Nonlinear Transmission of Two Successive Ultrashort Laser Pulses by a Thin Semiconductor Film under Two-Photon Generation of Biexcitons. Giant Oscillator Strength Model

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***Abstract* – The possibility was investigated to compress and to split laser pulses at their nonlinear optical transmission through semiconductor films.**

***Index Terms* – biexciton, exciton, thin semiconductor film, ultrashort laser pulse.**

I. INTRODUCTION†

In recent years the processes of interaction of resonance laser radiation with excitons and biexcitons in thin semiconductor films were studied in several works.

The thin-film approximation allows one to reduce the set of nonlinear partial differential equations for the electromagnetic field and the medium to a relatively simple set of ordinary differential equations, which in some cases admits exact analytical solutions.

Recent considerable advances in manufacturing of dimensionally confined semiconductor structures stimulate the investigations of nonlinear optical properties of semiconductor thin films. This research is of an obvious practical interest owing to the promising applications of thin semiconductor films for the development of the systems of ultrafast optical processing of information.

In this work the results are presented of theoretical investigations of the effects of nonstationary nonlinear transmission of two successive ultrashort pulses of resonance laser radiation, received from the same source, through a thin semiconductor film under conditions when each of the pulses can induce a two-photon generation of biexcitons from the crystal ground state. A similar problem for the case of one pulse was considered in [1, 2].

Let ultrashort pulses of laser radiation with the envelopes of the electric field strength $E_{in}(t)$ and the photon carrier frequency ω are normally incident on a thin semiconductor films with the thickness L in vacuum. It is assumed that the duration of each pulse t_p considerably exceeds the photon time of flight through the film t_f ($t_p >> t_f$), and the sum energy of two photons is in resonance with the generation energy of a biexciton from the crystal ground state. A part of radiation is reflected by the front end of the film, another part enters the film and generates biexcitons from the crystal ground state due to the process of two-photon absorption. The film thickness is of the order of the wavelength of propagating radiation or greater. Therefore, owing to the multiple re-reflections from the front and rear crystal ends a forward and a backward electromagnetic waves with the amplitudes $E_f\left(z,t\right)$ and $E_b\left(z,t\right)$, respectively, appear in the film. The amplitude of the forward wave on the rear end $E_f\left(L,t\right)$ defines the amplitude of the wave transmitted through the film; the amplitude of the backward wave on the front end $E_b\left(0,t\right)$ defines the amplitude of the reflected wave. The problem is to find the amplitudes of the transmitted and reflected waves. Such condition of the problem can be realized, for example, in CuCl or CuBr crystals, where the biexciton binding energy amounts to ~30–40 meV, and the oscillator strength of two-photon generation of biexcitons is gigantic.

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II. MAIN RESULTS

We consider the case of ultrashort laser pulses such that $t_p << \gamma_{biex}^{-1}$ and assume $t_p = 1\,ps$. For this case, the condition $t_p >> t_f$ is satisfied for the film thickness $L < 10^{-3}\,cm$. The results of numerical calculation of the set of equations describing the transmission of ultrashort pulses through a semiconductor film are shown in Figs. 1-4.

For large delay times between the incident pulses t_d, the first pulse induces the polarization of media, which completely disappears by the moment of incidence of the second pulse. Therefore, we can consider that there exist envelopes of each of two independent transmitted (reflected) pulses generated by two incident pulses. A considerable variation of the envelope of transmitted (reflected) radiation occurs for $0 \le t_d \le t_p$ when the envelopes of incident pulses partially overlap. For this case, the polarization of media induced by the first pulse has not enough time to disappear by the moment when the second pulse falls. In this case a nonlinear interaction of polarizations from the both pulses occurs; owing to this, the shape of the transmitted (reflected) pulse becomes more complicated.

It can be also seen in Figs. 1-4 that the amplitude of transmitted (reflected) pulse decreases fast with the increasing of the delay time between the incident pulses in the range of small delay times ($t_d \ll t_p$); the pulse further splits into two pulses, which propagate independently.

It follows from Fig. 1 that for low intensities of incident radiation $S \sim 10MW/cm^2$ the envelope of the transmitted (reflected) pulse even for zero delay between the incident pulses practically repeats their shape.

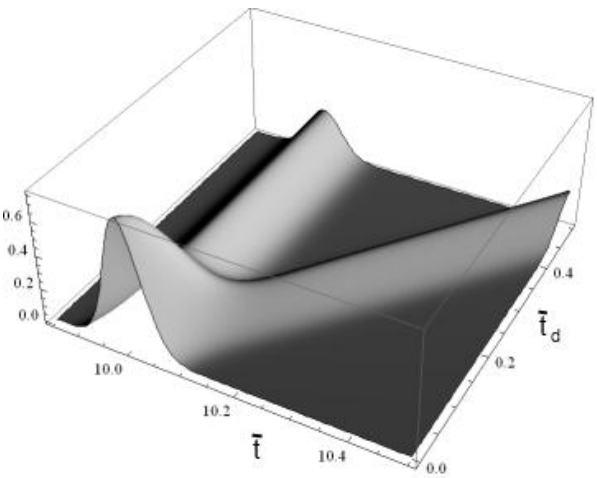

Fig. 1. Dependence of the normalized intensity of transmitted radiation versus the dimensionless time $\bar{t}$ and delay time between the pulses $\bar{t}_d$ for the film thickness $L = 10^{-3}\ cm$ and intensity of the incident radiation $S = 10\ MW/cm^2$ in the conditions of exact resonance ($2\omega = \omega_m$, where $\hbar\omega_m$ is the exciton formation energy).

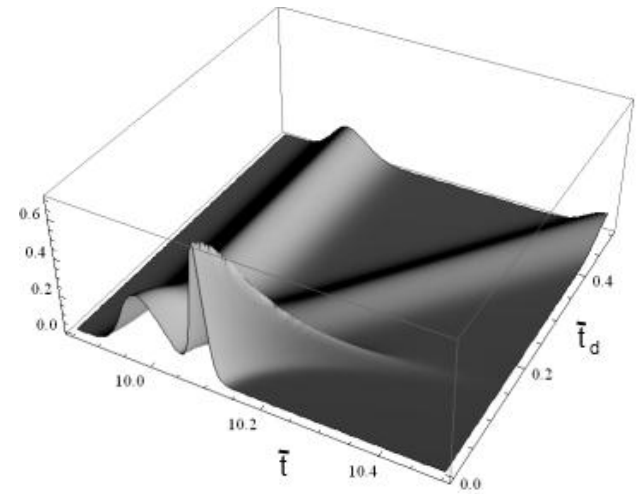

Fig. 2. Same as in Fig. 1 for $S = 60MW/cm^2$.

The transmission of incident pulses through a semiconductor film acquires additional peculiarities when the intensity of the pulses increases. For the intensity $S = 60MW/cm^2$ the transmission and reflection exhibit two or several peaks (see Fig. 2). It is interesting that the amplitude of the additional peak of transmission increases with the increasing of the excitation level and for $S = 60MW/cm^2$ it can already exceed the amplitude of the main peak. But for the case of reflection the amplitude of the additional peak is always smaller than the amplitude of the main peak.

For intensity $S = 100MW/cm^2$ the second transmission peak considerably exceeds the first (main) peak by its amplitude, and the third peak arise (Fig. 3).

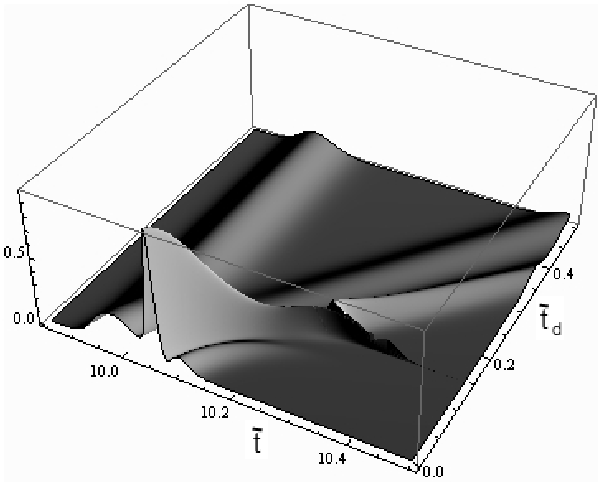

Fig. 3. Same as in Fig.1 for $S = 100MW/cm^2$.

For intensity $S = 200MW/cm^2$ and relatively large t_d the second subpulse of transmission arise.

When S further increases the number of additional transmission (reflection) peaks increases; their width becomes considerably less than the width of the incident pulses. The envelope of subpulses for transmission has the shape of the incident pulse.

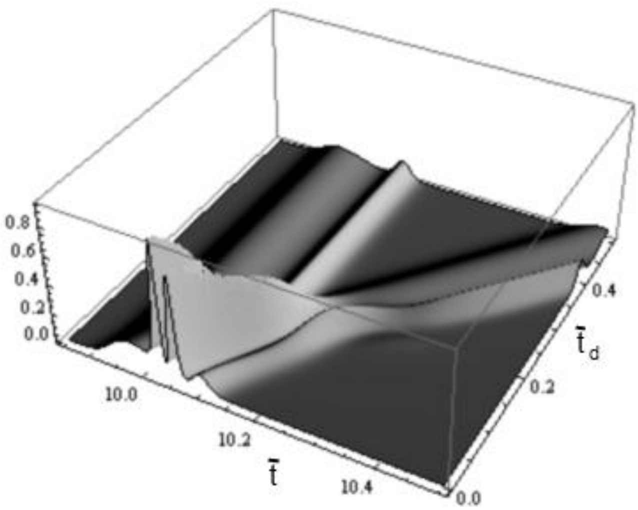

Fig. 4. Same as in Fig.1 for $S = 200MW/cm^2$.

III. CONCLUSION

Consequently, the thin semiconductor film substantially transforms successive ultrashort pulses passed through it and changes both their intensity and shape. While using films with various thickness, changing the intensity of incident pulses and the delay time between them one can obtain the compression of the initial pulse or to split it into a sequence of two or several pulses with considerably less duration.

REFERENCES

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