A NEW MECHANISM OF OPTICAL BISTABILITY

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A new mechanism is suggested to obtain optical bistability (OB) in bulky semiconductors near the two-photon biexciton resonance.

Two factors essential for OB are nonlinearity and optical feedback. Since large optical nonlinearities have been observed in a group of materials in the vicinity of the two-photon biexciton resonance, many works [1–8] have been devoted to the problem of OB in that spectral region.

In refs. [1–4] the feedback was provided by a crystal platelet resonator of width $D \approx 1$ μm. The reflectivity of the crystal surfaces determines the possibility of OB which would disappear at all if $D \to \infty$ (as in bulky materials). The authors of refs. [5,6] have shown that the local field effect (LFE) can generate a feedback in bulky samples. However, a detailed recalculation of ref. [7] excludes the occurrence of OB due to the LFE. Then, the question arises how OB may happen in bulky semiconductors making use of the fusion of two photons into a biexciton.

This Letter proposes a mechanism of OB taking into account the intracrystal photon energy renormalization caused by the interaction of the photon with the crystal valence electron. The total Hamiltonian of a coherent photon–biexciton system under the action of an external classical field with amplitudes $E_k^{(\pm)}$ and frequency $\omega \equiv \omega_k$ near the two-photon biexciton resonance can be written in the form

$$H = (\omega_k + A_k) c_k^+ c_k + \Omega_{2k} b_{2k}^+ b_{2k} + \frac{1}{\sqrt{V}} g_k (b_{2k}^+ c_k c_k + c_k^+ c_k^+ b_{2k}) - (\tfrac{1}{2} V\omega)^{1/2} E_k^{(-)} e^{-i\omega t} c_k^+ + \text{h.c.}, \quad (1)$$

where c_k and b_{2k} are bosonic operators for the photon with frequency ω_k and the biexciton with energy Ω_{2k}; $A_k = \omega_0^2 / 4\epsilon_\infty \omega_k$ stems from the A^2-type term of the light–matter interaction Hamiltonian describing the coupling of the photon with the valence electron; ω_0 is the plasma frequency; ϵ_∞ the background dielectric constant; g_k the effective two-photon–biexciton coupling constant and V the volume of the sample. Using the equation-of-motion method we can find [8] the steady state equation for the photon density $n = \langle c^+ c \rangle / V$:

$$n = \frac{\gamma\sigma\omega I [(\Omega - 2\omega)^2 + \Gamma^2]}{[\gamma\Gamma - A(\Omega - 2\omega) + 2ng^2]^2 + [A\Gamma + \gamma(\Omega - 2\omega)]^2}. \quad (2)$$

In (2) Γ^{-1} (γ^{-1}) and σ are the biexciton (photon) dephase time and the photon depopulation one. It can be proved [8] that n will be a three-valued function of the light intensity I, i.e. OB will appear, if the following conditions hold:

$$A > \gamma\sqrt{3} \quad (3)$$

and

$$2\omega < \Omega - \Gamma(\gamma + A\sqrt{3}) / (A - \gamma\sqrt{3}). \quad (4)$$

From (3) it is clear that if $A = 0$, i.e. the photon–valence-electron interaction is neglected, OB will never occur. In most cases this interaction causes only a shift in the photon energy spectrum and gives no qualitative effects. But here it becomes a possible reason to generate OB in bulky samples. Because all optical characteristics of a highly excited semiconductor are dependent on n [8], they all will behave

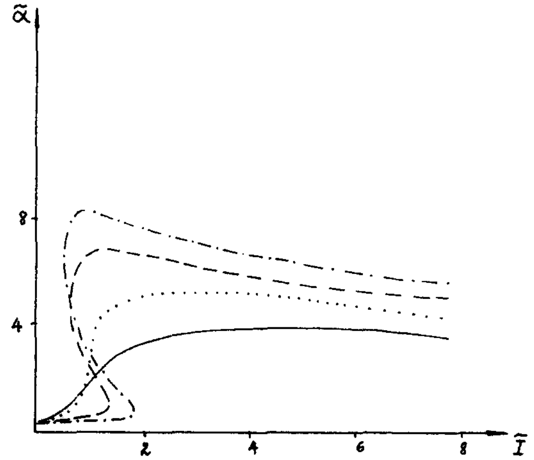

Fig. 1. The normalized dimensionless absorption coefficient $\tilde{\alpha}=0.02\alpha/\Omega$ versus normalized incident intensity $\tilde{I}=2\times 10^{-4}\omega\sigma g^2\Gamma^{-1}\gamma^{-2}I$ for $\omega=3186.16$ meV (solid curve; no bistability, $\omega=3186.06$ meV (dotted curve; critical case, $\omega=3185.87$ meV (dashed curve; bistable case) and $\omega=3185.69$ meV (dash-dotted curve; bistable, too).

bistably when (3) and (4) are met. For example, we plot in fig. 1 the intensity dependence of the nonlinear absorption coefficient α for CuCl with $\epsilon_\infty=5$, $\Omega=6.3725$ eV, $A=2.76$ meV, $\Gamma=0.2$ meV, $\gamma=0.1$ meV, $\sigma^{-1}=1$ meV and $g^2\approx 10^{-21}$ eV^2 cm^3.

In conclusion, we note that OB due to the mechanism suggested in this Letter occurs in the region of very low light intensity with a threshold intensity of about 13 W/cm^2.

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