EPJ Web of Conferences **220**, 02012 (2019) https://doi.org/10.1051/epjconf/201922002012
IWQO-2019

A monolayer of three-level quantum Λ-emitters: A perspective system from the viewpoint of nonlinear optical dynamics and nanophotonics

Igor Ryzhov[1,*], *Ramil* Malikov[2], *Andrei* Malyshev[3,4], and *Victor* Malyshev[1,5]

[1]Herzen State Pedagogical University of Russia, 191186 St.-Petersburg, Russia
[2]Akmullah State Pedagogical University of Bashkortostan, 450000 Ufa, Russia
[3]GISC, Departamento de Física de Materiales, Universidad Complutense, E-28040 Madrid, Spain
[4]Ioffe Physical-Technical Institute, 194021 St.-Petersburg, Russia
[5] University of Groningen, Z IAM, 9747 AG Groningen, The Netherlands

Abstract. The nonlinear optical response of a monolayer of regularly spaced three-level quantum emitters with a doublet in the ground state is studied theoretically. It is found that the system demonstrates multistability, self-oscillations and dynamical chaos. In a certain frequency range, the monolayer operates as a perfect bistable mirror.

We perform a theoretical study of the optical response of a monolayer of regularly spaced three-level quantum emitters (QEs) with a doublet in the ground state (Λ-type QE). The total (retarded) dipole-dipole interaction of QEs is taken into account. This interaction provides a positive feedback which, interplaying with the immanent QE's nonlinearity, results in multistability, self-oscillations and dynamical chaos of the response. In a certain frequency range, the monolayer operates as a perfect nanometric bistable reflector.

The monolayer is assumed to undergo an action of a CW external field of a Rabi amplitude Ω_0 and frequency ω_0, which is quasi-resonant with the QE's allowed transitions. A QE is modelled as a three-level Λ-type quantum system with the excited state $|3\rangle$, and a doublet $|1\rangle$ and $|2\rangle$ in the ground states. Only the optical transitions $|1\rangle\leftrightarrow|3\rangle$ and $|2\rangle\leftrightarrow|3\rangle$ are dipole-allowed. They are characterized by the transition frequencies ω_{31} and ω_{32}, and spontaneous decay constants γ_{31} and γ_{32}. The relaxation within the doublet with the splitting Δ_{21} is described by the constant γ_{21}.

The optical dynamics of a QE is governed by the 3x3 density matrix. The field Ω, acting on a given QE in the monolayer, represents a sum of the external field Ω_0 and the field produced by all other QEs in place of the given one. The near-zone (far-zone) part of the QE-QE interaction gives rise to a dynamic shift of the transition frequencies ω_{21} and ω_{32} (collective radiative relaxation of QEs), depending on the population difference of corresponding transitions [1,2], governing by the constants Δ_L (shift) and γ_R (relaxation).

In Fig. 1, we present the result of calculations performed for the case when the external field is tuned into the resonance with the transition $|1\rangle\leftrightarrow|3\rangle$ ($\Delta_{31} = \omega_{31} - \omega_0 = 0$). Panel (b) shows the steady-state solution $|\Omega|$-vs-$|\Omega_0|$ for the set of parameters [2,3] given in the figure

* Corresponding author: igoryzhov@yandex.ru

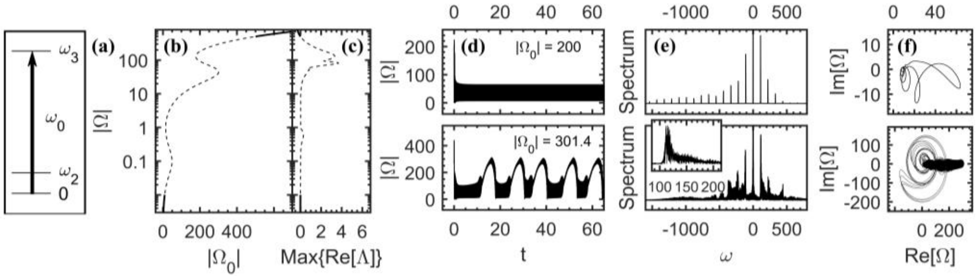

Fig. 1. (a) – Scheme of QE excitation. (b) – The monolayer's steady-state response. (c) – The real part of the major Lyapunov exponent. Solid (dashed) parts indicates stable (unstable) of the solution. (d), (e) and (f) – Respectively, dynamics, Fourier spectra and phase space trajectories of the system calculated for the field magnitudes $|\Omega_0|$ shown in panel (d). Parameters of calculations are: $\Delta_{21} = 100$, $\gamma_R = 100$, $\Delta_L = 1000$, $\gamma_{21} = 0.01$. All quantities are given in units of γ_{31}.

caption. As is seen, $|\Omega|$ turns out to be a multi-valued function of $|\Omega_0$ The stability of different parts of the solution has been explored analyzing the Lyapunov's exponents Λ_k ($k = 1,2\ldots8$). The maximal real part of $\{\Lambda_k\}$, Max$\{$Re$[\Lambda]\}$, is plotted in panel (c). Plots (d), (e) and (f) display, respectively, dynamics, Fourier spectra and phase space maps of the signals obtained for two values of $|\Omega_0|$ shown in the plots. For $|\Omega_0| = 200\gamma_{31}$, the dynamics demonstrates self-oscillations, while for $|\Omega_0| = 302.4\gamma_{31}$ – (quasi)chaotic behaviour.

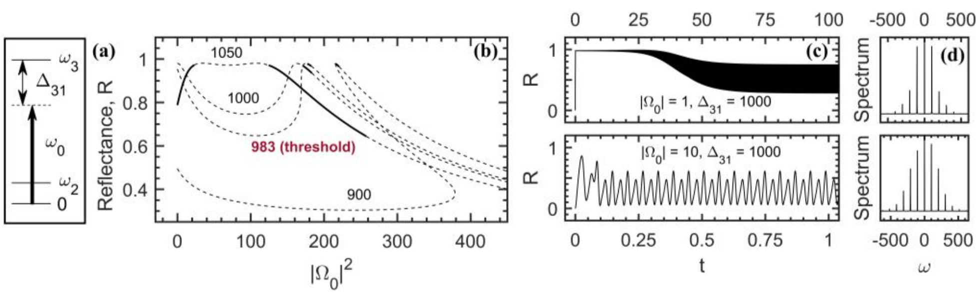

Fig. 2. (a) – Scheme of QE excitation. (b) – The steady-state layer's reflectance R calculated for a set of the detuning Δ_{31} (shown in the panel). Solid (dashed) parts of the curves indicate regions of stability (instability) of R. (c) and (d) – Dynamics and Fourier spectra, respectively, calculated for the values of $|\Omega_0|$ shown in the panel (c). All quantities are given in units of γ_{31}.

Fig. 2 shows the power refection coefficirnt R calculated in the vicinity of the resonance renormalized by the QE-QE dipole-dipole interaction, $\Delta_{31} = \Delta_L = 1000\gamma_{31}$ [1,2]. As follows from the figure, the monolayer exhibits high reflectance and bistability [panel (b)] as well as self-oscillations [panel (c)].

Summarizing, a monolayer of Λ-type QEs demonstrates multistability, self-oscillations, dynamical chaos and high reflectance, the features being perspective for nanophotonics.

R.F.M. acknowledges Akmullah State Pedagogical University for a support.

References

1. R.F. Malikov, V.A. Malyshev, Opt Spectrosc. 122, 955 (2017)
2. V.A. Malyshev et al., J. Phys.: Conf. Ser. 1220, 012006 (2019)
3. M.P. Boneschanscher, W.H. Evers, J.J. Geuchies et al., Science 344, 1377 (2014)