RADIATION EFFICIENCY IN THE CONTEXT OF EFFECTIVE IMPLEMENTATION

EFICIENȚA RADIAȚIEI ÎN CONTEXTUL IMPLEMENTĂRII EFICACE

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Sumar. *Aplicarea proprietăților luminii coerente în reglarea și controlul proceselor biomoleculare a devenit primordială, în contextul actual al avansării tehnologiilor moleculare și al controlului de precizie înaltă. Lucrarea abordează aspecte fundamentale ale interacțiunilor dintre lumină și materie, care sunt deosebit de relevante în mediile biologice: în primul rând, interacțiunea neliniară a luminii coerente cu medii biologice complexe și, în al doilea rând, interacțiunea cooperativă a fotonilor cu materie, cu accent deosebit pe biomolecule. Studiul pune un accent special pe mecanismele de legături de hidrogen dintre perechile de nucleotide Guanină și Citozină (G-C), analizând comportamentul lor structural și răspunsul dinamic în cadrul proceselor de împrăștiere Raman. Pentru a susține această investigație, este dezvoltat un model teoretic, bazat pe observații experimentale, care încorporează proprietățile locale de simetrie ale structurilor biomoleculare. Modelul oferă perspective asupra mecanismelor de transformare a fotonilor, contribuind la dezvoltarea de noi metode de control optic și monitorizare în medii biomoleculare. Constatările sugerează că lumina coerentă poate fi utilizată eficient pentru a sonda și manipula interacțiuni moleculare specifice, deschizând calea pentru aplicații avansate în biofotonică și diagnosticare moleculară.*

Cuvinte-cheie: *procese Raman; biomolecule; lumină coerentă.*

INTRODUCTION

This research focuses on radiation efficiency UVC from the perspective of a high-performance practical application based the Raman spectroscopy and the application of this effect in physical and biophysical field. Therefore, Raman spectroscopy is a powerful technique which can distinguish between healthy and unhealthy cells and cancerous and non-malignant cells. It has been successfully utilized to determine qualitatively and quantitatively the molecular compositions of solid, liquid, and gases samples. The nonlinear theory of the excitation of vibration modes of bio-molecule of viruses and bacteria is proposed, taking into consideration the bimodal coherent states in coherent Raman excitation of biomolecules.

The authors compare two different ways: the first a von Neumann-type process and second involves adding a dissipative term in the master equation [1, p. 40]. From molecular of biology point of view the highest important goal is the stability of DNA

[2, p. 388]. The authors mentioned about value of the eigenstate energy which is means that the transitions from one to another state takes place due to the light proprieties. They give the tunnelling factor obtained in the order of 10^{5}, which are means that the system readily interconverts between the canonical and tautomeric configuration via quantum effects [3, p. 550]. Recently were analysed the cooperative effects induced by UV excitation of several biologically relevant Tryptophan Mega-Networks for the reason of signalling and control [3, p. 555]. Raman microscopy is a promising quantum technology for visualizing the distribution of molecules in cells. Furthermore, its utility can be expanded to small-molecule imaging by using tiny Raman-active tags such as alkyne. The authors describe the optics, hardware and software to construct the Raman microscope, and discuss the conditions and parameters involved in live-cell imaging [4]. Below shall be analyzed a type of the technic Raman which is more applicable in different domains in **especially** at the control of biomolecular systems in physics and medicine. For this reason, the explanation how interacts photons in Raman process it will be detailed pointed. Because the optical pumping with nanosecond pulses, individual cells in a high-Q microcavity produce bright, directional and narrowband laser emission, with characteristic longitudinal and transverse modes. In paper [5, p. 680], is mentioned about Lasing cells remained alive even after prolonged lasing action. Light amplification and lasing from and within biological systems pave the way to new forms of intracellular sensing and imaging [6, p. 12].

1.1 THE INTERACTION HAMILTONIAN BETWEEN THE ATOMIC AND FIELD OPERATORS

Cooperative conversion of the photons from Stokes in anti-Stokes modes stimulated by a stream of atom flying through the micro-cavity two standing waves were given in common paper [7, p. 1335]. The Hamiltonian of interaction that describes the interaction of the atoms with Stokes and anti-Stokes modes of the cavity electromagnetic field can be represented through the atomic and field operators was done. In order to describe the collective processes, was introduced in Hamiltonian the collective operators for bimodal field, which are described by SU (2) symmetry. This reduction to SU (2) symmetry helps us to solve exactly the super radiant conversion between the Stokes and anti-Stokes photon using the conservation law of Bloch vector Fig. 1B. Where were propose the cooperative photon conversion in the dynamical regime of photon conversion between the two pulses belonging to two modes of nanofiber during the pulse propagation. The procedure of measurements, were changed, replacing the two-mode cavity with electromagnetic pulse in the fibre [7, p. 1338]. Still here on the Bloch sphere was presented the Laser working point, see. Fig. 1B.

During the pulse, propagation in the fibre wave mode the new pulse is generated due to the scattering conversion of the photons in anti-Stokes (or Stokes) mode becomes possible in the process of relaxation (excitation) of the atoms trapped in the evanescent zone of the fibre. In Fig. 1A the red part of the pulse is the Stokes component and the

blue part corresponds to the anti-Stokes one. In the Raman process the energy that occurs because of the interaction of light with vibrational modes associated with chemical bonds within the sample is change. Like it knows the state of light can be measured testing the number of atoms in the ground and excited states like in the Walther micro maser experiment. The procedure of measurements, replacing the two-mode cavity with electromagnetic pulse in the fibre. A nanofiber system is a device where the diameter of the evanescent zone is larger than the fibre diameter.

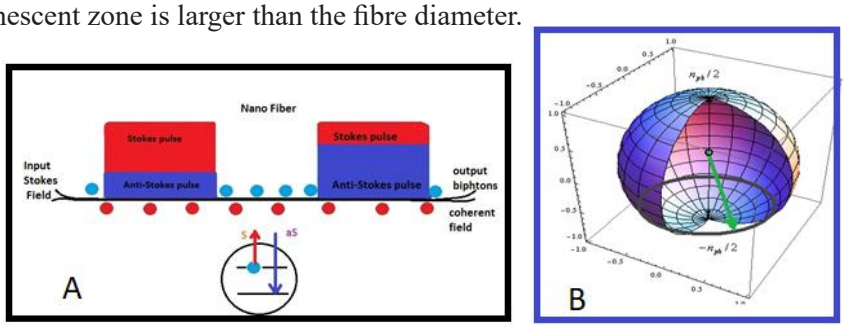


Figure 1. A. Propagation of Stokes pulse through nanofiber and its conversion in anti-Stokes pulse

The explained formalism can be used to study the intermolecular electronic excited-state interaction in much simpler molecular aggregates, such as dimers and trimers, [8, p. 82]. Typically, the significant regions of the Raman spectrum that are observed within biological specimens fall within 400–2,000 cm^{-1} wavenumbers, associated with bond vibrations of proteins (1,500–1,700 cm−1), carbohydrates (470–1,200 cm^{-1}), phosphate groups of DNAS (980, 1,080 and 1,240 cm^{-1}), [9, p. 111610]. The authors specify that the Raman spectroscopy has a high molecular specificity, making it an excellent technique for materials analysis. They mention that, Raman scattering is a rare phenomenon with an exceptionally low probability of occurrence (~1 in 10^8) in comparison with its counterpart Rayleigh scattering, and thus it is typically described as an insensitive technique. For some molecules such as DNA, it makes more sense to perform excitation in the UV region, because the laser frequency and the electronic transition of the molecule under investigation are similar [9, p. 111612].

The Hamiltonian that describes the interaction of the atoms with Stokes and anti-Stokes modes of the cavity electromagnetic field can be represented through the atomic and field operators

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

Here R_{zj} is the population inversion of atom j; R_j^+ and R_j^- represent the operators which describe the transitions from $|g\rangle$ - ground to $|e\rangle$ -excited state and from $|e\rangle$ -excited to $|g\rangle$ - ground state respectively (see Fig. 2).

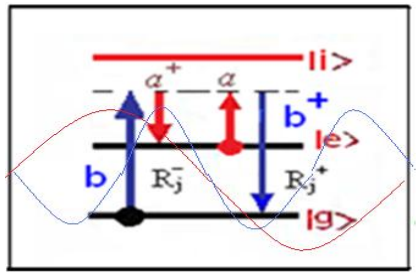


Figure 2. This scheme shows the collective excitation of atom with absorption of Stokes photon and generation of anti-Stokes quantum and vice versa

The operator $a^+(a)$ is the creation (annihilation) of Stokes photons and $b^+(b)$ is the creation (annihilation) of anti-Stokes field operators. The interaction constant $G_j(k_a,k_b)$ describes the effective nonlinear coupling of atom j with cavity modes k_a and k_b. For describing the scattering processes, let's introduced the collective operator for Stokes and anti-Stokes modes, $J^+ = \boldsymbol{b}^+$, and $J^- = \boldsymbol{b}^+$.

1.2 ELIMINATION OF THE ATOMIC OPERATORS

The operator $J^+ = \boldsymbol{b}^+$ describes the simultaneously process of creation of anti-Stokes and annihilation of Stokes photons. The operator $J^- = \boldsymbol{b}^+$ is described inverse process. As in the cavity the fool number of photons in the small-time interaction is conserved, let us introduced the operator of photons inversion between the Stokes and anti-Stokes photons: $J_z = \left(b^+ b - a^+ a\right)/2$. Taking into account, that the life time of atoms in the cavity are short than the time of scattering processes and considering that the atomic system is prepared in excited state, let us eliminate the atomic operators $\hat{J}^+$ and $\hat{J}^-$ from Heisenberg equation of arbitrary field operator $\hat{O}(t)$:

$$\frac{d}{dt}\left\langle \hat{O}(t)\right\rangle = \frac{i}{\hbar}\left\langle [\textstyle\sum_{j=1}^{N}\hbar\omega_0\hat{R}_z^j(t) + \hbar(\omega_b-\omega_a)\hat{J}_z(t), \hat{O}(t)]\right\rangle$$
$$+\frac{i^2}{\hbar}\textstyle\sum_{j=1}^{N}G_j(k_a,k_b)\left\langle [\hat{R}_j^-(t)\hat{J}^+(t) - \hat{J}_j^-(t)\hat{R}_j^+(t), \hat{O}(t)]\right\rangle. \quad (2)$$

The atomic pump of the scattering process with the transformation of n-Stokes photon field. The state of light can be measured testing the number of atoms in the ground state, (see. Fig. 3), like in Walter micro maser experiment [11, p. 55]. The correlation between the Stokes photons and anti-Stokes, [10, p. 665], in process of the cooperative conversion can be named super-radiance. Following super-radiance at conversion, the atoms from the ground state, leaves the cavity, forming one pulse in their time distribu-

tion, (see. Fig. 3). Detection of the cooperative conversion of super-radiance can be observed, if is detect the time distribution of the living atoms in the ground state using ionization method. Similar effect was proposed in the scattering processes between two cavity modes [12, p. 3]. In our case instead of instead of atoms there is photons. If the photons are scattering in other mode of cavity other mode we can consider like another state of cavity in other words it can associate the photons in distributed between two cavity modes as an ensemble of two-level system.

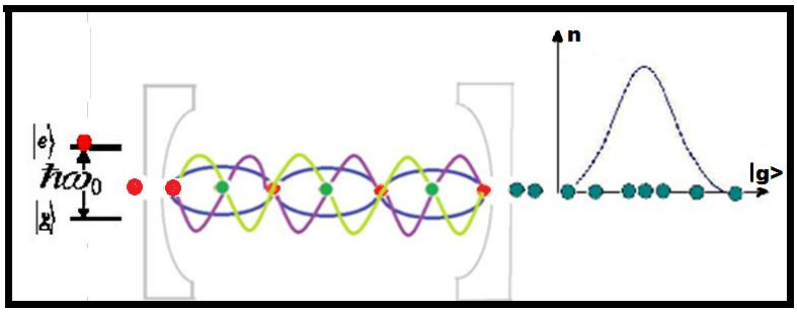


Figure 3. The populations of number of the atoms in the ground state

In equation (2) generalized for the bimodal cavity field operator, using a series of special permutations, the following master equation for the density operator is obtained

$$\begin{aligned}\frac{d\,W(t)}{dt} &= -i\chi\gamma_{\perp}[\hat{J}_{z},W(t)] + \tilde{\alpha}_{1_1}\{2\hat{J}^{+}W(t)\hat{J}^{-} - W(t)\hat{J}^{-}\hat{J}^{+} - \hat{J}^{-}\hat{J}^{+}W(t)\}\\ &-\tilde{\alpha}_{2}\Big\{\frac{1-\chi^{2}}{(1+\chi^{2})^{2}}[\hat{J}^{+}W(t)\hat{J}^{-}\hat{J}^{+}\hat{J}^{-} - W(t)\hat{J}^{-}\hat{J}^{+}\hat{J}^{-}\hat{J}^{+} + \hat{J}^{+}\hat{J}^{-}\hat{J}^{+}W(t)\hat{J}^{-} - \hat{J}^{-}\hat{J}^{+}\hat{J}^{-}\hat{J}^{+}W(t)]\\ &+\frac{1}{1+\chi^{2}}[\hat{J}^{+}\hat{J}^{+}W(t)\hat{J}^{-}\hat{J}^{-} - \hat{J}^{+}W(t)\hat{J}^{-}\hat{J}^{-}\hat{J}^{+} + \hat{J}^{+}\hat{J}^{+}W(t)\hat{J}^{-}\hat{J}^{-} - \hat{J}^{-}\hat{J}^{+}\hat{J}^{+}W(t)\hat{J}^{-}]\\ &+i\frac{2\chi}{(1+\chi^{2})^{2}}[\hat{J}^{+}W(t)\hat{J}^{-}\hat{J}^{+}\hat{J}^{-} - W(t)\hat{J}^{-}\hat{J}^{+}\hat{J}^{-}\hat{J}^{+} - \hat{J}^{+}\hat{J}^{-}\hat{J}^{+}W(t)\hat{J}^{-} + \hat{J}^{-}\hat{J}^{+}\hat{J}^{-}\hat{J}^{+}W(t)]\Big\}.\\ &+i\frac{2\chi}{(1+\chi^{2})^{2}}[\hat{J}^{+}W(t)\hat{J}^{-}\hat{J}^{+}\hat{J}^{-} - W(t)\hat{J}^{-}\hat{J}^{+}\hat{J}^{-}\hat{J}^{+} - \hat{J}^{+}\hat{J}^{-}\hat{J}^{+}W(t)\hat{J}^{-} + \hat{J}^{-}\hat{J}^{+}\hat{J}^{-}\hat{J}^{+}W(t)]\Big\}. \qquad (3)\end{aligned}$$

The equation (3) describes the collective transformation of Stokes photons into an anti-Stokes field and is similar to the master equation in super-radiance that is traditionally described in literature [13, p. 138], when emission rate is equal to zero, $\tilde{\alpha}_1\tilde{\alpha}_1 = 0$. For estimation the experimental condition from work [11, p. 48], is emission rate $\tilde{\alpha}_1 \approx 10^5 - 10^7\,1/s\tilde{\alpha}_1 \approx 10^5 - 10^7\,1/s$, is much higher than cavity losses $k=c(1-r)/l \approx 10^5 1/s$. Here $r \approx 0.99979$ is the reflection power of the cavity mirrors at a given frequency, $l \approx 10^{-3}\,cm$ is the length of the cavity. Let us first consider that, at the initial moment of time, it is 0 photons in the anti-Stokes mode and $n_{ph} = 2j$

photons in the Stokes, so that the bimodal cavity fields are described by the initial state $|\psi(0)\rangle = |0\rangle_a |n_{ph}\rangle_s$.

***THE STABILIZATION* PROCESS IN THE REZONATOR**

From the Q- and P- diagonal representation of the density matrix, if the right-hand side of the master equation (3), has a biquadratic form with respect to the $\hat{J}^+(t)$ and $\hat{J}^-(t)$, operators, the solution of the master equation can be represented by the diagonal operators bra-Ket of the angular momentum states

$$W(t) = \sum_{m=-j}^{+j} P_m(t) |m, j\rangle\langle m, j|. \quad (4)$$

The set of functions Pm describes the probability of simultaneous existence of (2j+1) Dicke states in the scattering process. The initial condition for the system of equations Pm is P(-j) = 1, P(-j+1) = P(-j+2) =...=P(j)=0 (all photons are prepared in Stokes pulse). The relative value of parameter α_2/α_1=0.005 is choose, according to the definition of the Raman gain $g_s=\alpha_1/c\sim(1/(\delta^2))$ (see as results from the Fig. 4, the transformation of 2j=9 (2j=5) Stokes photons into 9 (see Fig. 4a) anti-Stokes photons, take places in a very interesting way. This distribution can be regarded as the probabilistic repartitions between Stokes and anti-Stokes photons: (0, 9); (1, 8); (2, 7); (3, 6); (4, 5); …; (5, 4); (6, 3); (7, 2); (8, 1); (9, 0), which are described by simultaneous existence of such repartitions with the probabilities: $P_9(t)$, $P_8(t)$, …, $P_0(t)$, …, $P_{-8}(t)$, P_{-9}. In the brackets, the first number (n, m) represents the Stokes photons and the second number - the anti-Stokes photons. The sum of these probabilities is equal to unity: $\sum_{m=-j} P(x) \quad 1.$ This steady state solution describes the stabilization process in the resonator.

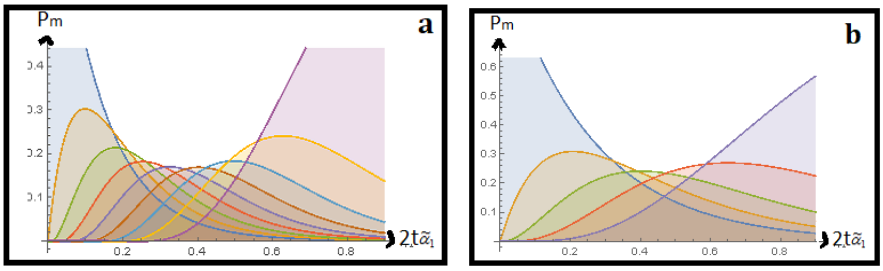


Figure 4. The time dependence of probabilities $P_m(t)$ for the following values of the relative parameters α_2/α_1=0.0075 and the number of photons 2j = 8 and 2j = 4

Regarding optical quantum system investigated by the authors [15, p. 7], value of the order of tunnelling factor give suggestion that the system readily interconverts

between the canonical and tautomeric configurations of Guanine - Cytosine (G-C) or Adenine-Thymine (A-T) base pairs, via quantum effects. From this reason it is can consider to give the same association with the cooperative quantum effect analysed in this paper.

CONCLUSIONS

The properties of coherent light can be effectively applied to the control of processes in biomolecular systems. In this context, a novel mechanism of cooperative photon conversion between Stokes and anti-Stokes pulses is proposed, stimulated by atoms trapped in the evanescent field of optical nanofibers. It is demonstrated that this cooperative conversion induces quantum correlations between photons in the Stokes (pump) and anti-Stokes modes, through nonlinear interactions with excited atoms confined within the evanescent region of the nanofiber. Notably, the emergence of second-order coherence between Stokes and anti-Stokes photons is observed. In this way this research demonstrated graphically the radiation efficiency UVC and the perspective of a high-performance practical application in near future. To describe these quantum properties, a set of collective operators is introduced. This formalism captures the cooperative dynamics between photons originating from the pump and anti-Stokes pulses. The transformations governed by these collective operators can be associated with quantum transitions between the canonical and tautomeric forms of Guanine–Cytosine (G–C) or Adenine-Thymine (A-T) base pairs, suggesting a quantum contribution to molecular switching mechanisms.

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