Dispersion-induced non-linearities in semiconductors

Mørk, Jesper; Mecozzi, A.

Published in:
1999 IEEE LEOS Annual Meeting Conference Proceedings

Link to article, DOI:
10.1109/LEOS.1999.813511

Publication date:
1999

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Mørk, J., & Mecozzi, A. (1999). Dispersion-induced non-linearities in semiconductors. In 1999 IEEE LEOS Annual Meeting Conference Proceedings (Vol. 1, pp. 127-128). San Francisco: IEEE. DOI: 10.1109/LEOS.1999.813511

4:45pm - 5:00pm
MO5

Dispersion-induced non-linearities in semiconductors

J. Mørk
Research Center COM, Technical University of Denmark
Build. 349, DK-2800 Lyngby, Denmark. E-mail: jm@com.dtu.dk

A. Mecozzi
Fondazione Ugo Bordoni
via B. Castiglione 59, Rome Italy

Pump-probe measurements on semiconductor waveguides have identified the existence of ultrafast processes in both the gain and the refractive index [1,2]. The effects are often referred to as Kerr effects and two-photon absorption, although a number of different processes may contribute. We show in this paper, for the first time we believe, that index dispersion in connection with the standard (slow) saturation of the medium due to carrier density changes, lead to ultrafast gain and index dynamics. Analytical formulas are derived, and it is shown that these new contributions may dominate experimentally observed results.

A first-order dressed-states approach assuming steady-state conditions for calculation of the coherent contributions to the material dynamics due to two-photon, Raman and Stark effects were presented in Ref. [3]. The change of the dispersion of the bands (light-induced gaps) was shown to give a repositioning of the Fermi levels, and thereby a modification of the Stark effect. Our results provide a generalization of such effects, and in addition include the time dependence of the different processes, which is crucial when their joint effect is considered. By analogy with the optical Stark effect for a two-level system, one may denote the new effect that we consider as a macroscopic Optical Stark effect.

Our approach is based on a calculation of the corrections to an adiabatic theory of the response of semiconductor waveguides [2] to include coherent effects. In particular, we obtain, a contribution from the generation of virtual carriers, which for a simple two-level system reduces to adiabatic following or optical Stark effects. In semiconductors, we obtain a local change of the level occupancy (microscopic contribution) and a change in the overall virtual carrier density (macroscopic contribution).

Fig. 1 shows the *amplitudes* of the microscopic and the macroscopic Stark effects for the

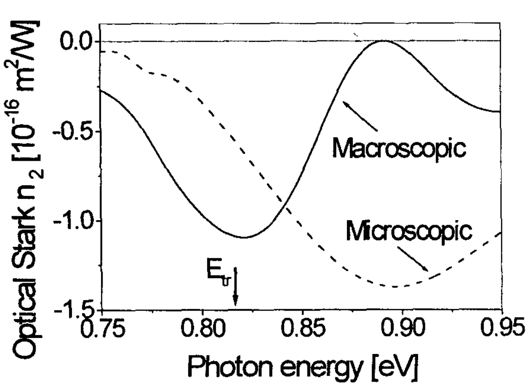

Fig. 1: Amplitude of macroscopic and microscopic contribution to the Kerr coefficient of a semiconductor. E_{tr} denotes the transparency point. Calculated for a carrier density $N=1.5\cdot10^{24}$ m^{-3}.

0-7803-5634-9/99/$10.00©1999 IEEE

phase of the propagating field and Fig. 2 shows the corresponding temporal behaviour of the responses for pulsewidths of 30 fs and 300 fs. The microscopic contribution follows the instantaneous pulse intensity for pulses much shorter than the carrier-carrier scattering time τ_1. For longer pulses the response develops into a derivative-like structure and is reduced in magnitude by the factor τ_1/τ_p , where τ_p is the pulsewidth. Conversely, the macroscopic contribution is nearly instantaneous for pulses longer than τ_1. Combining this with the overall amplitudes shown in Fig. 1, we conclude that the macroscopic effect is dominant for pulses longer than 100 fs in a photon energy range extending well above the transparency point (marked by E_{tr} in Fig. 1). The Kerr coefficients we deduce from this new theory are of the same order as experimental data [1,4], indicating the importance of this new effect.

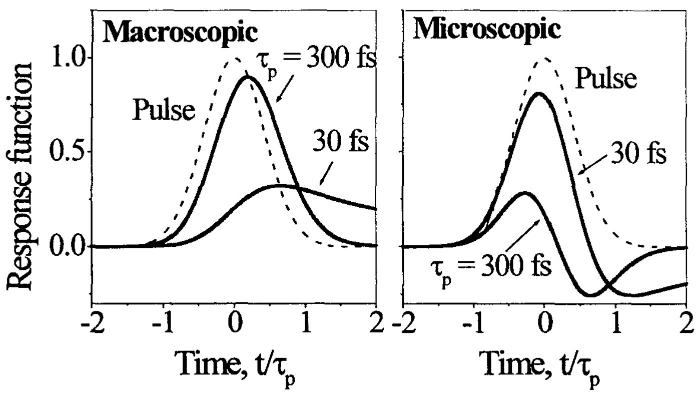

Fig. 2: Temporal factor (shown for pulsewidths of 30 fs and 300 fs and a fixed scattering time $\tau_1=70$ fs) to be multiplied with the amplitudes given in Fig. 1. The limit of instantaneous effects is reached for $\tau_p >> \tau_1$ and $\tau_p << \tau_1$, for the macroscopic and the microscopic effects, respectively.

We have derived very simple and general expressions for the amplitude of the instantaneous index and gain changes (effective Kerr and two-photon absorption coefficients) associated with the macroscopic effect:

$$n_2 = \frac{1}{\hbar c}\frac{\partial \Delta n}{\partial \omega}\frac{\partial \Delta n}{\partial N}; \qquad \beta_2 = -\frac{1}{\hbar c}\frac{\partial \Delta n}{\partial \omega}\frac{\partial g}{\partial N} \qquad (1)$$

A noticeable feature of the above equations is that the strength of the macroscopic optical Stark effect may be calculated from the sole knowledge of the dispersion of the linear refractive index (Δn) and the dependence of the gain (g) and refractive index on carrier density (N). We have shown that Eqs. (1) also can be derived using very general energy balance relations and therefore also hold if the gain and refractive index are calculated including many-body corrections via the semiconductor Bloch equations.

In conclusion, we have shown the existence of *minimal* instantaneous nonlinearities, which *must* be added to the saturation induced by carrier depletion if the *linear* gain and resonant refractive index are allowed to vary with frequency. Explicit expressions for the coefficients describing these nonlinearities have been given.

[1] K. L. Hall et al., Appl. Phys. Lett. **62**, 1320 (1993).
[2] J. Mørk and A. Mecozzi, J. Opt. Soc. Am. B **13**, 1803 (1996).
[3] M. Sheik-Bahae and E. W. Van Stryland, Phys. Rev. B **50**, 14171 (1994).
[4] C. T. Hultgren et al., Appl. Phys. Lett. **61**, 2767 (1992).