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Optics Communications 247 (2005) 381–392
OPTICS COMMUNICATIONS
www.elsevier.com/locate/optcom

Two-photon lasing stimulated by collective modes

Nicolae A. Enaki [a,*], Vitalie Eremeev [a,b]

[a] Institute of Applied Physics, Academy of Sciences of Moldova, Academiei str.5, Chisinau MD-2028, Moldova
[b] Department of Engineering and Computer Sciences, Free International University of Moldova, Vlaicu Parcalab str.52, Chisinau MD-2012, Moldova

Received 15 July 2004; received in revised form 3 November 2004; accepted 19 November 2004

Abstract

Considering the resonator losses in photon pairs the coherence between the photon pairs as the function of number of bimodes is studied. Taking into account the big number of resonator bimodes in which the photon pairs with fixed energy and phase are generated, it is demonstrated that the coherence between the pairs of photons remains larger than the coherence between individual photons. It is shown that the ignition of two-photon lasing from vacuum fluctuations increases with the increase in the number of resonator modes. This effect can be regarded as a collective phenomenon between the resonator bimodes in which the pairs of entangled photons are generated.

PACS: 42.50; 42.55; 42.50.A; 42.50.L
Keywords: Two-photon lasing; Collective effects; Photon statistics; Quantum fluctuations

1. Introduction

The generation of specific quantum states of light that possess desired correlation between the emitted photons is in the center of attention of many recent experimental and theoretical studies [1]. The property of entanglement between the photons emitted in the process of light generation (amplification) has now a great impact on the application in quantum information [2]. The statistics of light generated by lasers can be altered significantly by modifying the properties of the resonator or the light-matter interactions. In this consequence of ideas, it is interesting to study the process of two-photon generation, modifying the "traditional" scheme of photon losses from micro-resonator. Thus, one can obtain a different coherent correlation between the emitted photons, and the ignition process of laser emission will be different in comparison with the two-photon laser theories, proposed earlier.

* Corresponding author. Tel./fax: +37322 739805.
E-mail address: enache_nicolae@yahoo.com (N.A. Enaki).

0030-4018/$ - see front matter
doi:10.1016/j.optcom.2004.11.076

The possibility of induced two-photon generation per atomic transition was suggested by Prohorov, and Sorokin and Braslau [3]. The scattering effects in two-photon amplifier attenuate the possibility to realize two-photon lasing [4–6]. The first experiments demonstrated that two-photon amplification and lasing in the presence of external sources are possible [7–9]. From a theoretical point of view, it is known that for the one-photon laser the field amplitude starts from electromagnetic vacuum fluctuations of resonator above the threshold point, so that the external source for lasing ignition is not necessary. The one of the first theoretical treatments of two-photon lasers use the analogies between one- and two-photon lasers [10]. Following the Scully–Lamb theory of one-photon laser [11] many authors obtained the master equation in which two-photon analogs of parameters of gain, losses and saturation were introduced in analogy with the one-photon laser case. According to these theories, the two-photon laser starts from vacuum fluctuations and losses from one- or two-mode laser are introduced taking into account the detailed-balance consideration. Taking into account the real losses from the cavity in papers [12–14] the theory of two-photon laser was proposed, in which, in order to pass into lasing regime the non-zero value of field amplitude is necessary.

On the other hand, in the free space an inverted system of radiators relative to dipole-forbidden transition passes into the two-photon super-radiance, starting from vacuum fluctuations [15]. This type of correlation of atomic polarization takes place in the processes of two-quantum exchange between the atoms through the vacuum of electromagnetic field. As was shown in these papers the inverted system can generate a coherent pulse of biphotons in the broad-band emission spectrum. Due to a large number of bimodes in which the pairs of photons are generated the two-photon super-radiance successfully starts from vacuum fluctuations, and an external ignition pulse is not necessary as in the two-photon laser [12–14]. We emphasize that in this case the second-order coherence which describes the coherence between the pairs of photons is larger than the first-order one. In order to increase the two-photon interaction with vacuum modes, in paper [16] the possibility of two-photon cooperative emission in cavity was discussed, in which the two-photon spontaneous emission time is larger than in the free space due to the discrete mode structure of the cavity and less than the life-time of photons in the cavity. In this case, the emission of two-photon superradiant pulse, starting from vacuum fluctuation, is possible too.

In this paper we propose another model of two-photon generator of coherent light where the coherence between the pairs of entangled photons is larger than the coherence between the individual photons in resonator. In order to obtain it the ignition of two-photon lasing from vacuum fluctuations of cavity electromagnetic field is proposed. Thus we demonstrate that, in special case of resonator losses, the two-photon lasing process starting from vacuum fluctuation passes into the quantum states with maximal coherence between the photon pairs. This is possible when the entangled photons generated in large number of conjugate modes are absorbed or ‘‘leave’’ the micro-cavity simultaneously in pairs. The realization of losses in pairs can be provided by an injected stream of atomic beam prepared in the ground state perpendicularly to the generation zone of the resonator which is accorded in the two-photon resonance with entangled photon pairs. More than this, the statistics of field in the resonator can be tested by such flux and the stability between the processes of generation and losses is established by the intensity of the atomic flux.

It is shown that the collective condensation of the photon pairs generated in the conjugate modes with same phase is possible. This result is obtained using the quantum master equation for cavity electromagnetic field which consists from photon pairs. In semiclassical treatment it is demonstrated that the non-zero value for the product of two-boson amplitudes of field belonging for the photons with different energy is possible. This result corresponds to the minimal value of quasi-potential function introduced in this paper (see Fig. 2). The statistical properties of photon pairs generated in the large number of conjugate modes drastically differ from one-photon lasing statistics, though the behavior of biphotons in the process