Second Order Coherence and its Application in Communication

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***Abstract* — In this paper it is examined the coherence properties among the Stokes and anti-Stokes fields and its application in Communication. It is proposed novel two-photon entangled sources which take into account the coherence and collective phenomena between these fields. The quantum propriety of realistic sources of powerful coherent bi-boson radiation (coherent entanglement of the Stokes and anti-Stokes photons) is analyzed. The possibility of experimental applications of coherence between the Stokes and anti-Stokes photons in quantum communications and cryptography is proposed.**

***Key words* — Raman process, light generation, coherent field.**

I. Introduction

The property of entanglement between the emitted photons in the processes of light generation has a great impact towards applications dealing with quantum computing, and information security [1]. The modern investigations connected with the manipulation of quantum fluctuations of the generated light and there application in transmission and detection of information with high degree of security play an important role in the modern defense problems. An interesting behavior of the Stokes [2] and of the anti-Stokes generated modes in the Raman processes [3] can be observed for the small number of the pumped photon in nonlinear media.

In this article it is proposed the new type of two photon comunication through the bi-boson field which can be regarded as two coherent fields generate in the lasing process of the Stokes and anti-Stokes modes in nonlinear medium. Such a quantum correlations can be obtained in the processes of Raman scattering [4]. In this paper it is obtained new coherent states between the Stokes and anti-Stokes fields and it is proposed to use such a fields in quantum communication. It is demonstrated that these collective scattering phenomena take place due to information transfer between the photons of two cavity modes.

Studying the quantum fluctuations of the number of photon the new proprieties of the Stokes and anti-Stokes fields have been found and proposed for communication with hair degree of security of information. The new peculiarities of second order correlation functions between these fields are considered as potential algorithms in cryptography and are expressed through the lasing parameters of the source [5]. This manuscript reports the review of the transmission of information through entangled photons, obtained in parametric down conversion [6, 7]. In our paper it is proposed the new method of transmission of information taking in to account the two-field coherent states. The main difference between Ekert model [8] and new possibilities which include the second order coherent effects is given. It is considered that such coherence between the photon of two fields can be conserved in the process of propagation of the Stokes and anti-Stokes photon through different fibers over long distances after the focusing. The information encapsulated into coherent bi-boson light can be destroyed in the dispersive medium and restored over a certain distance. In both methods of transmission of the Stokes and anti-Stokes photons, the nature of the quantum communication between two points A (Alice) and B (Bob) does not allow eavesdropper, E (Eve), to know the transferred information. Below we shall discuss the cryptographic model on the basis of two entanglement photons obtained in parametrical down conversion and our model based on the two-field coherence effect between the Stokes and the anti-Stokes fields. These models are described in the second and third sections.

II. Protocols with Entanglement Effect Between Photons

The transmission of information through entangled photons is based on he the Ekert's protocol [8]. This protocol is encoded by its physical nature. The system based on the entanglement effect between the photons consists in the following: Alice receives one of the photons of the pair and Bob the second. Alice and Bob have de same detection basis and for every particle pair everyone choose independently an accidentally axis and measure the polarization along the axis. After that a series of photons pair are transmitted, they announce what axis of polarizer were chosen in the process of measurement and analyze in which cases they obtained the particles simultaneously [8]. So, the channel is established. This system is encoded automatically. A detailed description can be found in the works [8]. The pulses formed from pairs of entangled photons can be applied in quantum communication and cryptography using the great investigations of quantum optics. It was demonstrated that in the process of transmission of correlated two photons which were obtained with parameter down-conversion effect through two optical fibers, the correlation between the photons pairs is conserved at a very big distance (30 km), and for more than 6 km in free-space [9]. For the distance that is mach than 20 km in free space Chinese physicist realizes [9] it today. He thinks that simultaneously with an output to geostationary satellites the communication through quantum cryptography will be possible for distance around 10 thousands km. In other words, the humanity will have cryptographic channels that cannot be listened by eavesdropper (Eve), because the nature of the communication through pairs of photons does not allow this. Below we give the scheme that describes this process of transmission at the distance of 13 km [9]. The generator of pairs of photons (probably the nonlinear crystal without a inversion centre (MgO:LiNbO3) is situated in Chinese place Dashu. The flux was expanded using a optic telescope. The signal was compressed with telescopes of the same type at the detectors Alice and Bob situated in USTC (University of Science and Technology of China) and the place Taouhua. The protocols Alice and Bob coincided, that means a high efficiency in the process of transmission of the information.

III. New Architecture Using uhe Coherence Between Stokes and Anti-Stokes Fields

It is propose a novel architecture for quantum communication. The amplitude of a simple block of coherent the Stokes and anti-Stokes photons obtained after two-photon interaction in scattering lasing effects can be described by the square value of electrical vector $\Pi(t) = g_S g_A \hat{b}^{+}\hat{a} Exp[\omega_0 t - (k_a - k_s)z + \varphi_0]$.

$\Pi(t) = E_A^{+} E_S$, representing these amplitudes through $E_A^{+} = \hat{b}^{+}\exp[i(\omega_A t - k_z z)]g_A$ and $E_S^{-} = \hat{a}\exp[-i(\omega_S t - k_S z)]g_S$ where $\hat{b}^{+}$ and $\hat{a}^{+}$ are creation photon operators in the anti-Stokes and Stokes fields respectively, $\hat{b}$ and $\hat{a}$ are annihilation photon operators in these fields. In the quasi-classical limits the amplitude $\Pi_0(t) = g_S g_A < \hat{b}^{+}\hat{a} >$, has the same proprieties as amplitude of coherent laser field. In this approximation a nice idea is to use the classical of two wave modulation of this square amplitude for transmission of information. At first glance, it is observed that this method does not have a substantial differences in comparison with classical methods of information processing, but if we send this information in dispersive media, which separates the anti-Stokes and Stokes photons from coherent entanglement fields, the information is drastically destroyed, because $< \hat{b}^{+} >$ and $< \hat{a} >$ take zero values. The possibility of restoration of information on the square amplitudes is interesting problem of many particle coherent states, formed from blocks of the Stokes and anti-Stokes photons. These studies are necessary because in a bi-boson lasing effect [10], the photon statistics depend on the statistics of the ignition field [11]. Of course, the start up from vacuum fluctuations preserves the entanglement character of the generated the Stokes and the anti-Stokes coherence state. This effect is very interesting in quantum communication. It is propose an interesting effect that takes into account the classical method of registration of information. A large number of modes in the coherent states give as the possibilities of the increase the security of information storages in bimodal field [9-11]. In this approximation, the classical information may be introduced in the amplitude $\Pi_0(t)$. Such registration of information may have nothing to do with the traditional method. If the bi-boson pulses pass through a dispersive medium, the anti-Stokes and Stokes photons from the field change their directions. Focusing the anti-Stokes and Stokes photons into different optical fibers the're totally dropping the coherence among the photons. However, after a certain time interval, the anti-Stokes and Stokes photons from the field are mixed again, and it can observe that the coherence is restored see Fig. 1.

The coherent states between the Stokes and anti-Stokes fields can be realized in cooperative scattering effects [11]. In order to obtain the cooperative generation of the coherences states between the Stokes and anti-Stokes fields we consider a stream of atoms [10, 14, and 15] with two levels traveling through the cavity.

The total Hamiltonian which describes the interaction of the atoms with the Stokes and anti-Stokes fields of the cavity can be represented through the atomic and field operators

$$H_T = \sum_{j=1}^{N} \hbar\omega_0 R_{zj} + \hbar\omega_a \hat{a}^{+}\hat{a} + \hbar\omega_b \hat{b}^{+}\hat{b} + i\sum_{j=1}^{N} G(k_a, k_b)\left\{\left\langle \hat{R}_j^{-}\hat{J}^{+} - \hat{J}^{-}\hat{R}_j^{+} \right\rangle\right\} \quad (1)$$

where the last term represent the interaction Hamiltonian. Here Rzj is the population inversion of atom j; $\hat{R}_j^{+}$ and $\hat{R}_j^{-}$ represent the operators which describe the transitions from ground state to excited state and from excited state to ground state, respectively [10]. The operator $a^{+}(a)$ is the creation (annihilation) of the Stokes photons and $b^{+}(b)$ is the creation (annihilation) of the anti-Stokes field operators. The interaction constant G (k_a, k_b) describes the effective nonlinear coupling of atom j with cavity modes k_a and k_b with the energies $\hbar\omega_a$ and $\hbar\omega_b$. In order to describe the scattering processes, let us introduce the collective operators for the Stokes and the anti-Stokes modes, $J^{+} = ab^{+}$ and $J^{-} = ba^{+}$ [12]. The operator J^{+} describes the simultaneously process of creation of the anti-Stokes and annihilation of the Stokes photons. The inverse process is described by operator: J^{-}. As the full number of photons in the cavity, in the small time moment the interaction is conserved, I'll introduce the operator of photons inversion between the Stokes and anti-Stokes photons: $J_z = (b^{+}b - a^{+}a)/2$ and energy difference $\hbar\tilde{\omega} = \hbar\omega_b - \hbar\omega_a$.

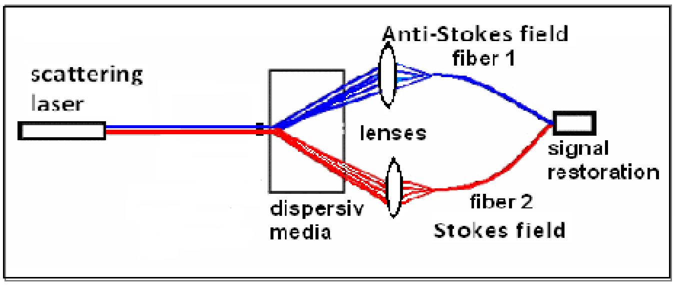

Fig. 1 Represent the possibility of the restored information.

IV. THE MASTER EQUATION

Taking into account, that the lifetime of atoms in the cavity are shorter than the time of scattering processes and considering that the atomic system is prepared in excited state, let us eliminate the atomic operators $\hat{R}_j^+$ and $\hat{R}_j^-$ from Heisenberg equation of arbitrary field operator. By representing the operators $\hat{R}_j^+$ and $\hat{R}_j^-$ through the field operators J^+ and J^- in according with Hamiltonian (1). After consecutive elimination of free parts of these operators the master equation for the Stokes and anti-Stokes field can be represented in the forth order on the interaction $G(k_a, k_b)$ constant

$$\frac{d}{dt}\langle J^+(t)\rangle = -2\tilde{\alpha}_1\langle J_z(t)\rangle\langle J^+(t)\rangle + 4\tilde{\alpha}_2\langle J_z\rangle\langle J^+\rangle\langle J^-\rangle\langle J^+\rangle, \quad \frac{d}{dt}\langle J^-(t)\rangle = \left[\frac{d}{dt}\langle J^+(t)\rangle\right]^+ \quad (2)$$

The behaviour over time of the mean value of operators J^+ and J^- can be found in accordance with the generalized equation propose in paper [12]. In semi classical approximation, when the fluctuations of these operators are neglected $J^\pm(t) \approx <\hat{J}^\pm(t)>$ and $J_z(t) \approx <\hat{J}_z(t)>$ the equations (2) for mean values of these operators J^+ and J^- take the following simple expression

$$\frac{d}{dt}\langle J^+(t)\rangle = -2\tilde{\alpha}_1\langle J_z(t)\rangle\langle J^+(t)\rangle + 4\tilde{\alpha}_2\langle J_z\rangle\langle J^+\rangle\langle J^-\rangle\langle J^+\rangle \quad (3)$$

Considering that, at initial stage of ignition of generation the inversion operator can be approximate photons inversion with minus j , and following the idea proposed in paper [11], the equation (3) can be represented by the generalized potential function, $V(J^+, J^-)$, $d<J^+(t)>/dt=\partial V/\partial <J^-(t)>$. In accordance with this definition, we obtain the following potential function

$$V(z) = -2\tilde{\alpha}_1 j|z|^2 + 2\tilde{\alpha}_2 j|z|^4 \quad (4)$$

with the minimum in point $|z|_{\min} = \tilde{\alpha}_1/(2\tilde{\alpha}_2)$, where $|z| = |J^+| = |J^-|$.

The dependence of this potential V(z) as function of the amplitude $|z|$ decrease achieving and after that increase. As follows from the expression (4), the amplitude value of two-photon coherent fields is proportional with the ratio between scattering rate and diffusion coefficient α_2 and increases with increasing of scattering rate, α_1. This steady state solution describes the stabilization process in the resonator.

The interest is in the behavior of quantum fluctuations of this bi-field intensity, $\hat{J}^+(t)\hat{J}^-(t)$, in the process of time evolution to steady state: $\Delta^2=G_2(t)-G_1^2(t)$ where $G_1(t)=<\hat{J}^+(t)\hat{J}^-(t)>$ and $G_2(t) = <\hat{J}^+(t)\hat{J}^+(t)\hat{J}^-(t)\hat{J}^-(t)$, are the intensity and square of intensity of bi-boson field consisted from the Stokes and anti-Stokes fields. Following the method proposed in paper [11] let now found the behavior of correlation functions $G_1(t)$ and $G_2(t)$.

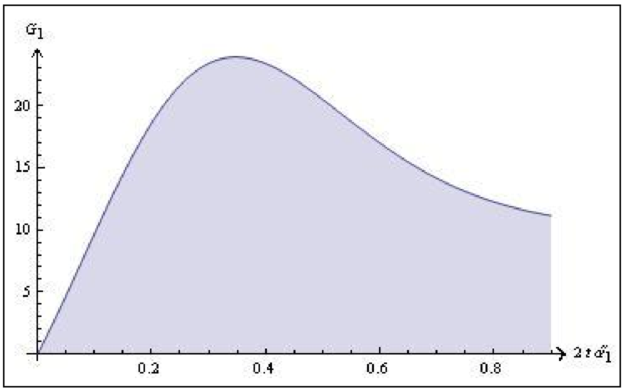

Fig. 2: The dependence of correlation functions G1(t) on the relative time $2t^*\alpha_1$, for the the following value of parameters $\alpha_2/\alpha_1=0.005$ and 2j=10.

Taking in to account the solution of quantum equations (2), in the Fig. 2 present the dependence of correlation function $G_1(t)$ on the relative time $2t^*\alpha_1$, for the parameters $\alpha_2/\alpha_1=0.005$ and 2j=10. As results from Fig.2, in the time, the correlation functions $G_1(t)$ reach the maximal value, after that that correlation tend to the stabilization of the scattering processes in resonator.

The interest is in the behavior of quantum fluctuations of this bi-field intensity, $\hat{J}^+(t)\hat{J}^-(t)$, over evolution time and have studied the behavior of relative quantum fluctuations $\delta^2=G_2(t)/G_1^2(t)-1$. In Fig. 3 is plotted the time behaviour of relative square fluctuations δ^2. From this figure, it follows that in the process of the stabilization of generation process, the square fluctuations has from negative value to positive. These effects have many analogies with the transition from anti-bunging to bunching processes in single photon emission. In this case the transition corresponds to the fluctuations of the normal products of the Stokes and anti-Stokes field operators J^+ and J^- belonging to SU(2) group [11, 15].

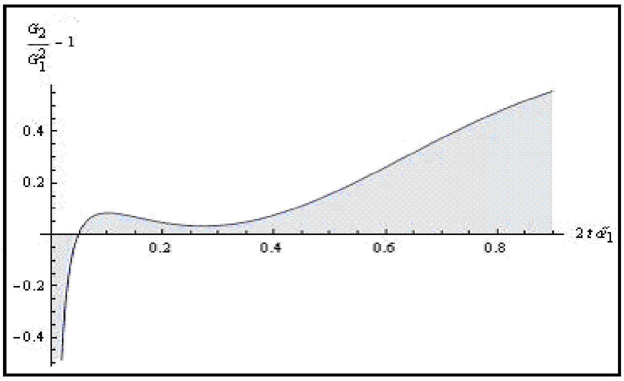

Fig. 3. The dependences of relative fluctuation $\delta^2=G_2(t)/G_1^2(t)-1$ as function of relative time $2t^*\alpha_1$, for the same parameter as in Fig. 2.

CONCLUSIONS

The recent advances in quantum communication by using quantum optical proprieties of light are reviewed. The quantum communication protocols are carefully discussed. On the basis of these protocols many laboratories work for development and implementation of quantum optics devices. It is proposed a new method of quantum communication, which takes in to account the coherence between the entangled photon fields and the application of this effect in quantum communication. Considering coherent and corpuscular properties of light, consisted of photon fields, the new scheme for quantum communication has been offered.

CONTRIBUTIONS

The author would like to acknowledge stimulating discussions with Professor Enaki N.A. from Institute of Applied Physics of the Academy of Sciences of Moldova. This paper was supported by the NATO project: No. G4890.

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