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Absorption of High Intensity Femtosecond Pulses in Semiconductor Amplifiers

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For picosecond or longer pulses the gain saturation model provides an adequate physical basis for understanding pulse propagation in semiconductor amplifiers.¹ In this model only amplification of the output pulse energy with respect to the input can occur because the gain is saturated and the carrier density approaches its value at transparency (at transparency the propagation is lossless). We have observed extreme departures from the gain saturation model predictions in numerical simulations of femtosecond pulse propagation in semiconductor amplifiers.² In particular, we predict absorption of high intensity input pulses even though the input pulse spectrum is fully inside the gain region.

The numerical simulations were performed using the semiconductor Maxwell Bloch equations³ with parameters appropriate for bulk GaAs amplifiers. Figure 1(a) shows the variation pulse energy, normalized to the input energy, with

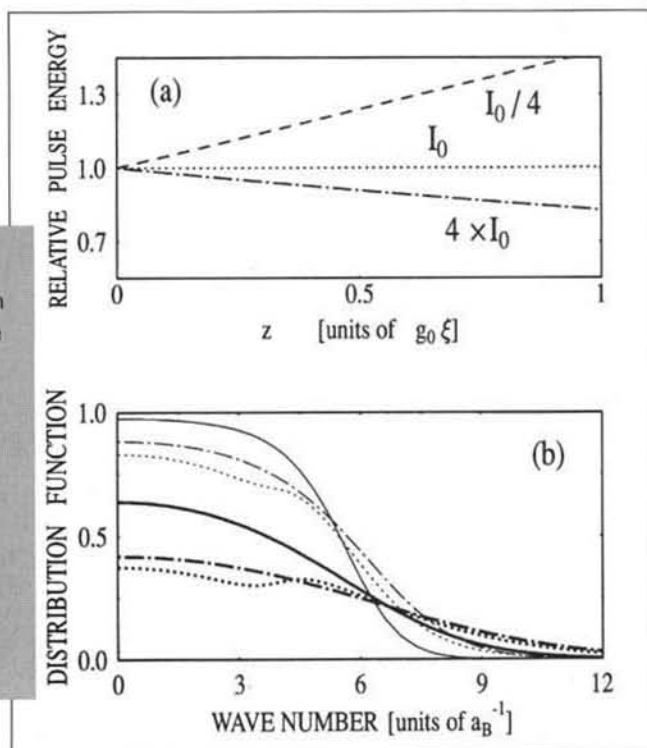
propagation distance $g_0\xi$. For the low input intensity, pulse amplification of the pulse energy is clearly seen. In contrast, for the intermediate intensity, the pulse energy propagates essentially unchanged, and for a high intensity the transmitted pulse suffers a net absorption!

To understand these results we recall that prior to the pulse the electronic states are partially populated by the electron-hole plasma, according to Fermi-Dirac distributions, and that these states are only inverted in the spectral region between the renormalized bandgap up to the chemical potential. Hence, one always has the coexistence of a spectral gain region and a region of optical absorption above the chemical potential. Thus, when exciting into the gain region, the pulse also interacts with absorbing states that have a finite linewidth, and therefore give rise to absorption of the pulse. For high intensity pulses, when gain saturation becomes appreciable, this absorption can overcompensate the amplification.

The above explanation implies a new carrier heating mechanism when the pulse is absorbed. Figure 1(b) shows the variation of the carrier distributions $n_{e,h}(0,t)$, $a = e, h$, at the front face of the sample: before, during, and after the pulse for the example showing net absorption ($I = 4I_0$). Prior to the pulse, the electrons and holes are both in Fermi-Dirac distributions, the corresponding temperature being that of the lattice ($T = 300\text{K}$). During the pulse, the distributions are in a highly non-equilibrium state, whereas after the pulse they rapidly relax toward a Fermi-Dirac distribution, but at a greatly elevated temperature ($T > 600\text{K}$). This temperature increase results from the absorption into high-lying k -states with above average kinetic energy. A Fermi-Dirac distribution with elevated temperature exhibits a reduced occupation of the lower k -states, which corresponds to gain saturation.

Figure 1. Computed results for bulk GaAs with a carrier density $N = 2.5 \times 10^{18} \text{cm}^{-3}$ prior to the pulse. Sech shaped pulses of duration of 150 fsec duration were used, and a polarization dephasing time of 60 fsec was assumed. The input pulse spectrum lay entirely in the gain region, and the sample length L set equal to one linear gain length $g_0^{-1} = 5 \mu\text{m}$.

(a) Pulse energy transmission [pulse energy divided by the input pulse energy] versus $g_0\xi$ for $I_0/4$ (dash line), $I_0 = 1.8 \text{GW/cm}^2$ (dotted line), and $I_0 = 4I_0$ (dot-dash line); and **(b)** electron distributions $n_{e,k}$ [thin lines] and hole distributions $n_{h,k}$ [thick lines] at the front face, before the pulse ($t = \infty$, solid line), during the pulse ($t = \infty$, dotted line), and after the pulse ($t = \infty$, dot-dash line), for the example showing net absorption ($I = 4I_0$).



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Nonlinear Optics and Photonic Applications of Photorefractive Polymeric Composite Materials

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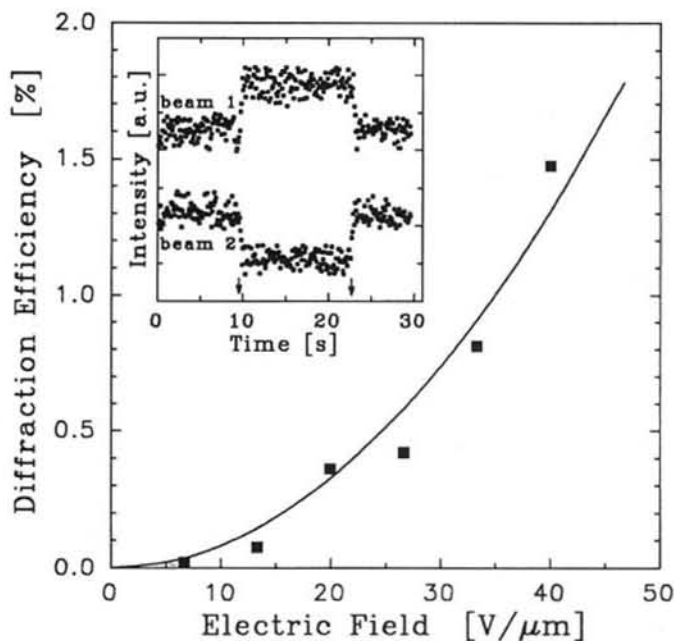
Until very recently the photorefractive effect has been observed exclusively in inorganic crystals, such as BaTiO₃, doped GaAs, BSO, and others. The organic polymeric photorefractive films define an entirely new and very promising class of media exhibiting photorefractive response. The crucial functions for photorefractivity are photoconductivity and electro-optic activity. Known inorganics show high $\chi^{(2)}$ nonlinearities and moderate to high carrier mobilities. However, there is an inherent limitation imposed on the photorefractive figure of merit, $n^3 r_{\text{eff}} / \epsilon$ (where n is the refractive index, r_{eff} the effective electro-optic coefficient, and ϵ the material's dielectric constant), for these systems due to the ionic polarizability origin of their nonlinearities resulting in high values of ϵ .¹ Secondly, these materials are very difficult to fabricate and process. Organics differ from their inorganic counterparts in that they are easy to process and, due to the localized nature of their electronic properties, combine low dielectric constants and relatively high electro-optic coefficients.

We adopted the approach of dividing, among independent components of the system, the different functions that a photorefractive material has to fulfill.² From the perspective of engineering photonic materials, this approach has two main advantages. First, the composite can be spectrally sensitized for information writing at a desired wavelength by choosing the proper photosensitizer, the NLO-active chromophore being chosen to keep its absorption resonances away from the working wavelength and thus avoid creation of local absorption gratings (*e.g.* of photochromic origin). Second, the polymeric matrix can also be independently

optimized with respect to carrier mobility, concentration of trapping centers, and optical quality. An example of such designed material is the polymeric composite PVK:C₆₀:DEANST, containing C₆₀ fullerene molecules responsible for photogeneration of charge carriers, diethylaminonitrostyrene (DEANST) moieties providing high electro-optic response, and poly[vinylcarbazole] (PVK) polymer as a charge transporting host matrix.

Two key defining parameters for photorefractives are their diffraction efficiency and two beam coupling gain. The figure below shows the dependence of diffraction efficiency on applied dc electric field, measured in a non-degenerate four-wave mixing geometry. Values of diffraction efficiency for a ~300 μm -thick film at applied field of 40 V/ μm reach 1.5%.⁴

The nonlocal photorefractive nature of the effect finds its confirmation in an asymmetric two-beam coupling experiment⁴ (see the Inset in the figure), where the gain coefficient measured at $\lambda = 645$ nm is ~ 4 cm⁻¹. This effect allows for a controllable stationary energy transfer between the interacting beams—the phenomenon of considerable photonic significance, *e.g.*, for all-optical parallel image processing.



The dependence of diffraction efficiency on applied dc electric field for a PVK:C₆₀:DEANST composite film ($\lambda_{\text{write}} = 645$ nm, $\lambda_{\text{read}} = 632.8$ nm). The solid line is calculated according to the model describing formation of space-charge gratings in photoconducting polymers.³ The Inset shows the beam intensity changes in an asymmetric two-beam coupling process ($\lambda = 645$ nm). The arrows denote the moments of switching the electric field "on" and "off."