# Coherent Control of Emitters in a Photonic Crystal Environment

Dmitri Mogilevtsev and Solange Bessa Cavalcanti

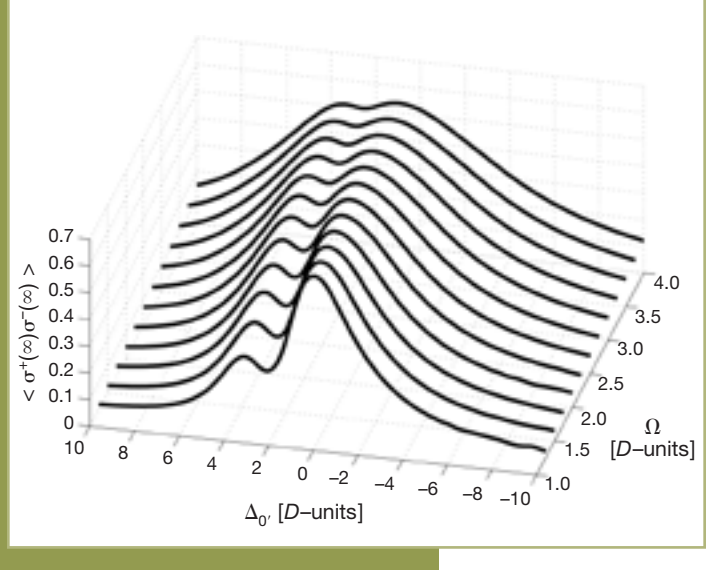
Photonic-band gap materials have provided us with a new dimension in our ability to control the properties of light. The rapidly developing realm of photonic crystals abounds with challenges, both theoretical and experimental. One of the most difficult problems is that of emitters inside a photonic crystal. When the transition frequency of a two-level atomic system falls within the gap, there are no modes available for coupling and thus spontaneous emission might be completely inhibited. Actually, this happens only when the transition frequency is far away from the band edge.

However, if the atomic frequency is close to the edge, the emitter is still able to "feel" the reservoir and their consequent coupling yields to unexpected behavior: After an initial short decay period, the upper-level population starts to oscillate, and finally attains a non-zero stationary level. In the 1970s, V. Bykov predicted such a phenomenon for an emitter embedded in periodic structures long before the advent of the photonic crystals.[1] Actually, emission here is not inhibited. What happens is that the emitted radiation is only partly dissipated through the reservoir.

A remaining large fraction stays localized in the vicinity of the atom, forming an atom-field bound state (AFBS), which behaves like a single compound entity. Besides preserving the complete information about the initial state of the emitter, the AFBS is quite robust with respect to dephasing losses as well as to mode losses of the photonic crystal due to the coupling to the external world.[2] Thus, the AFBS seems to be promising for quantum information processing. However, to exploit it, one needs to provide ways to access it.

Moreover, one must build an adequate theoretical apparatus to model such a process, since its essence lies in the entanglement between the emitter and the field. Standard methods are not applicable in this case. The reason is that by carrying out the usual procedure (i.e., averaging over the reservoir of the photonic modes), one washes out the very effect that one is interested in.

We have proposed a novel theoretical framework, using the idea of the collective operator master equation, to address the AFBS dynamics.[3] This method is tailored to separate the reservoir of modes on an entangled part and a non-entangled one. By applying this approach to the analysis of the interaction of a two-level emitting system with a bosonic structured reservoir, we have been able to show that the AFBS is liable to be controlled by a coherent driving through those reservoir's modes close to the band edge—a feature that is quite convenient for developing devices based on the reversible optical quantum memory cell.[4]




Population of the excited state as a function of the detuning $\Delta_0$ between the atomic transition frequency and the external driving frequency is shown for various driving intensities illustrating resonance fluorescence near the band edge. *D* represents the interaction strength between the modes of the reservoir with the atomic system.

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# Temporal Coherent Control with Incoherent Light

José Ferraz de Moura Nunes Filho, Daniel Felinto Pires Barbosa, Lúcio Hora Acioli and Sandra Sampaio Vianna

Laser control of chemical reactions is an enduring aspect of optical research. In order to achieve control of such a complex system involving many reactants, it is first necessary to be able to understand and manage the interaction of laser light with individual atoms and molecules.

In coherent quantum control, the primary goal is to select the outcome of a certain process by manipulating the interference between different quantum paths that connect the same initial and final states. Researchers have investigated several methods, and one of the most successful consists of shaping the phase, $\phi(\omega)$, of a femtosecond laser pulse.[1]

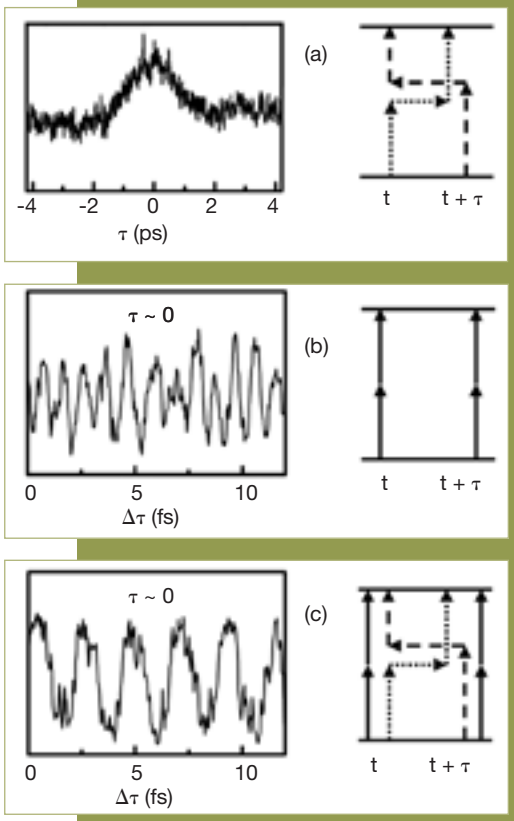
A closely related technique is temporal coherent control,[2] which consists of using two identical time-delayed pulses to exploit two quantum paths. These present a relative phase, which is introduced by changing the delay between the two pulses. Usually temporal coherent control is achieved using pulses delivered by a coherent source that generates an almost transform-limited ultrashort pulse: It has a well-defined phase over the spectrum of the laser.

Recently, we have demonstrated that incoherent light can also be used to perform temporal coherent control.[3] We used time-delayed pairs of pulses generated by a broadband dye laser to investigate the time-resolved four-wave mixing (FWM) response of atomic rubidium when a two-photon resonance is involved in the nonlinear process. The atomic system is especially interesting because several kinds of interferences are possible, each related to a particular resonance in the frequency domain.

This source of radiation has been well described as an incoherent source (thermal light). We were able to clearly distinguish between optical and quantum interferences observed in the signal beam generated by the FWM process. We observed the optical interferences—oscillations at the same central frequency of the incoherent laser that drives the two-photon transition—within the coherence time of the source.

However, we detected the quantum interferences, which present oscillations at twice the frequency of the optical interferences, for time delays larger than the coherence time of the incoherent source and smaller than the relaxation times of the system (hundreds of nanoseconds in our case).

In addition, by controlling the polarization of the laser beams, we were able to exploit the FWM signal dependence in order to select the different quantum pathways that contribute to the signal. In particular, we could cancel the paths that lead to optical interferences and observe only the quantum interferences (see figure).




FWM signal as a function of the relative delay between the incoherent pulses (τ) and the quantum paths related to the two-photon absorption for three different polarization configurations. The delayed pulses have perpendicular polarizations and the signal is detected (a) perpendicular and (b) parallel to the polarization of the third pulse. (c) All beams have parallel polarizations.

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# Dynamical Hysteresis Loops with Controllable Shape, Direction and Area

Amitabh Joshi, Wenge Yang and Min Xiao

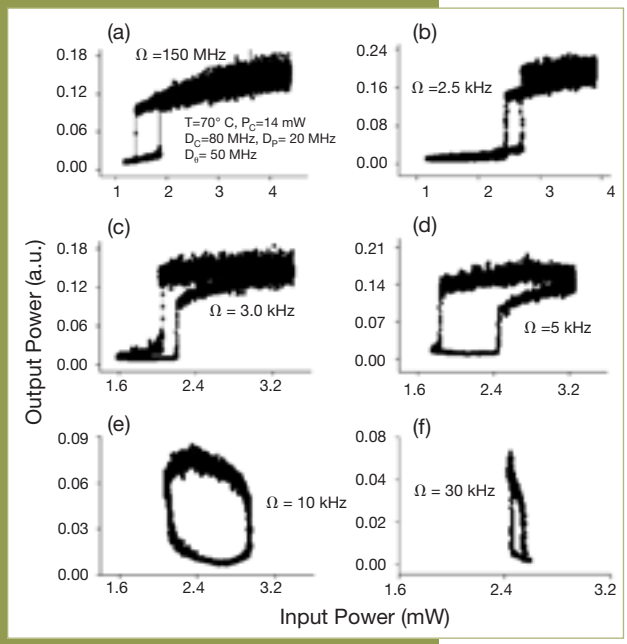
The phenomenon of hysteresis is ubiquitous in the magnetic, optical, electronic, mechanical, chemical, oceanic and biological sciences. Understanding the formation of hysteresis loops and how to control them is interesting from a fundamental physics point of view and can lead to many potential applications. The hysteresis cycle (HC) typically proceeds counterclockwise (noted as "forward"), as experimentally demonstrated in many systems, such as ferroic materials, spin glasses, polymers, porous media, granular systems, magnetic carbon, thermohaline circulation in oceans, ecosystems, circadian oscillations, elastoplastic systems and shape memory alloys.

The mechanisms responsible for forward HCs are different for various systems. For example, in ferromagnetic materials, the moving out of domain walls separating regions of antiparallel domains requires an increase of magnetic field; thus the hysteresis curve (i.e., magnetization as a function of applied magnetic field) represents the work needed to displace the domain walls—which ensures forward HCs. In the system of two-level atoms contained in an optical resonator, the bistable curves in the input-output intensities are either due to the saturated absorption of the medium or the dependence of refractive index nonlinearly on the input intensity of the field together with the feedback effect from the optical cavity.[1] Simple arguments show that such bistable curves should have forward hysteresis cycles.

We have demonstrated experimental control of the width of the hysteresis curves (bistability thresholds)[2] and have observed "multistable" behavior[3] in a system of an optical ring cavity containing three-level ($\Lambda$-type configuration) hot rubidium atoms inside a vapor cell (see figure, a-b). The important aspect of our work is that we were able to control the shape, direction and area of the HCs in the cavity input-output intensity characteristics (for the probe laser beam) using a second (coupling) laser beam.

This observed phenomenon is caused by the greatly modified absorption, dispersion and nonlinear optical properties of the three-level atomic medium due to the induced atomic coherence (related to electromagnetically induced transparency). When we changed one of the experimental parameters, such as the coupling beam frequency detuning[4] or the sweeping rate ($\Omega$) of the cavity input intensity,[5] we noted that the hysteresis loop in the input-output intensity plot was changed in shape (figures, a-b), direction (b-d) and area (c-f).

Such experimental controls in the width (thresholds), shape (multistability), direction (forward to backward) and area of an HC can create interesting applications, such as two-way or reversible all-optical switching. Also, studies of hysteresis behaviors in such a relatively simple physical system shed light on the underlying mechanisms and nonlinear dynamics involving HCs in more complicated systems, such as biological systems and ecosystems.




(a-b) Observed typical OB and multistability in the input-output intensity characteristics under different $\Omega$ for the parametric conditions of the system as mentioned in (a). (b–d) The observed input-output intensity characteristics in which the HC changes shape and rotation direction as $\Omega$ increases. (e-f) Hysteresis cycle changes area as $\Omega$ further increases.

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