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OPTICAL BISTABILITY IN LASERS INDUCED BY ELECTRONIC-VIBRATIONAL COUPLING

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1. Introduction. In the electronic excitation of molecules or crystals by radiation, vibrational couplings may significantly modify the behaviour of the system. Here we study the modifications in a single mode laser system which arise from the coupling between the electronic system and vibrational normal modes of the nuclei in the active medium. If the active medium is either a crystal or a polymer, then this interaction takes place between the electronic system and phonons [1].

2. Equations. The Hamiltonian of the electronic system is $H = H^0 + H^{e-r} + H^{e-v}$, where H^0 is the free electronic Hamiltonian, the electric dipole interaction with the radiation is given by $H^{e-r} = -\mu E$. Assuming a linear coupling between the electronic states and the normal vibrational modes [2] the electron-vibration Hamiltonian is

$$(1) \qquad H^{e-v} = \sum_{s_1} \hbar\omega_{s_1} \left(u^*_{s_1} b_{s_1} + u_{s_1} b^+_{s_1}\right)|1\rangle\langle 1| + \sum_{s_2} \hbar\omega_{s_2} \left(u^*_{s_2} b_{s_2} + u_{s_2} b^+_{s_2}\right)|2\rangle\langle 2|$$

where b_{s_i}, $b^+_{s_i}$ are the vibrational quanta annihilation and creation operators, ω_{s_i} is the vibrational frequency and u_{s_i} depends on the interaction strength and relates to the relative displacement of the nuclei equilibrium positions. Following the semiclassical treatment [3] (using the rotating wave and the slowly varying amplitude approximations) we obtain dimensionless and simplified evolution equations of the system

$$(2) \qquad \frac{\partial E}{\partial \tau} = \sigma\left(P - E\right)$$

$$(3) \qquad \frac{\partial P}{\partial \tau} = -\left(1 + i\Delta + i\delta\right)P + ia\sigma DP + DE$$

$$(4) \qquad \frac{\partial D}{\partial \tau} = -\gamma\left[D - r + \frac{1}{2}\left(E^*P + EP^*\right)\right]$$

where P is the polarization, D is the population inversion, σ relates to the cavity losses, Δ is the usual detuning, a is the electronic-vibrational coupling constant, γ is the ratio between the depolarization time of the dipoles and the lifetime of the population inversion and r is the pump. This system of equations is similar to the Complex Lorenz Equations (CLE), except for two terms: the non-linear term $ia\sigma DP$ which depends on the population inversion and acts as a dynamic detuning; and the linear term $-i\delta P$, which can be included in a new detuning $\Omega = \Delta + \delta$, where the constant δ depends on the vibrational coupling parameters.

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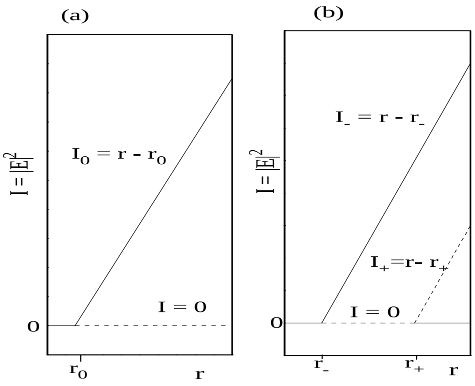

FIG.1. *Stable solution (solid line), unstable solution (dashed line).*

3. Linear stability of the solutions. The results of the linear stability analysis of the solutions versus the pump is shown in Fig. 1: (a) without electronic-vibrational coupling (CLE), (b) with electronic-vibrational coupling (Eqs. (2)-(4)). The stability condition of the trivial solution $E = 0$, $P = 0$, $D = r$ (no laser emission $I = 0$) gives us the laser threshold. The first laser thershold (r_-) shifts to a higher value ($r_- > r_o$), so the coupling delays the onset of the laser emission. Another pump value (r_+) appears above at which the no laser solution ($I = 0$) becomes stable again, so the trivial solution is stable for $r < r_-$ and $r > r_+$. The typical laser solution (I_-) shows up above the threshold (r_-), as in the case without coupling in which I_0 appears above r_o. Therefore, for $r > r_+$, both solutions ($I = 0$, I_-) coexist (bistable region). There is another oscilating solution (I_+), but it is always unstable.

4. Attraction basins from numerical analysis. To study the attraction basins in the bistable region we use molecular data of a laser which active centers are substituted aromatic molecules. As the pump r increases, the no laser solution basin ($I = 0$) grows up. For example, if we suddenly changed the value of the pump from a value below the threshold ($r < r_-$) to another value above the threshold inside the bistable region ($r > r_+$), we would not get laser emission.

5. Conclusions. Electronic-vibrational coupling of a single mode laser leads to two new terms in the semiclassical CLE. Such terms are proportional to the coupling strength and act as detuning terms. This coupling has two effects. On the one hand it induces a new type of optical bistability in lasers allowing the no laser emission to be stable again above a certain value of the pump. On the other hand, it has a stabilizing effect on the no laser emission due to the fact that the laser threshold moves to a higher value.

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