + E_0$  is the electric field,  $V$  the applied voltage and  $L$  the crystal length. Using Eq. (6),  $J_0$  can be found assuming an one-dimensional and spatially periodic grating formation with period  $\Lambda$  in the same direction of the grating wave number.

### 3. Numerical Method.

To model the process, the equations (2), (3), (5) and (6), with the constrain (7) were numerically solved using a new and powerful procedure.

The method of lines [6], using a finite element collocation procedure with second degree time independent polynomials, for the discretization of the spatial variable  $x$ , was employed. The approximate solution at any time was a second order polynomial over each subinterval  $[x_n, x_{n+1}]$ .

The coefficients in the polynomials only varied with time. A continuity condition for both the polynomial and its first spatial derivative on each extreme of the subinterval was used. In order to obtain the oscillations of the space charge field, the period of the grating was divided into an adequate number of segments. Satisfactory results were achieved with 30 segments for a fringes spacing of  $5\mu$ . The time step used at each iteration was less than the free-carrier recombination time in order to obtain stability in the solution. Therefore this simulation is a time continuous description within the resolution limit of the step size.

### Results.

A numerical simulation of photorefractive recording in BSO at high modulation depth regime  $m = 1$  was performed having an interference square pulse of 15 ns length. The pulse intensity applied, was in the range of 3 to 800  $\text{KW}/\text{cm}^2$ . As shown in Fig. 1, the results comprise a set of recording curves of the amplitude of the space charge field  $E_{sc}$  for different intensities of writing pulse. The grating spacing in all cases was  $5\mu$  and the DC electric field applied was 3.75  $\text{KV}/\text{cm}$ . Clearly, it has been observed two new effects on the recording curves. The amplitude of the space charge field has a dynamic motion and remains increasing, even after the pulse was turned off. Moreover, damped oscillations in the amplitude were observed before attaining the saturation level. These oscillations tend to disappear when the incident power was increased, and the amplitude only dropped off until the saturation level was reached. Time evolution of the charge carrier density is given in Fig. 2, two cases of different writing intensity have been included. A fast increment of carrier density was observed during the illumination, but decaying when the light was interrupted, showing a small oscillation at the end.

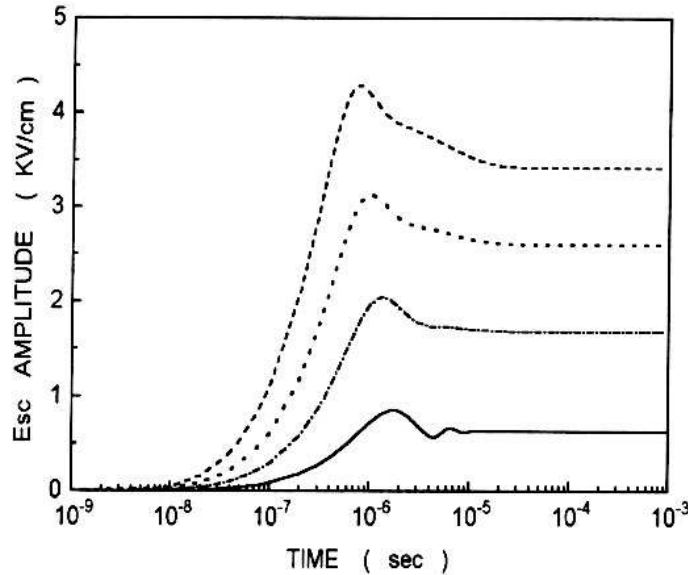


Figure 1. Time evolution of the amplitude of the space charge field for a  $5\mu$  grating period and an electric field applied  $E_0 = 3.75 \text{ KV}/\text{cm}$ , for different average writing intensity pulses;

—————:  $I_0 = 9 \text{ KW}/\text{cm}^2$ ; —•—•—•—:  $I_0 = 30 \text{ KW}/\text{cm}^2$ ;  
 .....:  $I_0 = 63 \text{ KW}/\text{cm}^2$ ; - - - - -:  $I_0 = 120 \text{ KW}/\text{cm}^2$ .

#### 4. Discussion.

The present investigation has revealed new effects on the recording curves of the space charge field and the charge carrier density by using pulses of nanosecond length by numerical simulation. From these results, it was observed that the amplitude of the space charge field was increased even though the pulse was turn off, presenting further oscillations which were temporarily damped. These effects were found to be at high modulation depth. A close correlation between the oscillations of both, space charge field and carrier density, was observed. A high amplitude oscillation of the space charge field was induced at once, due to the occurrence of small oscillation in the carrier density.

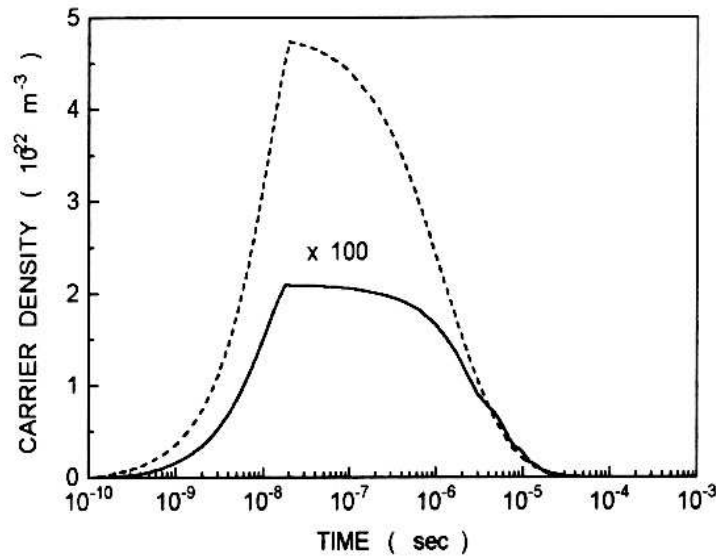


Figure 2. Time evolution of the average carrier density for a  $5\mu$  grating period and an electric field applied  $E_0 = 3.75$  KV/cm, with writing intensity pulses of:  $I_0 = 3.5$  KW/cm<sup>2</sup> : ————— and  $I_0 = 800$  KW/cm<sup>2</sup> : — — — — . Notice that the average carrier density in the first case is magnified by a factor of 100.

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