Preparation and control of atomic optimal entropy squeezing states for a moving two-level atom under control of the two-mode squeezing vacuum fields*

Zhou Bing-Ju(周并举), Liu Yi-Man(刘一曼), Zhao Ming-Zhuo(赵明卓), and Liu Xiao-Juan(刘小娟)†

Department of Physics, Hunan University of Science and Technology, Xiangtan 411201, *China*

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From the viewpoint of quantum information, this paper studies preparation and control of atomic optimal entropy squeezing states (AOESS) for a moving two-level atom under control of the two-mode squeezing vacuum fields. Necessary conditions of preparation of the AOESS are analysed, and numerical verification of the AOESS is finished. It shows that the AOESS can be prepared by controlling the time of the atom interaction with the field, cutting the entanglement between the atom and field, and adjusting squeezing factor of the field. An atomic optimal entropy squeezing sudden generation in different components can alternately be realized by controlling the field-mode structure parameter.

Keywords: atomic optimal entropy squeezing state, squeezing factor of the field, the field-mode structure parameter

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1. Introduction

The squeezing of quantum fluctuations is one of the most fundamental manifestations of the Heisenberg uncertainty relation (HUR) which is among the most important principles in quantum mechanics. Over the past decades, much attention has been paid on atomic squeezing.[1,2] On one hand, atomic squeezing has potential applications to the field of quantum optics,[3,4] on the other hand, it has been shown that squeezed atoms can radiate a squeezed light field,[5] which can effectively inhibit quantum noise (QN), cause distortion of the encoded quantum state and lead to decoherence in quantum information processing (QIP) and quantum computer (QC), then become a main obstacle of experimental realization of the QIP and QC.[6] Because an atomic optimal squeezing state corresponds to a quantum state with minimum noise, its preparation and control are very important tasks in this research field.[7−9]

Many previous studies of atomic squeezing are based on the HUR formulated according to the variance of the system observable.[10,11] But, the HUR cannot give us sufficient information on atomic squeezing in such cases as shown in Refs. [12] and [13]. Fang *et al.*[12] have defined the entropy squeezing for a two-level atom by using the quantum information theory, according to entropic uncertainty relation (EUR) for position and momentum, thus the limitation of the HUR can be overcome.

More recently, many investigations on atomic entropy squeezing have been reported,[3,14−16] the atomic optimal entropy squeezing sudden generation (AOESSG) and its control are studied[7] in different Jaynes–Cumming model. However, less attention has been focused on to prepare and control the atomic optical entropy squeezing states (AOESS) for a moving two-level atom entangling with the two-mode squeezing vacuum fields, which are studied by using quantum information entropy theory. We analyse the necessary conditions of preparing the AOESS, discuss the influences of squeezing factor of the field and atomic coherence on the AOESS, and obtain the system parameter of AOESSG. Utilizing AOESSG we can maximize inhibited QN instantly, our results may be important for experimental realization of effective control of QN in QIP and QC.

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†Corresponding author. E-mail: lxjdx@163.net

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2. The model and its solution

The present cavity quantum electrodynamics experiments are provided with an atomic beam passing along the axis of the rectangular or cylindrical cavity so that one can investigate the interaction of an atom in motion with different field modes. The system considered here consists of a two-level atom in motion interacting with a quantized field via the two quantum transition processes. The effective Hamiltonian in the rotating-wave approximation[17] is

$$H = \omega_0 S_z + \sum_{j=1}^{2} \omega_j a_j^\dagger a_j + g f_1(z) f_2(z)(a_1^\dagger a_2^\dagger S_- + a_1 a_2 S_+), \tag{1}$$

where i $(i = z, +, -)$ are the usual pseudo-spin operators of the two-level atom, $a_j^\dagger$ (a_j) is the photon creation (annihilation) operator of the field mode of frequency w_j $(j \equiv 1, 2)$ and g is the coupling constant between the atom and the two-mode coherent fields, $f_i(z)$ $(i = 1, 2)$ denotes the mode structure of the i-th-mode coherent fields. We restrict our studies of the atomic motion along z axis so that the z-dependence of the field-mode function should be taken into account. The atomic motion can be incorporated in a usual way[18]

$$f_i(z) \to f_i(vt), \tag{2}$$

where v denotes the atomic motion velocity. For easiness of discussion, a $\mathrm{TEM_{mnp}}$ mode is defined by

$$f_i(vt) = \sin\Big(\frac{p_i \pi v t}{L}\Big), \tag{3}$$

where p_i represents the number of half-wave length of the i-th filed mode inside a cavity of the length L.

For simplicity, we consider the two-photon resonance case, that is $\omega_0 = \omega_1 + \omega_2$. Let $p_1 = p_2 = p$, thus the atom enters cavity and leaves the cavity after passing p half-wavelengths of electric field and atomic speed $v = gL/\pi$. Using standard techniques,[14] in the interaction picture and two-dimensional atomic space we can write the time evolution Dyson operator as

$$U_{\mathrm{I}}(t) = \begin{bmatrix} \hat{u}_{11} & -\mathrm{i}\hat{u}_{12} \\ -\mathrm{i}\hat{u}_{21} & \hat{u}_{22} \end{bmatrix}, \tag{4}$$

where

$$\begin{cases} \hat{u}_{11} = \cos(\hat{A} g\theta(t)), & \hat{u}_{12} = a_1 a_2 \dfrac{\sin(\hat{B} g\theta(t))}{\hat{B}}, \\ \hat{u}_{22} = \cos(\hat{B} g\theta(t)), & \hat{u}_{21} = a_1^\dagger a_2^\dagger \dfrac{\sin(\hat{A} g\theta(t))}{\hat{A}}, \\ \hat{A} = \sqrt{(a_1 a_2 a_1^\dagger a_2^\dagger)}, & \hat{B} = \sqrt{(a_1^\dagger a_2^\dagger a_1 a_2)}, \\ \theta(t) = \displaystyle\int_0^t [\, f(vt'\mathrm{d}t')] = \int_0^t \Big[\sin\Big(\frac{p\pi v t'}{L}\Big)\Big]^2 \mathrm{d}t' \\ \quad = \dfrac{1}{2}\Big[t - \dfrac{1}{2pg}\sin(2pgt)\Big]. \end{cases} \tag{5}$$

We consider that at the time $t = 0$ the atom is in a coherent superposition state of the excited state $|e\rangle$ and the ground state $|g\rangle$, i.e.

$$|\psi_A(0)\rangle = \cos(\xi/2)|e\rangle + \exp(\mathrm{i}\varphi)\sin(\xi/2)|g\rangle, \tag{6}$$

the field is in the two-mode squeezing vacuum state

$$|\psi_F(0)\rangle = \frac{1}{\cosh(r)} \sum_0^\infty (\tanh^n(r)|n, n\rangle, \tag{7}$$

where $0 < \xi < \pi$ denotes the atomic distribution, $0 < \varphi < 2\pi$ is the phase of the atom dipole, r denotes squeezing factor of the field.

The initial state of the system can be expressed as

$$|\psi_{\mathrm{af}}(0)\rangle = |\psi_{\mathrm{a}}(0)\rangle \otimes |\psi_{\mathrm{f}}(0)\rangle. \tag{8}$$

At any time $t > 0$ the state vector of the system is given by

$$|\psi_{\mathrm{af}}(t)\rangle = U_{\mathrm{I}}(t)|\psi_{\mathrm{af}}(0)\rangle = |D\rangle|e\rangle + |T\rangle|g\rangle \tag{9}$$

with

$$|D\rangle = \sum_{n=0}^{\infty} \{(\cos(\xi/2)\ F_n \cos((n+1)g\theta(t)) - \mathrm{i}\sin(\xi/2)\exp(\mathrm{i}\phi)\ F_{(n+1)}\sin((n+1)g\theta(t))\}|n, n\rangle, \tag{10}$$

$$|T\rangle = \sum_{n=0}^{\infty} \{-\mathrm{i}\cos(\xi/2) F_{(n-1)}\sin(ng\theta(t)) + \sin(\xi/2)\exp(-\mathrm{i}\iota\phi) F_n \cos(ng\theta(t)\}|n, n\rangle, \tag{11}$$

where

$$F_n = \frac{1}{\cosh(r)} \sum_0^\infty (\tanh^n(r)). \tag{12}$$

Also, the density operator for the system has the form of

$$\rho_{\rm af}(t) = |\psi_{\rm af}(t)\rangle\langle\psi_{\rm af}(t)| = \begin{bmatrix} |D\rangle\langle D| & |D\rangle\langle T| \\ |T\rangle\langle D| & |T\rangle\langle T| \end{bmatrix}, \tag{13}$$

while the reduced density operator of the two-mode squeezing vacuum field is given by

$$\rho_{\rm f}(t) = {\rm Tr}_{\rm a}(\rho_{\rm af}(t)) = |D\rangle\langle D| + |T\rangle\langle T|. \tag{14}$$

The reduced density operator of the atom can be expressed as

$$\rho_{\rm a}(t) = \begin{bmatrix} \langle D|D\rangle & \langle T|D\rangle \\ \langle D|T\rangle & \langle T|T\rangle \end{bmatrix} = \begin{bmatrix} \rho_{\rm a22} & \rho_{\rm a21} \\ \rho_{\rm a12} & \rho_{\rm a11} \end{bmatrix}. \tag{15}$$

Then the eigenvalues of $\rho_{\rm a}(t)$ can be obtained as

$$\lambda_{\rm a}^{\pm} = \frac{1}{2}(1 \pm \sqrt{(\rho_{\rm a22} - \rho_{\rm a11})^2 + 4|\rho_{\rm a21}|^2}). \tag{16}$$

It turns out that the eigenvalues of $\rho_{\rm f}(t)$ equal those of $\rho_{\rm a}(t)$. That is $\lambda_{\rm f}^{\pm} = \lambda_{\rm a}^{\pm} = \lambda^{\pm}$. The eigenstates of $\rho_{\rm a}(t)$ and $\rho_{\rm f}(t)$ are[15]

$$|\psi_{\rm a}^{\pm}\rangle = \frac{1}{\sqrt{2\lambda^{\pm}\cosh(\delta)}}(\exp(1/2({\rm i}\alpha \mp \delta))|e\rangle \pm |\exp(1/2(-{\rm i}\alpha \pm \delta)))|g\rangle, \tag{17}$$

$$|\psi_{\rm f}^{\pm}(t)\rangle = \frac{1}{\sqrt{2\lambda^{\pm}\cosh\delta}}(\exp[1/2({\rm i}\alpha \pm \delta)]|D\rangle \pm \exp[-1/2({\rm i}\alpha \pm \delta)]|T\rangle), \tag{18}$$

where

$$\delta = \sinh^{-1}\left[\frac{1}{2|\rho_{\rm a21}|}(\rho_{\rm a22} - \rho_{\rm a11})\right], \tag{19}$$

$$\alpha = \tanh^{-1}\left[\frac{{\rm Im}\rho_{\rm a12}}{{\rm Re}\rho_{\rm a12}}\right]. \tag{20}$$

Hence the atomic reduced entropy $S(\rho_{\rm a})$ can be written, in terms of the eigenvalue $\lambda^{\pm}$ of $\rho_{\rm a}(t)$ given by Eq. (16)[16−18]

$$S(\rho_{\rm a}) = -\lambda^{+}\log_2\lambda^{+} - \lambda^{-}\log_2\lambda^{-}. \tag{21}$$

If $S(\rho_{\rm a})$ takes its minimum value to be zero, the two-mode coherent fields and the atom are disentangled; if $S(\rho_{\rm a})$ takes its maximum value to be 1, the two-mode squeezing vacuum fields and the atom are in maximal entangled state.

3. The definition of AOESS and AOESSG

First, using the atomic reduced density operator $\rho_{\rm a}(t)$ given by Eq. (15), we find[10]

$$\begin{cases} H(S_x) = -\Big[\frac{1}{2} + {\rm Re}(\rho_{\rm a21}(t))\Big]\ln\Big[\frac{1}{2} + {\rm Re}(\rho_{\rm a21}(t))\Big] - \Big[\frac{1}{2} - {\rm Re}(\rho_{\rm a21}(t))\Big]\ln\Big[\frac{1}{2} - {\rm Re}(\rho_{\rm a21}(t))\Big], \\ H(S_y) = -\Big[\frac{1}{2} + {\rm Im}(\rho_{\rm a21}(t))\Big]\ln\Big[\frac{1}{2} + {\rm Im}(\rho_{\rm a21}(t))\Big] - \Big[\frac{1}{2} - {\rm Im}(\rho_{\rm a21}(t))\Big]\ln\Big[\frac{1}{2} - {\rm Im}(\rho_{\rm a21}(t))\Big], \\ H(S_z) = -\rho_{\rm a22}(t)\ln\rho_{\rm a22}(t) - \rho_{\rm a11}\ln\rho_{\rm a11}(t), \end{cases} \tag{22}$$

in which $H(S_\alpha)$ $(\alpha = x, y, z)$ are the information entropy of the Pauli operators S_α $(\alpha = x, y, z)$ for a two-level atom system, $\rho_{{\rm a}ij}(t)$ is given by Eq. (15).

The fluctuation of the atomic dipole component $S(\alpha)$ $(\alpha \equiv x$ or $y)$ is concluded to be atomic entropy squeezing if $H(S_\alpha)$ satisfies the following condition:[12,13]

$$E(S_\alpha) = \delta H(S_\alpha) - \frac{2}{\sqrt{|\delta H(S_z)|}} < 0, \quad (\alpha \equiv x \text{ or } y), \tag{23}$$

where $\delta H(S_\alpha) = \exp[H(S_\alpha)]$, $E(S_\alpha)$ is called the entropy squeezing factor.

The ranges of $H(S_\alpha)$ and $\delta H(S_\alpha)$ are

$$H(S_\alpha) \in 0 \sim \ln 2, \quad \delta H(S_\alpha) \in 1 \sim 2, \tag{24}$$

so the minimum value of entropy squeezing factor is

$$E_{\rm O}(S_\alpha) = -0.414, \tag{25}$$

here we put some definitions:

(i) $E_{\rm O}(S_\alpha)$ is defined as atomic optimal entropy squeezing of component S_α.[12]

(ii) If $E_{\rm O}(S_\alpha)$ at time t occurs in atomic state $|\psi_a(t)\rangle$, we name $|\psi_a(t)\rangle$ the AOESS.

(iii) If $E(S_\alpha)$ evolves as a rectangular wave and falls suddenly from the maximum to the $E_{\rm O}(S_\alpha)$ in the linear finite time, we call that it is defined as AOESSG in component S_α.[7]

Reference [12] has proven that the eigenstates of S_x and S_y can be expressed as

$$|\psi_{{\rm a}x}\rangle = \frac{1}{\sqrt{2}}(|e\rangle + |g\rangle), \tag{26}$$

and

$$|\psi_{{\rm a}y}\rangle = \frac{1}{\sqrt{2}}(|e\rangle + {\rm i}|g\rangle), \tag{27}$$

where $|\psi_{{\rm a}\alpha}\rangle$ $(\alpha \equiv x, y)$ are the AOESS of components S_x and S_y, respectively.

Based on the HUR, the fluctuation in the component S_α of the atomic dipole is derived to be squeezed if $S(\alpha)$ satisfies the condition

$$V(S_\alpha) = \Delta S_\alpha - \sqrt{|\langle S_Z\rangle|/2} < 0, \quad (\alpha \equiv x, y), \tag{28}$$

where $\Delta S_\alpha = [\langle S_\alpha^2\rangle - \langle S_\alpha\rangle^2]^{1/2}$.

Substituting Eqs. (26) and (27) into the atomic inversion formula as

$$|\langle S_Z\rangle| = \langle\psi_{{\rm a}\alpha}|S_z|\psi_{{\rm a}\alpha}\rangle = 0 \quad (\alpha = x, y), \tag{29}$$

we find that whose atomic variance squeezing cannot be shown in the $|\psi_{{\rm a}\alpha}\rangle$.

4. Preparation and numerical validation of the AOESS

4.1. Preparation of the AOESS

By means of Schmidt theorem,[19] the system state vector can be rewritten as

$$|\Psi_{\rm af}(t)\rangle = \sqrt{\lambda^+}|\psi_{\rm f}^+\rangle|\phi_{\rm a}^+\rangle + \sqrt{\lambda^-}|\psi_{\rm f}^-\rangle|\phi_{\rm a}^-\rangle, \tag{30}$$

where $|\psi_{\rm a}^\pm\rangle$ and $|\psi_{\rm f}^\pm\rangle$ are eigenstates of $\rho_{\rm a}(t)$ and $\rho_{\rm f}(t)$, respectively. They have the same eigenvalues $\lambda^\pm$.

In addition to special circumstances, equation (30) is always an entanglement state, but the atom evolves from initial pure states to a mixed state:

$$\begin{aligned}\rho_{\rm a}(t) =& \rho_{\rm a22}(t)|e\rangle\langle e| + \rho_{\rm a21}(t)|e\rangle\langle g| + \rho_{\rm a12}(t)|g\rangle\langle e| \\ &+ \rho_{\rm a11}(t)|g\rangle\langle g|,\end{aligned} \tag{31}$$

where $\rho_{\rm a22}(t)$, $\rho_{\rm a21}(t)$ and $\rho_{\rm a11}(t)$ are given by Eqs. (10) and (11).

Consequently, cutting off entanglement between the atom and the field, and letting atom evolve from the mixed state into a pure state are necessary conditions for preparation of the AOESS.

To meet the condition, first it is required to control interaction time between atoms and field as $gt_m = m\pi$ $(m = 0, 1, 2, 3, \ldots)$, for any value of p and r, substituting them into Eq. (16), we find that the eigenvalues of $\rho_a(t)$ equal

$$\lambda^+ = 1, \quad \lambda^- = 0. \tag{32}$$

Accordingly, from Eq. (21) we can see

$$S(\rho_{\rm a}) = -\lambda^+\log_2\lambda^+ - \lambda^-\log_2\lambda^- = 0. \tag{33}$$

This shows that entanglement between the atom and the field has been cut off, they are always in a separable pure state in these moments. Further, two cases are discussed below.

Case 1 Choose $p = 0.5$ and $\xi = 0$, the atom initially in an excited state. The atom evolves into the following pure state after a time interval,

$$\begin{aligned}|\psi_{\rm a}(t_O)\rangle =& \frac{1}{\sqrt{1+\tanh^2(r)}}[|e\rangle + {\rm i}\tanh(r)|g\rangle] \\ & (t_{\rm O} = (2n+1)\pi/g, n = 1, 2, 3, \ldots),\end{aligned} \tag{34}$$

$$|\psi_{\rm a}(t_{\rm E})\rangle = |e\rangle \quad (t_{\rm E} = 2n\pi/g,\ n = 0, 1, 2, \ldots). \tag{35}$$

Clearly, equation (34) may be prepared to the eigenstate of S_y by adjusting squeezing parameter r of the field.

If $r = 0$, then $\tanh(0) = 0$, equation (34) becomes

$$|\psi_{\rm a}(t_{\rm O})\rangle = |e\rangle, \tag{36}$$

which means that atom is in a pure state, but not in AOESS.

If $r = 0.5$, then $\tanh(0.5) \simeq 1/2$,

$$|\psi_{\rm a}(t_{\rm O})\rangle = \frac{1}{\sqrt{1+(1/2)^2}}[|e\rangle + {\rm i}/2|g\rangle]. \tag{37}$$

Although the atom is in coherent superposition state, it is not in AOESS, again.

If $r = 2$, then $\tanh(2) \simeq 1$, equation (34) becomes

$$|\psi_{\rm a}(t_{\rm O})\rangle = \frac{1}{\sqrt{2}}[|e\rangle + {\rm i}|g\rangle]. \tag{38}$$

Thus, when the atom is initially in an excited state $\xi = 0$, we adjust $r = 2$, the AOESS of component of S_y can be prepared at time $t_{\rm O}$ and cannot at $t_{\rm E}$. But component of S_x is never squeezing for any r. A necessary condition of preparation of the AOESS is cutting the entanglement between the atom and field and adjusting squeezing factor $r = 2$ of the field.

Case 2 Suppose $p = 0.5$ and $\xi = \pi/2$, adjust $r = 2$, atom is always in the following pure states by Eq. (17), respectively:

$$|\psi_{\rm a}(t_{\rm O})\rangle = \frac{1}{\sqrt{2}}(|e\rangle + {\rm i}|g\rangle) \quad (t_{\rm O} = (2n+1)\pi/g, n = 1, 2, 3, \ldots), \tag{39}$$

and

$$|\psi_{\rm a}(t_{\rm E})\rangle = \frac{1}{\sqrt{2}}(|e\rangle + |g\rangle) \quad (t_{\rm E} = 2n\pi/g, n = 1, 2, 3, \ldots). \tag{40}$$

So, we have prepared AOESS of S_y and S_x, respectively. In other words, the number of components of the AOESS can be controlled by choosing atomic coherence.

4.2. Numerical validation of the AOESS

In this part, we verify case $\xi = 0$, $p = 0.5$. First figure 1 illustrates the time evolution of atomic reduced entropy $S_{\rm a}$ and entropy squeezing factor $E(S_y)$, at different r. Dashed line, dotted line and solid line indicate $r = 0$, $r = 0.5$ and $r = 2$, respectively.

See Fig. 1(a), at the time $t = m\pi/g$ $(m = 0, 1, 2, \ldots)$, $S_a = 0$, entanglement completely between the atom and the field, which lead the atom to achieve its pure state at these time intervals for any value of r, figure 1(b) shows, when $gt_{\rm E} = 2n\pi$, there is no entropy squeezing of S_y for any value of r, but when $t_{\rm O} = (2n+1)\pi/g$, and r is from zero to 0.5, and 2, $E(S_y)$ is from zero to -0.1439 and -0.414, S_y occurs for the AOESS. Also at any time, there is no entropy squeezing of S_x for any r, see Fig. 1(c).

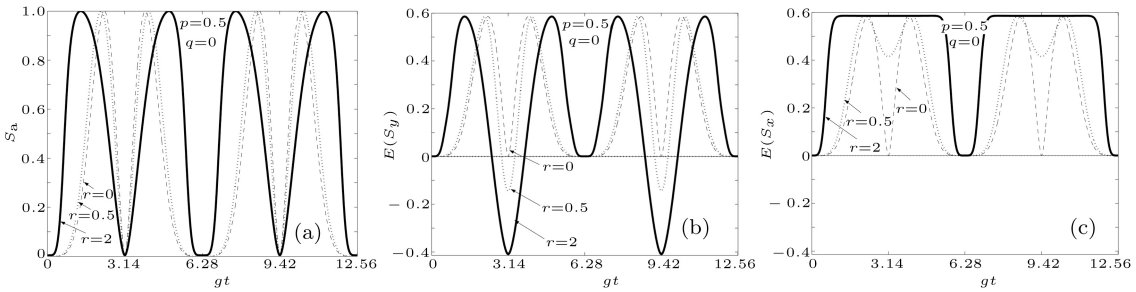


Fig. 1. The time evolution of (a) $S_{\rm a}(t)$, (b) $E(S_y)$ and (c) $E(S_x)$. The atom is initially in an excited state with $\xi = 0$, $p = 0.5$; dashed line with $r = 0$; dotted line with $r = 0.5$ and solid line with $r = 2$.

Further, we verify the second case. In Fig. 2, let $\xi = \pi/2$ and $r = 2$, other parameters are the same as those in Fig. 1.

Figure 2(a) shows that the time evolution period of $S_{\rm a}(t)$ is the same as that in Fig. 1(a), but degree of entanglement between the atom and the field is reduced due to atomic coherence.

In Fig. 2(b) when $t_{\rm E} = 2n\pi/g$ $(n = 1, 2, 3, \ldots)$, $E(S_x)$ takes its minimum -0.414. But at $t_{\rm O} = (2n+1)\pi/g$ $(n = 0, 1, 2, \ldots)$, $E(S_y)$ reached its minimum -0.414, see Fig. 2(c). So, Case 2 has been verified. Then we can prepare the AOESS of S_x and S_y in times $t_{\rm E}$ and $t_{\rm O}$, respectively.

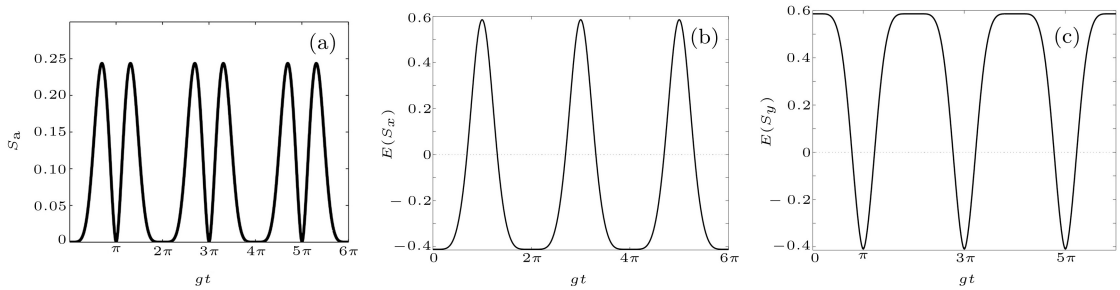


Fig. 2. The time evolution of (a) $S_{\rm a}(t)$, (b) $E(S_x)$ and (c) $E(S_y)$. The atom is initially in an excited state with $\xi = \pi/2$, $p = 0.5$; the field with $r = 2$.

4.3. Realization of the AOESSG

The AOESSG can maximize the inhibition of QN instantly.[7] Thus, the realization of AOESSG is a significant work. Now, we discuss the contents.

Figures 3(a) and 3(b) present the time evolution of $E(S_x)$ and $E(S_y)$ for the atom initially in the coherent superposition state with $\xi = \pi/2$, and the field-mode structure parameter $p = 0.5$, $p = 1$, $p = 2$, respectively. The fields are in the two-mode squeezing vacuum state with squeezing factor $r = 2$.

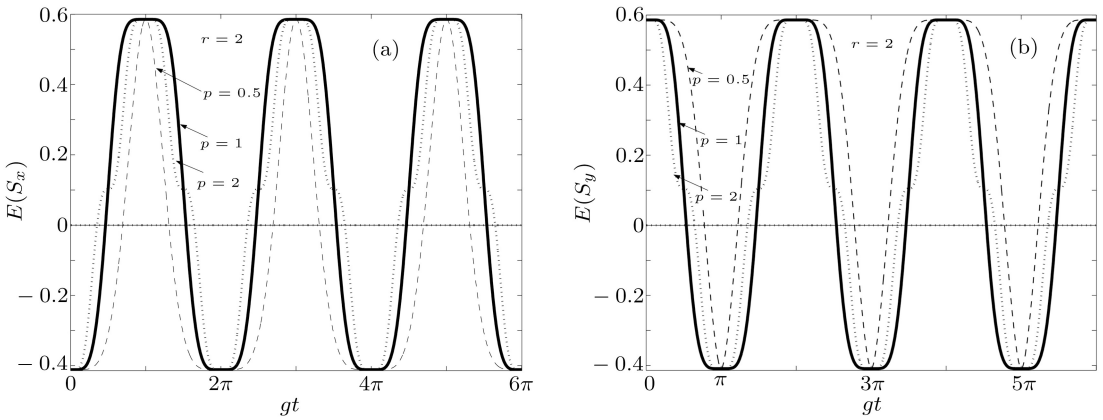


Fig. 3. The time evolution of (a) $E(S_x)$ and (b) $E(S_y)$. The atom is initially in an excited state with $\xi = \pi/2$, the fields with $r = 2$; dashed line with $p = 0.5$; solid line with $p = 1$; dotted line with $p = 2$.

From these figures we can conclude: when $p = 1$, $E(S_x)$ and $E(S_y)$ evolve periodically as an approximate wave. In other words, $E(S_x)$ and $E(S_y)$ change rapidly from maximum value to minimum value -0.414, alternately around the time $t_{\rm E} = 2n\pi/g$ (Fig. 3(a)) and $t_{\rm O} = (2n + 1)\pi/g$ (Fig 3(b)), respectively. That is to say, not only are there AOESSG but also it can be kept in a certain time interval. So we can realize the AOESSG of S_x and S_y alternatively. This conclusion is very important to suppress QN of the QIP and the CP for an instant, but in the case $p = 0.5$ and 2, the AOESSG does not appear .

5. Conclusion

From the viewpoint of quantum information, we studied preparation of the AOESS for a moving two-level atom under control of the two-mode squeezing vacuum fields. Necessary conditions of preparation of the AOESS are analysed, and numerical verification of the AOESS is provided. We can conclude that, first, choose time $t = m\pi$ $(m = 0, 1, 2, \ldots)$, entanglement between the atom and field can be cut, atom evolves from a mixed state to pure states. Secondly, when the atom is initially in an excited state with $\xi = 0$, by choosing time $t_{\rm O} = (2n+1)\pi/g$, and adjusting squeezing factor $r = 2$ of the field, we can prepare the AOESS

component of S_y. Thirdly, let the atom be initially in the coherent superposition state with $\theta = \pi/2$, adjusting $r = 2$, at time $t_{\rm O} = (2n+1)\pi/g$ and $t_{\rm E} = 2n\pi/g$, we can prepare and control the AOESS of S_x and S_y separately. Finally, AOESSG of S_x and S_y can be realized alternately by controlling the atom initially in the coherent superposition state and field-mode structure parameter $p = 1$. Our results may be important for experimental realization of effective control of QN in QIP and QC. By the way, since a three-level atom in the λ, Ξ and $\wedge$-type configuration respectively with arbitrary detuning can be exactly reduced to a two-level system,[20−22] whose effective Hamiltonian is given by Eq. (1), then our results can also be suitable for the entropy squeezing question of a three-level system.

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