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Numerical Analysis, Processing and Prediction of a Populations Dynamics of Atomic Systems in a Laser Pulse Field: Quantum dynamics and Bi-stability Effects

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Abstract: The paper is devoted to presentation of an effective approach to numerical analysis, modelling and forecasting a populations dynamics of atomic ensembles in a field of laser pulse of different shape and quantitative studying the dynamical bi-stability (optical hysteresis) effects The results of computing kinetics of resonant levels for atoms in the laser pulse of different shape (sinusoidal, rectangular, etc) on the basis of the modified Bloch equations are presented. Cited equations describe an interaction between two-level atoms ensemble and resonant radiation with an account of the atomic dipole-dipole interaction. It has been found for a case of $ch^{-1}t$ laser pulse a strengthen possibility of manifestation of the internal optical bistability effect in the temporal dynamics of populations for the atomic resonant levels under adiabatic slow changing the acting field intensity.

Keywords: oprocessing and prediction, atomic dynamics, laser puls, bistability

1. Introduction. Dynamics of atomic Systems in a Laser Field and Bi-stability

Present paper has for an object (i) to simulate numerically a temporal dynamics of populations' differences at the resonant levels of atoms in a large-density medium in a nonrectangular form laser pulse and (ii) to determine possibilities that features of the effect of internal optical bistability at the adiabatically slow modification of effective filed intensity appear in the sought dynamics. It is known that the dipole-dipole interaction of atoms in dense resonant mediums causes the internal optical bistability at the adiabatically slow modification of radiation intensity [1-4]. The modified Bloch equations, which describes the interaction of resonance radiation with the ensemble of two-layer atoms subject to dipole-dipole interaction of atoms, are as:

$$\frac{dn}{d\tau} = \frac{i2\mu T_1}{\hbar}(E^* P - P^* E) + (1-n)$$
$$\frac{dP}{d\tau} = \frac{i2\mu T_1 n}{\hbar} - PT_1 \frac{1 - i(\delta + bn)}{T_2}, \qquad (1)$$

where $n = N_1 - N_2$ are the populations' differences at the resonant levels, P is the amplitude of atom's resonance polarization, E is the amplitude of effective field, $b = 4\pi\mu^2 N_0 T_2/2h$ is the constant of dipole-dipole interaction, T_1 is the longitudinal relaxation time, $\delta = T_2(\omega - \omega_{21})$ is the offset of the frequency ω of effective field from the frequency of resonance transition ω_{21}, N_0 is the density of resonance atoms, μ is the dipole moment of transition, $\tau = t/T_1$.

2. Results and Discussion

There are obtained the results on atomic dynamics for different shapes of laser pulse, including the following one:

$$E(\tau)=|E_0|^2\, ch^{-1}\frac{\pi\tau T_1}{T_2}\,. \qquad (2)$$

In the numerical experiment τ varies within $0 \le \tau \le T_p/T_1$ and T_p is equal to $10T_1$. On the assumption of $b > 4$ and $b > |\delta|$ with $\delta < 0$ (the long-wavelength offset of incident light frequency is less than Lorenz frequency $\omega_L = b/T_2$) and if the intensity of light field has certain value ($I_0 = 4|E_0|^2\mu^2 T_1 T_2/h^2$) then there are three positive stationary states n_i (two from them with maximal and minimal value of n are at that stable). A fundamental aspect lies in the advanced possibility that features of the effect of internal optical bistability at the adiabatically slow modification of effective filed intensity for pulse of $ch^{-1}t$ form, in contrast to the pulses of rectangular form, appear in the temporal dynamics of populations' differences at the resonant levels of atoms. Figure 1 shows the results of our numerical modeling the temporal dynamics of populations' differences at the resonant levels of atoms for the nonrectangular form pulse (2). More mathematical and physical details of the model can be found in [1-3].

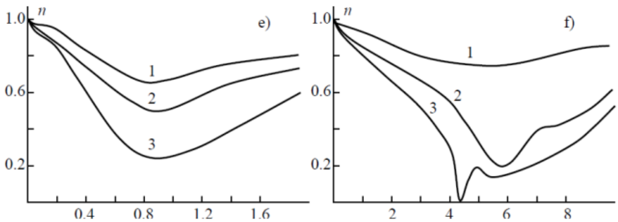

Fig.1 - Results of modeling temporal dynamics of populations' differences $n(\tau)$ at resonant levels of atoms for pulse (2) with $\delta = 2$, $T_1 = 5T_2$; $b = 0$ (e); $b = 6.28$ (f); $I_0 = 2$ (1), 5 (2), and 10 (3)

3. Concluding Remarks

The increase of field intensity above certain value $I_0 = 2.5$ for selected parameters (shown in Fig. 1) leads to the abrupt increase of populations' differences. This fact represents the Z-shaped pattern of dependence $n(I)$ observed in the stationary mode. For rectangular-shaped pulse, the dependence $n(\tau)$ tends to stationary state with magnitude defined by zero values of right-hand terms in the set (1) [4]. For the sinusoidally-shaped pulse, the slow rise of intensity is typical, and the explicit hysteresis pattern for the dependence of populations' differences from the field intensity is obtained.

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