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Rabi Waves for Excitation of Quantum Nanoantenna with Electrically Controlled Radiation Pattern and Its Application

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ABSTRACT

Rabi waves for the excitation of quantum nanoantennas with electrically controlled radiation and frequency characteristics were studied. The operational frequency of the visible range was based on the high frequency component of the current. The low frequency component and its operational frequency was in the terahertz range. The feature of the Rabi wave antenna depends on the carrier frequency on the electromagnetic field intensity. The contribution of high order magnetic multipoles became essential. The radiation properties of an antenna were the same as the ideal magnetic dipole. The antenna frequency spectrum corresponded to the amplitude modulated Rabi oscillations. The high frequency current was in the optical range in the vicinity of the quantum transition frequency. The radiation field of the nano antenna was considered equivalent to the field of magnetic dipole placed in the centre of current ring and oriented orthogonal to the ring plane. The equivalence was consequence of the electrical smallness of the antenna over the working range of frequency. The results obtained were in good agreement with previous results.

KEYWORDS

Rabi Waves, Excitation, Quantum Nano Antenna, Operational Frequency, Terahertz Range, Multipoles, Quantum Transition Frequency.

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INTRODUCTION

Balanis [1] studied radiative properties of antennas were strongly depended on their configuration. To design nano antenna, the nanowires nano antennas of different natures were fabricated [2-4]. Their radiation patterns were similar to the radiation of an ideal electric dipole. The nano structures with toroidal geometry have been presented by different investigators [5-7]. Rabi [8] studied that oscillations are oscillating transitions of two level quantum systems between its stationary states under the effect of an oscillating driving field. Rabi oscillations were predicted as the periodic change of nuclear spin orientation in the radio frequency magnetic field. Allen and Eberly [9] presented that the effect was found not only in spin systems but in another types of oscillators, such as electromagnetically driven atoms. The effect of oscillating transitions take place only in the strong coupling regime of a quantum oscillator with external field, which cannot be considered as a small perturbation. Scully and Zubairy [10] studied temporal dynamics of the inversion reduces to harmonic oscillations with the Rabi frequency. Svidzinsky et al [11-12] showed that spatially delocalized systems such as quantum wires, atoms chains collective effect was found. Some of them such as the correlated spontaneous emission of a single photon quantum interference in cooperative Dick emission [13], the collective Lamb sift in single-photon super radiance [14], finite time disentanglement via spontaneous emission [15], directed spontaneous emission [16] occurred even in weak coupling regime. The quasi particles are characterized by non zero quasi momentum and energy dependence on that quasi momentum. The Hopfield polariton in the strong coupling regime [17-20] can serve as an example. Indirect transitions corresponding to both energy and quasi momentum exchanges between light and charge carrier are possible in the system [21-22]. The Rabi waves take place both for classical and quantum light.

METHOD

We have considered nano antennas based on Rabi waves. This utilization of Rabi waves in nanoantennas is possible both in optical and low frequency ranges. The mechanism based on the Mallow triplet and leading to the excitation of polarization current be prospective in the optical range. The use of tunneling current leaded to the low frequency nano antenna. The tunneling ac current spectrum covers the vicinity of the Rabi frequency and for realistic quantum dots and host materials this vicinity corresponded to the terahertz. We have considered a toroidal chain of quantum dots exposed to a whispering gallery mode of the cylindrical microcavity. The electromagnetic field satisfied the periodic boundary conditions, which leaded to the discrete spectrum of the wave number $K\left(K=\dfrac{q}{R_0}\right)$

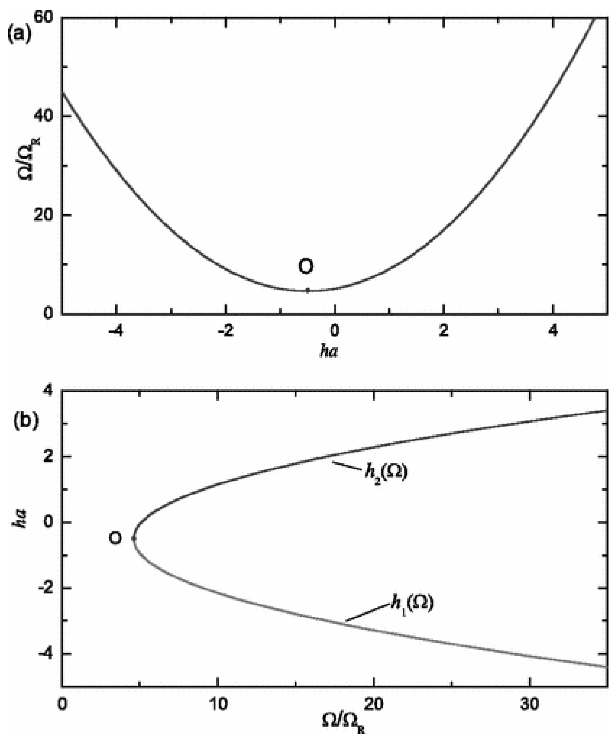
where q is an integer, R_0 is the toroid radius and the Rabi frequency is in dependent of the quantum dot coordinate x. A ring shaped quantum dot chain placed coaxially nearby a ring shaped metallic wire and increasing with the plasmon of the wire. It was assumed that the radius of the toroid R_0 was larger than the chain period and was less than the wave length $R_0 > a$, $kR_0 < 1$. The toroid chain was considered as locally flat. The current in the antenna was uniformly distributed around the ring with radius R_0. For calculation of operator $\hat{f}_h$ we have used the following relation.

$$\hat{f}_h = \frac{R_0}{2\pi}\int_0^{2\pi} \hat{\rho}\left(R_0\cos\theta, 0\right) e^{ihR_0\cos\theta} \times \sin\theta . d\theta .$$

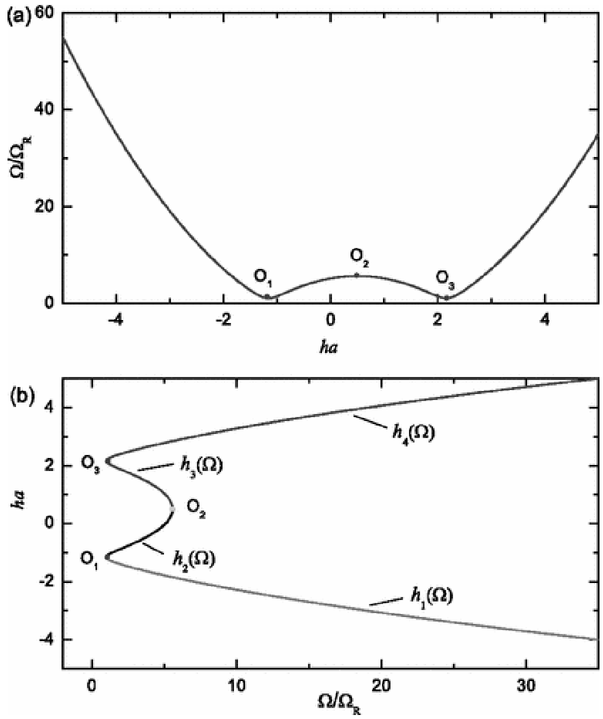
We have used Fourier integral to obtain results. We have also demonstrated the qualitative character of dispersion curve.

RESULTS AND DISCUSSION

Graph (1) (a) and (2) (a) show the character of dispersion curves. It indicates that two different regimes are possible. The first is shown in graph (1) (a) and its corresponds to the case $\Delta > -\left(h_0 a\right)^2\left(\xi_2-\xi_1\right)$, $h_0 = -k\dfrac{\left(\xi_2+\xi_1\right)}{2\left(\xi_2-\xi_1\right)}$ is the root of the equation $\dfrac{d\Delta 4}{dh}=0$. The second case is of graph (2)(a) corresponds to the inequality $\Delta < -\left(h_0 a\right)^2\left(\xi_2-\xi_1\right)$. For the frequency domain we have inverted the dependence of $\Omega=\Omega(h)$ i.e., to transform it into $h=h(\Omega)$. Dependence of $h(\Omega)$ is not single valued because $\Omega(h)$ has local branching points. It shows that the transition from the integration with respect to h to integration will respect to Ω should be performed separately for each branch of $h(\Omega)$. In the first case we have one local turning point o and as a result, two branches $h_1, 2(\Omega)$ as shown in graph (2)(b). We have obtained a model of the nano antenna excited by a spatially homogeneous nonharmonic ring current. The radiation patterns of the antenna have been calculated from the current Fourier transformation with respect to Ω using standard methods of the antenna theory. The radiation field of the nanoantennas has been considered equivalent to the field of a magnetic dipole placed in the centre of te current ring and oriented orthogonal to the ring plane. The frequency spectrum of he antenna is bounded from the bottom by the finite value of the frequency $\Omega = \Omega_{cr}$ for the first case and $\Omega = \Omega_R$ for the second case. Radiated signal has the form of the amplitude modulated oscillation with the carrier frequency Ω_{cr} and the amplitude modulation $u(x)$. The feature of the Rabi wave antenna is the dependence of the carrier frequency on the electromagnetic field intensity. The contribution of high order magnetic multipoles becomes essential and the radiation pattern becomes more complicated. The Bessel function was used for the study. This peculiarity opens some useful opportunities for the electrical control of the radiation pattern of the Rabi wave nano antenna. The positive definiteness condition requires the initial state to be an arbitrary super position of the rabitons i.e, state with $j = 2,4$. In this case at least one rabiton and amplitudes of the states should be small enough. This type of initial condition is of the presence of state leaded to the qualitatively new effects. One of them is the low frequency tunnel current has been considered below as the basis for new types of nanoantennas. The obtained results were compared with previously obtained results of theoretical and experimental works and were found in good agreement.



Graph 1: Dispersion characteristics of Rabie wave.



Graph 2: Dispersion characteristics of a Rabi Wave.

CONCLUSION

We have studied the excitation of quantum nano antennas with electrically controlled radiation pattern and characteristics of frequency. We have found that high frequency current was in the optical range of quantum transition frequency. The physical nature was analogous to the Mollow triplet. It was different from the standard Mollow triplet in the present case and the spectrum in continuous due to the mixing. Rabi waves be applied qualitatively to system with inter quantum dot coupling of another physical nature. The excitation and dissipation of Rabi waves was the consequence of the quantum dot chain interaction with another quantum system where mites quantum states corresponding to different subsystems. The application of Rabi waves to the electrically controlled quantum nanoantennas of terahertz range is possible. The obtained results are in good agreement with comparison to previous results.

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