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УДК 535.8

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SELECTIVE EXCITATION OF QUBITS AND TRANSFER OF QUANTUM INFORMATION FROM ONE QUBIT TO ANOTHER[1]

Abstract.

Background. The proposed construction of a qubits as fragments of composite nanostructured materials with quasi-zero refractive index allows to realize the resonance energy transfer over long distances by selective excitation of one of the qubits using the continuous ultraviolet radiation.

Materials and methods. A new construction of the qubit made of composite material with quasi-zero-refractive index synthesized by us is represented. Qubit is a fragment of this material with one silver nanoparticle inside a cylinder with a base area $\pi \cdot (28\,nm)^2$ and a height of 56 nm, which corresponds to 3 % of weight content of the silver in the composite material with uniformly distributed nanoparticles with a radius of 2.5 nm.

Results. On the basis of the equations of motion for coupled quantum dipoles and integro-differential equations for the electric field, a nonlocal problem was solved, in which one qubit is excited by continuous radiation, and at the location of the other qubit the local field is induced. The distance between the qubits is 5 m. Quantum information is transmitted due to entanglement of quantum states of qubits.

Conclusions. The article shows that the system of two qubits, which are fragments of a composite material with a quasi-zero refractive index, is an ideal energy transporter from one qubit to another over long distances. The new construction of a qubit with nanofibers, allowing to implement selective excitation of qubits by external radiation, was represented.

Key words: composite materials with a quasi-zero-refractive index, Ag-nanoparticle cubit, quantum information, inversion and local dipole moments of cubits, entanglement of quantum states, transfer of the quantum information between cubits.

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СЕЛЕКТИВНОЕ ВОЗБУЖДЕНИЕ КУБИТОВ И ПЕРЕДАЧА КВАНТОВОЙ ИНФОРМАЦИИ ОТ ОДНОГО КУБИТА К ДРУГОМУ

Аннотация.

Актуальность и цели. Предлагается конструкция кубитов как фрагментов композитного наноструктурного материала с квазинулевым показателем преломления, которая позволяет реализовать резонансную передачу энергии на

[1] This work was supported by the Ministry of Education and Science of the Russian Federation (Project № 14.Z50.31.0015).

большие расстояния при селективном возбуждении одного из кубитов непрерывным ультрафиолетовым излучением

Материалы и методы. Представлена новая конструкция кубита из синтезируемого нами композитного материала с квазинулевым показателем преломления. Кубит представляет собой фрагмент этого материала с одной наночастицей серебра внутри цилиндра с площадью основания $\pi \cdot (28\,\text{нм})^2$ и высотой 56 нм, что соответствует 3 % весовому содержанию серебра в композитном материале при равномерном распределении наночастиц радиусом 2,5 нм.

Результаты. На основе уравнений движения для связанных квантовых диполей и интегродифференциального уравнения для напряженности электрического поля решена нелокальная задача, в которой один из кубитов возбуждается непрерывным излучением, а вместе расположения другого кубита индуцируется локальное поле. Расстояние между кубитами равно 5 м. Передача квантовой информации обусловлена перепутыванием (entanglement) квантовых состояний кубитов.

Выводы. Показано, что система из двух кубитов, представляющих собой фрагменты композитного материала, обладающего квазинулевым показателем преломления, является идеальным транспортером энергии от одного кубита к другому на большие расстояния. Представлена новая конструкция кубита с нановолокном, позволяющая реализовать селективное возбуждение кубитов внешним излучением.

Ключевые слова: композитный материал с квазинулевым показателем преломления, серебряная наночастица – кубит, квантовая информация, инверсные и локальные дипольные моменты в кубитах, перепутывание квантовых состояний, передача квантовой информации между кубитами.

Introduction

Quantum information related to the solution of some problems such as the transfer of quantum information at any distance, quantum teleportation, quantum computing in a quantum computer, quantum cryptography, decoherence problem [1–4]. The basis for the solution of these problems is the physical realization of a quantum bit (qubit) as a physical system, enabling them to realize the selective excitation without a noticeable influence of various random processes, to encode, to store, to transmit information from one qubit to another, to record and to erase information. In quantum communication systems, information can be transmitted by the physical transfer of a qubit - the information medium or by the teleportation of the quantum state of the qubit [5]. Qubit can be represented as a quantum system with two states $|0\rangle$ and $|1\rangle$ with energy E_0 and E_1, respectively. These basic functions allow to submit the wave function of the qubit as follows:

$$\Psi = a|1\rangle \exp\left(-\frac{i}{\hbar}E_1 t\right) + b|0\rangle \exp\left(-\frac{i}{\hbar}E_0 t\right),\ |0\rangle = \begin{vmatrix}0\\1\end{vmatrix},\ |1\rangle = \begin{vmatrix}1\\0\end{vmatrix}, \quad (1)$$

where a and b are complex coefficients of quantum superposition, depending on time in the field of excitation and satisfies the normality condition $|a|^2 + |b|^2 = 1$. Excitation of qubits by the electromagnetic fields allows to realize all quantum states with different values of the inversion w as the difference between the probability of detection of the qubit in the excited and ground states $\left(w = |a|^2 - |b|^2\right)$.

This property of qubit is what fundamentally distinguishes it from the classical bits of information, where only two states are realized, for example, in magnetic film [1]. There are proposals of the physical realization of qubits, for example, using nuclear or electron spins $I = \frac{1}{2}$ [1, 2] or Ca^{2+} ion composed of a single ionic crystal [1]. There are other options of choice of qubit states [1, 2]. A large number of experiments are performed on the qubit represented as a single photon with two orthogonal polarizations. Systems of photonic and atomic qubits are investigated experimentally in a resonator in cavity QED [6].

In this article we propose the construction of a qubit based on silver nanoparticles (Ag-nanoparticle cubit), which is a fragment of a composite film made of composite material synthesized by our technology [7]. This fragment is a cylinder of glass or polymer 56nm in height and base radius of 28 nm (Fig. 1).The cylinder is dimensioned so that at 3 % of weight content of the silver in the composite material the average distance between nanoparticles of silver is equal to 28 nm. The optical properties of the layer of the composite material with silver nanoparticles with radius 2,5 nm are shown in [8, 9] using the experimental spectra of reflection and transmission in the wavelength range from 400 to 1200 nm. The theoretical description of these spectra is represented in our works [8–11], which proved that the synthesized materials have a quasi-zero refractive index and low absorption in the wavelength range of at least from 400 to 1200 nm. Excitation of qubits with proposed construction can be performed using the optical nanofibers, such as those described in [12], wherein excitation of photons in the optical fiber of glass with a facing of silver, was made by electron beam.

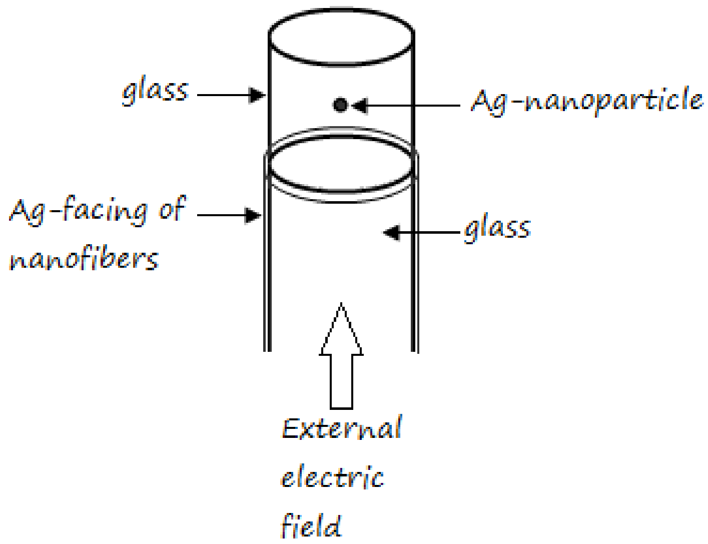

Fig. 1. Construction of Ag-nanoparticle qubit

The interaction between qubits by the optical circuit (Fig. 2) is described in this work using a system of equations for coupled quantum dipoles [11] and the integral-differential equation for the electric field at different points of observation both inside and outside of these nanoparticles in the far and near zone [13].We found a particular solution of these equations, which shows that the transfer of quantum information from one qubit to another can occur at arbitrary distances between qubits. This mechanism of transmission of quantum information by selective excitation of one of the qubits is significantly different from the quantum teleportation, where the two qubits simultaneously excited by pulsed field and the transfer of quantum information over long distances is a result of quantum interference of two qubits [5].

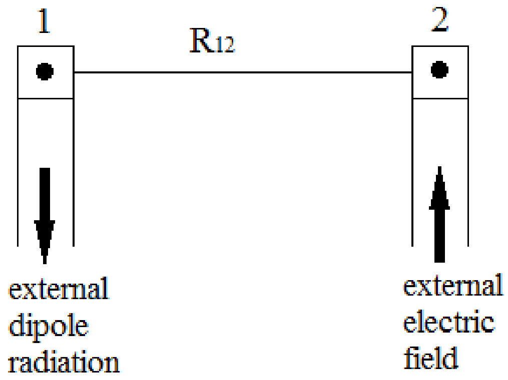

Fig. 2. Optical circuit of selective excitation of qubits by field of external radiation. R_{12} – distance between qubits

1. The equation of motion for two Ag-nanoparticle cubits as composite parts

The electric field strength $\mathrm{E}(\mathrm{r},t)$ for different observation points for two qubits is defined by the following equation [13]:

$$\mathbf{E}(\mathbf{r},t)=\mathbf{E}_I(\mathbf{r},t)+\sum_{j=1}^{2}\int \text{rot rot } N\frac{\mathbf{d}_j(\mathbf{r}',t-R/c)}{R}dV', \tag{2}$$

where $\mathbf{E}_I(\mathbf{r},t)$ is the electric field strength of the external wave, $R=|\mathbf{r}'-\mathbf{r}|$ is the distance between the radius vector $\vec{r}\,'$ inside of spherical qubits and the observation point $\mathbf{r}$, N is the concentration of free electrons in qubits, c is the speed of light in a medium surrounding the Ag-nanoparticle and the quantum-mechanical average $\mathbf{d}_j=\mathbf{X}_j\exp(-i\omega t)$ of induced electric dipole moments of qubits obeys the equations for coupled quantum dipoles:

$$\dot{\mathbf{X}}_j=-i\Delta\mathbf{X}_j-\frac{2i}{\hbar}w_j|\mathbf{d}_0|^2\mathbf{E}_{0j}-\frac{1}{T_2'}\mathbf{X}_j, \tag{3}$$

$$\dot{w}_j=\frac{i}{\hbar}(\mathbf{X}_j^*\mathbf{E}_{0j}-\mathbf{X}_j\mathbf{E}_{0j}^*)-\frac{1}{T_2'}(w_j-w_0), \tag{4}$$

where $\Delta=\omega_0-\omega$ is the detuning from the resonance frequency ω_0, ω is the frequency of the external field, $\mathbf{d}_0$ is the transition dipole moment of the free electrons in the Ag-nanoparticle cubit, w_0 is the inversion of the equilibrium state is equal to -1 , $1/T_2'$ is the width of the resonance at a frequency ω_0 , w_j is the inversion of qubits, $\mathbf{E}_{01}$ and $\mathbf{E}_{02}$ are a local fields without the factor $\exp(-i\omega t)$. Values $\mathbf{X}_1$, $\mathbf{X}_2$ and w_1 , w_2 of qubits in according to sense of equations (3) and (4) can be represented by the coefficients of quantum superposition a_1, b_1 and a_2, b_2 of qubits as follows:

$$\mathbf{X}_1 = 2\mathbf{d}_0 b_1^* a_1 \, , \; \mathbf{X}_2 = 2\mathbf{d}_0 b_2^* a_2 \, , \; w_1 = |a_1|^2 - |b_1|^2 \, , \; w_2 = |a_2|^2 - |b_2|^2 \, . \qquad (5)$$

When qubits are being excited by short pulses, the duration of which is much less T_2', last term on the right-hand side of equations (3) and (4) can be dropped, resulting in the implementation of the following conservation laws during $\Delta = 0$

$$|\mathbf{X}_1|^2 + w_1{}^2 d_0{}^2 = d_0{}^2 \, , \; |\mathbf{X}_2|^2 + w_2{}^2 d^2 = d^2 \, . \qquad (6)$$

2. Single-qubit transformations

The equations (3) and (4) allows us to define a single-qubit transformation when $\mathbf{E}_{0j} = \mathbf{E}_{0I}$, ie local fields are converted to the external field. Consider the case of pulsed irradiation one of the qubits, for example, qubit 1 by external field. Suppose that the pulse duration is much less time T_2'. Then for qubit 1 we have (omit the index 1):

$$\dot{\mathbf{X}} = -i\Delta\mathbf{X} - \frac{2i}{\hbar} w |\mathbf{d}_0|^2 \, \mathbf{E}_{0I} \, , \qquad (7)$$

$$\dot{w} = \frac{i}{\hbar}\left(\mathbf{X}^* \mathbf{E}_{0I} - \mathbf{X}\mathbf{E}_{0I}^*\right) . \qquad (8)$$

The values $\mathbf{X}$ and w are defined as the quantum-mechanical average of the Pauli matrices $\sigma_1, \sigma_2, \sigma_3$ in the energy space with the help of the wave function (1). Herewith

$$\langle\Psi|\sigma_1|\Psi\rangle = a^* b + b^* a = u \, , \; \langle\Psi|\sigma_2|\Psi\rangle = -i(a^* b - b^* a) = v \, ,$$

$$\langle\Psi|\sigma_3|\Psi\rangle = |a|^2 - |b|^2 = w \, , \qquad (9)$$

and the value $\mathbf{X}$ is defined as

$$\mathbf{X} = \mathbf{d}_0(u - iv)\exp(-i\omega t) = 2\mathbf{d}_0 a b^* \exp\left(-\frac{i}{\hbar}(E_1 - E_0)t\right) . \qquad (10)$$

The functions u and v change over time much more slowly than $\exp(-i\omega t)$ and obey to the law of conservation

$$u^2 + v^2 + w^2 = 1 \, . \qquad (11)$$

The coefficients of superposition a and b can be represented as

$$a = |a| e^{i\varphi_a} \, , \; b = |b| e^{i\varphi_b} \, . \qquad (12)$$

Also these coefficients can be identified through the variables u, v, w

$$a = \frac{2(w+|b|^2)}{u+iv} b = \frac{w+|b|^2}{|a|} e^{i\varphi_a}, \; b = \frac{2(|a|^2 - w)}{u-iv} a = \frac{|a|^2 - w}{|b|} e^{i\varphi_b}. \quad (13)$$

The equations of motion for the variables u, v and w with accordance to equations (7) and (8) in the case of the exact resonance $\Delta = 0$ take the following form:

$$\dot{u} = 0, \; \dot{v} = w\chi E_{0I}, \; \dot{w} = -\chi E_{0I} v, \quad (14)$$

where $\chi = (2/\hbar)|\mathbf{d}_0'|$, $\mathbf{d}_0'$- the real part of the transition dipole moment $\mathbf{d}_0$, $\mathbf{E}_{0I}$ is the real amplitude of the external wave parallel to the vector $\mathbf{d}_0'$.

The pulse area can be represented as

$$\Theta(t) = \chi \int_{-\infty}^{t} E_{0I}(t')dt'. \quad (15)$$

Then the solution of (14) takes the following form:

$$u(t) = u(0), \; v(t) = w(0)\sin\Theta(t) + v(0)\cos\Theta(t),$$

$$w(t) = -\text{v}(0)\sin\Theta(t) + w(0)\cos\Theta(t), \quad (16)$$

where $u(0), v(0), w(0)$ are values of functions u, v, w at the initial time $t = 0$. If at the initial time $w(0) = -1$, than, according to the law (11), we have $u(0) = v(0) = 0$. The pulse area (15) can be regarded as the angle of rotation of the Bloch vector $\boldsymbol{\rho}\,(u,v,w)$ in the energy space. For rectangular pulse $\Theta = \chi E_{0I}\tau$, where τ- pulse width. At $\Theta = \pi$ we have $w(\tau) = 1$, i.e. the operation NOT is implemented , as

$$NOT|0\rangle = |1\rangle, \quad (17)$$

when the qubit is transferred from the ground to the excited state. Other quantum states of the qubit according to the equation (13) can be implemented by changing the pulse area Θ.

In a field of continuous radiation instead of equations (14) using (3), (4) for one qubit, when $\Delta \neq 0$ we obtain the following equations:

$$\dot{u} = -\Delta v - (u/T_2'), \; \dot{v} = \Delta u + \chi E_{0I} w - (v/T_2'), \; \dot{w} = -\chi E_{0I} v - \left(\frac{w+1}{T_2'}\right). \quad (18)$$

The stationary solution of this system of equations under the conditions $\dot{u} = \dot{v} = \dot{w} = 0$ is:

$$u = \frac{(\Delta T_2')(\chi E_{0I} T_2')}{1 + (\Delta T_2')^2 + (T_2')^2(\chi E_{0I})^2}, \; v = -\frac{\chi E_{0I} T_2'}{1 + (\Delta T_2')^2 + (T_2')^2(\chi E_{0I})^2},$$

$$w = -\frac{1 + (\Delta T_2')^2}{1 + (\Delta T_2')^2 + (T_2')^2(\chi E_{0I})^2}. \quad (19)$$

When

$$\left(\chi E_{0I}\right)^2 (T_2')^2 << 1 \quad (20)$$

according to the solution (19), a qubit inversion does not change and it is equal to $w_0 = -1$. In this case, under the influence of a low-intensity excitation only quantum information in the qubit will be changed which is associated with a phase of the qubit in accordance with formula (13) for the coefficients of the quantum superposition. In intensive field in case of violation of conditions (20) both amplitude and phase quantum information of the qubit will be changed, herewith, to define phase quantum information of the qubit, it is necessary to use interference measurements. Full definition of the state vector is called quantum state tomography [2].

3. Selective excitation of the qubits by the field of continuous radiation. Two-qubit transformation

Consider the stationary solution of equations (3), (4), under the conditions

$$\dot{\mathbf{X}} = 0, \quad \dot{w}_j = 0 . \quad (21)$$

These conditions can be implemented by stationary excitation of one of the qubits, for example, qubit 2 by external continuous radiation. In this case of selective excitation of qubit 2 the local fields according to the equation (2) can be represented as follows:

$$\mathbf{E}_{01} = \mathbf{X}_2 \hat{a}_R N + \mathbf{X}_1 a_T N , \; \mathbf{E}_{02} = \mathbf{E}_{0I} + \mathbf{X}_1 \hat{a}_R N + \mathbf{X}_2 a_T N , \quad (22)$$

where $\mathbf{E}_{0I}$ is the amplitude of the external wave, $\hat{a}_R$ and a_T are external and internal geometric factors, which for spherical nanoparticles are calculated using the appropriate procedure for transitions from the volume integral to a surface by using the Green's theorem [14]. For spherical nanoparticles of small radius as such that $k_0 a << 1$, we have the following expression for the geometric factor a_T :

$$a_T = -\frac{4\pi}{3}(1 + ik_0 a) , \quad (23)$$

where $k_0 = (\omega / c) n_M$, c is the speed of light in vacuum, n_M is the refractive index of the sphere surrounding the silver nanoparticles in the qubit. Diagonal tensor $\hat{a}_R$ was calculated for observation points outside the spherical nanoparticles and after appropriate calculations it takes the following form:

$$a_R^y = \frac{4\pi A}{n k_0^3 (n^2 - 1)} \left(\frac{2}{R^3} - \frac{2ik_0}{R^2} \right) e^{ik_0 R} ,$$

$$a_R^{x,z} = -\frac{4\pi A}{n k_0^3 (n^2 - 1)} \left(\frac{1}{R^3} - \frac{ik_0}{R^2} - \frac{k_0^2}{R} \right) e^{ik_0 R} , \quad (24)$$

where

$$A = -n \cos(k_0 n a) \sin(k_0 a) + \cos(k_0 a) \sin(k_0 n a) . \quad (25)$$

Let us define the refractive index n by following [8], with the formula:

$$\frac{n^2-1}{n^2+2}=\frac{4\pi}{3}\frac{N_0\alpha_{eff}q+N_m\alpha_m}{1-\beta(N_0\alpha_{eff}q+N_m\alpha_m)}, \tag{26}$$

where q is the number of free electrons in the silver nanoparticles, N_m, α_m are the concentration and the polarizability of the molecules in the matrix of the composite, N_0 is the concentration of silver nanoparticles in the composite, α_{eff} is the effective polarizability of the free electrons in the silver nanoparticles, $\alpha_{eff}=\frac{\alpha}{1-a_T N\alpha}$, α is the quantum polarizability

$$\alpha=\frac{2d_0{}^2}{\hbar}\frac{1}{\omega_0-\omega-(i/T_2')}. \tag{27}$$

β is the structural factor that takes into account the discrete distribution of nanoparticles within an imaginary sphere surrounding the observation point. We will explain the meaning of the structural factors in the assessment of the final results.

We consider the interaction of two qubits at a great distance between the qubits such that $k_0R_{12}>>1$. In this case, in the external geometrical factor (24) is sufficient to take into account only the terms proportional to $1/R$, which corresponds, for example, the x – component of the tensor. In line with this we will consider only the x – component of the external and local fields in the equation (22). For a small radius of nanoparticles $k_0a<<1$ under the condition of exact resonance $\omega=\omega_0$ we have:

$$a_R^x=-\frac{2\pi(k_0a)^3(n^2+2)}{3(n^2-1)k_0R_{12}}e^{ik_0R_{12}},\ \alpha=\frac{2d_0{}^2}{\hbar}iT_2',\ k_0=\frac{\omega_0}{c}=\frac{2\pi}{\lambda_0}. \tag{28}$$

From equation (3) under the condition (7) we have the following equality

$$\mathbf{X}_1=-w_1\alpha\mathbf{E}_{01},\ \mathbf{X}_2=-w_2\alpha\mathbf{E}_{02}. \tag{29}$$

Therefore, solving the system of algebraic equations (8), we obtain the following expression for the local field at the center of nanoparticles in the qubits 1 and 2:

$$E_{01}^x=-E_{0I}^x\frac{w_2\alpha a_R^x N}{(1+w_1\alpha a_T N)(1+w_2\alpha a_T N)-w_1w_2(a_R^x N\alpha)^2}, \tag{30}$$

$$E_{02}^x=E_{0I}^x\frac{1+w_1\alpha a_T N}{(1+w_1\alpha a_T N)(1+w_2\alpha a_T N)-w_1w_2(a_R^x N\alpha)^2}. \tag{31}$$

Single-qubit operations describe the rotation of the vector $\boldsymbol{\rho}(u,v,w)$ of individual qubit, where the components of this vector is uniquely connected with the coefficients of the quantum superposition associated with (13). Two-qubit operations involve the interdependence of states of two qubits, a some kind of control of one qubit (controlled) by another (controlling). This interdependence requires physical interaction between the qubits, which can be turned on at the time of the operation, or can be constant. It is important, as discussed in this article, to be able to selectively excite the individual qubits by the external field.

With continuous irradiation of one of the qubits by resonant radiation the coefficients of quantum superposition of qubit can be expressed in terms of variables u, v and w of qubit (omit the index of qubit) according to the expressions:

$$\mathbf{X}\exp(-i\omega t) = 2\mathbf{d}_0 ab^* \exp(-i\omega_0 t) =$$

$$= \mathbf{d}_0(u - iv)\exp(-i\omega t) = -w\alpha\mathbf{E}_0 \exp(-i\omega t). \quad (32)$$

From these expressions using (11) - (13) we obtain that:

$$2\mathbf{d}_0 \frac{2(w + |b|^2)}{u + iv} |b|^2 = -w\alpha\mathbf{E}_0, \quad (33)$$

$$|a|^2 = w + |b|^2, \quad (34)$$

$$2\frac{(w + |b|^2)(|a|^2 - w)}{|a||b|} e^{i(\varphi_a - \varphi_b)} = u - iv. \quad (35)$$

Using equations (33) and (34) we will define $|b|$ and $|a|$, respectivetly, through the u, v and w, and using (35) we will define the phase difference of the states $|a\rangle$ and $|b\rangle$ of the qubit.

4. Entanglement and resonance energy transfer in the system of two qubits with selective excitation of one of the qubits by the field of continuous radiation

Consider the property of the solution (30), (31), in which the entanglement of the qubit state allows to achieve the transfer of quantum information between qubits over long distances between qubits. The entanglement of quantum states of qubits in this decision reflected in the fact that the local fields at the location of qubits 1 and 2 depends on inversion of both 1 and 2 qubits. This means that the selective excitation of qubit 2 is detected at the location of the qubit 1 due to induction at the location of the qubit 1 the local field, and hence the local induced dipole moment $X_{1x} = -w_1\alpha E_{01}^x$. The induction of a local field E_{01}^x is getting weaker with the distance between the qubits, if qubits 1 and 2 are represented as silver nanoparticles in vacuum. Let us consider the qubits 1 and 2 as fragments of a composite material with a quasi-zero refractive index.

Consider the property of the solution (30), (31), wherein the induction of local moments at the location of qubits 1 and 2 not decreases with increasing distance between qubits, and vice versa, even increases. For this it is necessary to consider conditions under which part of the denominator in (30), (31)

$$(1 + w_1\alpha a_T N)(1 + w_2\alpha a_T N) = 0. \quad (36)$$

vanishes. For this it is necessary that one of the factors in (36) becomes zero. If this ratio is $(1+w_1\alpha a_T N)$, it will lead to the fact that the induction of the local field at the location of qubit 2 will become impossible, ie E_{02}^x will be zero. Therefore, to satisfy the equation (36), we assume that

$$(1+w_2\alpha a_T N)=0\ . \tag{37}$$

from which we obtain the value of a inversion for qubit 2

$$w_2=\frac{1}{(4\pi/3)|\alpha|N}. \tag{38}$$

The second value of w_2, which correspond to the solution of the equation $\mathrm{Re}(1+w_2 a_T\alpha N)=0$ when $k_0 a<<1$ gives the value $w_2>>1$ that contradicts the physical significance of inversion.

Thus, the qubit 1, which is in the ground state $w_1=-1$ prior to the moment, when the excitation field, at the position of the qubit 2, will be turned on, can get quantum information which is defined by the inversion (38). When the equation (37) is true, a local induced dipole moment of the qubit 1 takes the following form:

$$X_{1x}=\alpha\frac{2E_{0I}^x R_{12} i}{a^3 k_0{}^2}. \tag{39}$$

Local induced dipole moment of the 2nd qubit wherein, in accordance with the solution (31) and the condition (37) is equal to:

$$X_{2x}=-\alpha\frac{4E_{0I}^x(1+w_1 a_T\alpha N)R_{12}{}^2}{w_1(a^3 k_0{}^2)^2}. \tag{40}$$

In the formulas (39), (40) takes into account only the terms of the external geometric factor (24), which are dominated for large distances between qubits. Formulas (39), (40) demonstrate the ability to transmit quantum information over long distances between the qubits, due to the effect of quantum teleportation. Inversion of qubit 2 is given by (38) and it is close to the value of 1, and inversion w_1 of first qubit can take different values from –1 to +1, including $w_1=0$.

As follows from (39), (40), the induced dipole moment of qubits 1 and 2 increases with increasing distance between qubits. However, there is a limit to the values E_{01}^x and E_{02}^x of local fields in the center of qubits, which follows from the equation (4) for the inversions w_1 and w_2. For stationary solutions of equations under conditions (21), from (4) we obtain the limit of values of the fields E_{01}^x and E_{02}^x:

$$\left|E_{01}^x\right|^2=\frac{(\hbar/T_2{}')(w_1+1)}{w_1|\alpha|},\ \left|E_{02}^x\right|^2=\frac{(\hbar/T_2{}')(w_2+1)}{w_2|\alpha|}. \tag{41}$$

Consider qubits, as fragments of composite material with a quasi-zero refractive index. In [8] a formula for the refractive index of the material, which has a form (26), was obtained. Following [8], we obtain the following expression for the structure factor in (26):

$$\beta = \frac{1}{N_0}\left(\frac{2\pi}{\lambda_0}\right)^2 n_M^2 \sum_a \frac{1}{r_a}. \quad (42)$$

Where r_a is the distance from the observation point at the center of an imaginary sphere to a silver nanoparticle with index a, n_M is the refractive index of the matrix of the composite. When the weight of silver content in the composite is equal to 3% [7], the radius of silver nanoparticles $a = 2.5$ nm and concentration of nanoparticles $N_0 = 0.4555 \cdot 10^{17}$ cm^{-3} is uniform, we obtain that at the imaginary sphere whose radius is significantly smaller than the wavelength $\lambda_0 = 300$ nm, there are 26 silver nanoparticle. Then the structure factor $\beta = 21.42$ if the refractive index of the matrix composite $n_M = 1.49$. Let us define value $|\alpha| N$ when the refractive index of the composite becomes to zero. As follows from formula (26), this will happen if the following equation is true:

$$1 + \frac{8\pi}{3}\frac{N_0\alpha_{eff}q + N_m\alpha_m}{1-\beta(N_0\alpha_{eff}q + N_m\alpha_m)} = 0. \quad (43)$$

Then we find that

$$N|\alpha| = \frac{1-\beta N_m\alpha_m + \frac{8\pi}{3}N_m\alpha_m}{-(1-\beta N_m\alpha_m + \frac{8\pi}{3}N_m\alpha_m)|a_T| + \beta N_0 V_0 - \frac{8\pi}{3}N_0 V_0} \quad (44)$$

where $V_0 = \frac{4\pi}{3}a^3$ is the volume of spherical silver nanoparticles. For $a = 2.5$ nm and $N_m\alpha_m = 0.077$, $N|\alpha| \approx -\frac{1}{(4\pi/3)}$ therefore inversion of 2nd qubit, according to formula (38) is about $w_2 \approx -1$, that is close to the equilibrium value.

Finally, let us calculate the maximum distance R_{12} between qubits, at which there is a resonance transfer of the energy from qubit 1 to qubit 2. For this we will use the maximum value of the local field E_{01}^x, in accordance with the formula (41). When $w_1 = 1$ and $1/T_2' = 10^{15}$ s^{-1} we obtain the value $\left|E_{01}^x\right| = 4.9 \cdot 10^5 SGSE$ and the maximum distance between qubits $R_{12} = 519$ cm if the external field, which selectively excite a qubit 2, is small or equal $\left|E_{0I}^x\right| = 10^{-6} SGSE$.

Conclusions

So, in this article was shown that the system of two qubits, which are fragments of a composite material with a quasi-zero refractive index, is an ideal energy transporter from one qubit to another over long distances. A new construction of a qubit with nanofibers that allows to implement selective excitation of qubits by external radiation, was represented. The resonance transfer of energy from one qubit to another with selective excitation of one of the qubits by external radiation results in a change of qubits inversion and induction of local electric dipole transitions of qubit 1(qubit-observer) and the qubit 2 (qubit- inductor). Qubit 2 is being irradiated by external radiation and it is induces a local field at the location of the qubit-observer 1, located at a great distance from the qubit-inductor 2. This means that there is a transfer of quantum information that is obtained by applying the coefficients of quantum superposition by (13).

Resonance energy transfer between the qubits is described using the resulting solutions (30), (31) and equation of motion (2), (3), (4). Due to the entanglement of quantum states of qubits and coherence in the system of qubit caused by the zero refractive index of qubits, the local field at the location of qubit-observer achieved an increase in $4.9 \cdot 10^{11}$ times, at the distance between the qubits $R_{12} = 519$ cm if inducing field at the location of the qubit-inductor is small. The law of conservation of energy in this case is represented as follows:

$$\left(E_{0I}^{x}\right)^{2} \frac{V_R}{4\pi} = \hbar\omega_0 w_1 - \frac{4}{3}\frac{\omega_0{}^4}{c^3}\frac{R_{12}^2 \Delta\Omega}{\left(Na^3 k_0{}^2\right)^2}\left(E_{0I}^{x}\right)^{2} \times 1s,$$

where V_R is the volume of the quantization of the electromagnetic field, $\Delta\Omega$ is the solid angle in the direction of dipole radiation of qubit 1. If dipole radiation of qubit 1 is emitted in the direction of nanofibers attached to qubit 1 (fig.1), then $\Delta\Omega = 0.2461 \cdot 10^{-10} sr$ and the electric field strength E_{0I}^{x} exciting the qubit 2, in accordance with the law of conservation of energy (45) is equal to small value $E_{0I}^{x} = 3.14 \cdot 10^{-6} SGSE$ if $V_R = 1\, cm^3$, $w_1 = 1$, $R_{12} = 519\, cm$.

Thus, the proposed construction of a qubits as fragments of composite nanostructured materials with quasi-zero refractive index allows to realize the resonance energy transfer over long distances by the selective excitation of one of the qubits using the continuous ultraviolet radiation. The proposed construction of qubits, in our opinion, can be applied to the implementation of quantum computing in a quantum computer, where the transmission of quantum information over long distances is not required. Herewith it is necessary to define logical operations NOT and CNOT under the influence of short radiation pulses, and this is what we will devote our next article.

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УДК 535.8

Gadomsky, O. N.

Selective excitation of qubits and transfer of quantum information from one qubit to another / O. N. Gadomsky, G. V. Yakimov, I. A. Shchukarev // Известия высших учебных заведений. Поволжский регион. Физико-математические науки. – 2015. – № 3 (35). – С. 112–124.