Optomechanical detection of weak microwave signals with the assistance of a plasmonic wave

A. Asghari Nejad,* H. R. Askari, and H. R. Baghshahi
Department of Physics, Faculty of Science, Vali-e-Asr University of Rafsanjan, Rafsanjan 7718897111, Iran

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Entanglement between optical fields and microwave signals can be used as a quantum optical sensing technique to detect received microwave signals from a low-reflecting object which is encompassed by a bright thermal environment. Here, we introduce and analyze an optomechanical system for detecting weak reflected microwave signals from an object of low reflectivity. In our system, coupling and consequently entanglement between microwave and optical photons are achieved by means of a plasmonic wave. The main problem that can be moderated in the field of quantum optical sensing of weak microwave signals is suppressing the destructive effect of high temperatures on the entanglement between microwave signals and optical photons. For this purpose, we will show that our system can perform at high temperatures as well as low ones. It will be shown that the presence of the plasmonic wave can reduce the destructive effect of the thermal noises on the entanglement between microwave and optical photons. Also, we will show that the optomechanical interaction is vital to create an appropriate entanglement between microwave and optical photons.

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I. INTRODUCTION

In recent years considerable efforts have been devoted to study and fabricate quantum systems, in which optical modes interact with mechanical resonators, creating different physical phenomena, such as cooling of mechanical oscillations [1–3], optical bistability [4–8], photon blockades [9,10], and optomechanical mass sensors [11]. Due to their remarkable coupling capability, micromechanical and nanomechanical resonators have been coupled with different physical systems, such as Cooper pair boxes [12,13], superconducting microwave circuits [14–16], and Josephson junctions [17]. Among proposed works in optomechanics, the possibility of quantum detection of microwave signals has been investigated in some hybrid optomechanical systems [16,18,19]. Quantum target detection is a modern way for detecting reflected microwave signals from a low-reflecting object, which is embedded into a thermal bath [16,20–22]. In this area of research, entanglement between optical and microwave photons is denoted as the detection mechanism [19]. A typical protocol toward approaching this purpose is optomechanical interaction, which enables creation of entanglement states between microwave and optical photons by means of a mechanical resonator [16,19,23,24].

The main problem in entanglement between microwave and optical photons is the destructive effect of the thermal noise on it. Some proposed optomechanical systems for quantum target detection are based on direct coupling of both optical and microwave photons with mechanical oscillators of the system [16,20]. Presented results in Ref. [20] show the destructive effect of the increasing temperature of the environment on the entanglement between optical modes and microwave signals.

In this paper, we introduce a scheme as a quantum target detection system which employs a different mechanism to entangle between optical and microwave photons and also can perform at high temperatures. In spite of the presented systems in Refs. [16,19], our system utilizes a plasmonic wave which acts as an interface between the microwave signal and the optical field to create a considerable entanglement between them. Potentially, our system can be used as an appropriate device for detection of the weak reflected microwave signals from a low-reflecting object which is embedded into a bright thermal environment.

II. SYSTEM DESCRIPTION

As sketched in Fig. 1, we consider a driven optomechanical cavity (annihilation operator a, resonance frequency ω_{0a}, decay rate κ_a) which on its fixed side is coupled to the circuit of a microwave cavity (annihilation operator a_w, resonance frequency ω_{0w}, decay rate κ_w) by means of a propagating plasmonic wave (annihilation operator b, resonance frequency ω_{0p}, decay rate κ_p) through the fixed side. Optically, the system is driven by an external optical field with a frequency of ω_c and an amplitude of E_c, which is applied to the optomechanical cavity. The oscillating side of the optomechanical cavity is a movable mirror with a resonance frequency of ω_m, corresponding decay rate γ_m, and effective mass m. The fixed side of the optomechanical cavity is a thin, high-reflecting metal plate, the plasmonic wave of which plays the role of an interface between the optical mode and the microwave field to convert them together and is supplied by an external pump (frequency ω_{dpw}, amplitude E_{dpw}). A weak microwave signal, reflected from a low-reflecting object, with a frequency of ω_w and amplitude E_w is applied to the microwave cavity. The Hamiltonian of the system is given by (considering RWA conditions)

$$H = H_0 + H_{int} + i\hbar E_c(a^\dagger - a) + i\hbar E_w(a_w^\dagger - a_w) + i\hbar E_{dpw}(b^\dagger - b),$$

*a.asghari@stu.vru.ac.ir

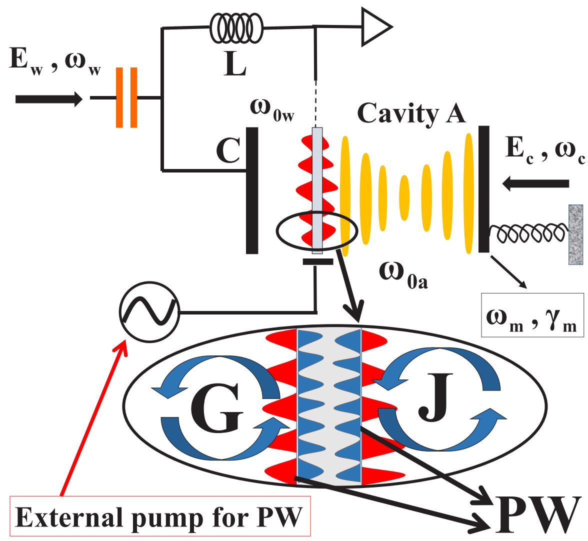

FIG. 1. Schematic of plasmonic assisted quantum optical detector of reflected microwave signals from a low-reflecting object. The propagating plasmonic wave (PW) is the interface between the optical and microwave photons, where the conversion between them is carried out by the plasmonic wave.

$$H_0 = \hbar\Delta_{0a}a^\dagger a + \hbar\Delta_{0w}a_w^\dagger a_w + \hbar\Delta_{0p}b^\dagger b + \tfrac{1}{2}\hbar\omega_m(P^2+Q^2),$$
$$H_{int} = -\hbar g a^\dagger a Q + \hbar J(ab^\dagger + a^\dagger b) + \hbar G(a_w b^\dagger + a_w^\dagger b). \tag{1}$$

First, the three terms of H_0 show the free Hamiltonians of the optomechanical cavity (detuning of $\Delta_{0a} = \omega_{0a} - \omega_c$), microwave cavity (detuning of $\Delta_{0w} = \omega_{0w} - \omega_w$), and the plasmonic wave (detuning of $\Delta_{0p} = \omega_{0p} - \omega_{dpw}$), respectively. The last term of H_0 depicts the energy of the mechanical resonator (movable mirror), where, respectively, P and Q are its dimensionless momentum and position operators which satisfy the commutation relation $[Q,P] = i$. H_{int} shows interactions in the system, where the first term arises from the interaction between the optical cavity (OC) and mechanical resonator (MR) (with coupling strength g), the second term accounts for the interaction between the optical mode and plasmonic wave (PW) (with coupling strength J), and the last one depicts the coupling between the microwave cavity (MC) and plasmonic wave (with coupling constant G). The third (fourth) term of H in Eq. (1) gives the interaction between the optomechanical cavity (plasmonic wave) and the driving laser (external driving field). Also, the last term of H represents the interaction between the microwave cavity and the weak input microwave signal.

III. EQUATIONS OF MOTION

The dynamics of the system is governed by the quantum Langevin equations of motion, given by

$$\dot{Q} = \omega_m P, \tag{2}$$

$$\dot{P} = -\omega_m Q - \gamma_m P + g a^\dagger a + \xi(t), \tag{3}$$

$$\dot{a} = -[i(\Delta_{0a} - gQ) + \kappa_a]a - iJb + E_c + \sqrt{2\kappa_a}\delta a_{in}(t), \tag{4}$$

$$\dot{a}_w = -[i\Delta_{0w} + \kappa_w]a_w - iGb + E_w + \sqrt{2\kappa_w}\delta a_{in,w}(t), \tag{5}$$

$$\dot{b} = -(i\Delta_{0p} + \kappa_p)b - iJa - iGa_w + E_{dpw} + \sqrt{2\kappa_p}\delta b_{in}(t). \tag{6}$$

Respectively, $\delta a_{in}(t)$, $\delta a_{in,w}(t)$, and $\delta b_{in}(t)$ are quantum noise operators to OC, MC, and the plasmonic wave with zero mean values, which satisfy the following correlation relations [25]:

$$\langle\delta a_{in}(t)\delta a_{in}^\dagger(t')\rangle = (N(\omega_{0a}) + 1)\delta(t-t'), \tag{7}$$

$$\langle\delta a_{in,w}(t)\delta a_{in,w}^\dagger(t')\rangle = (N(\omega_{0w}) + 1)\delta(t-t'), \tag{8}$$

$$\langle\delta b_{in}(t)\delta b_{in}^\dagger(t')\rangle = (N(\omega_{0p}) + 1)\delta(t-t'), \tag{9}$$

in which $N(\omega_{0a}) = [\exp(\hbar\omega_{0a}/k_BT) - 1]^{-1}$, $N(\omega_{0w}) = [\exp(\hbar\omega_{0w}/k_BT) - 1]^{-1}$, and $N(\omega_{0p}) = [\exp(\hbar\omega_{0p}/k_BT) - 1]^{-1}$ are equilibrium mean thermal photon numbers of the optical cavity, microwave cavity, and plasmonic wave, respectively. In this paper, in the range of considered frequencies for optical, microwave, and plasmonic modes we have approximately $N(\omega_{0a}) = N(\omega_{0p}) \simeq 0$ and $N(\omega_{0w}) \neq 0$. Also, $\xi(t)$ is the Brownian noise operator, which describes the heating of the movable mirror by the thermal bath at temperature T with zero mean value, where [26]

$$\langle\xi(t)\xi(t')\rangle = \frac{\gamma_m}{2\pi\omega_m}\int d\omega\left[1 + \coth\left(\frac{\hbar\omega}{2k_BT}\right)\right]\omega e^{-i\omega(t-t')}.$$

Applying the steady-state conditions, i.e., all time derivatives in Eqs. (2)–(6) are set equal to zero and considering $\langle\xi(t)\rangle_s = 0$, $\langle\delta a_{in}(t)\rangle_s = 0$, $\langle\delta a_{in,w}(t)\rangle_s = 0$, $\langle\delta b_{in}(t)\rangle_s = 0$, from Eqs. (2)–(6), the steady-state mean values of the operators are obtained as

$$P_s = 0, \tag{10}$$

$$Q_s = \frac{g}{\omega_m}|a_s|^2, \tag{11}$$

$$a_s = \frac{E_c - iJb_s}{i\Delta_a + \kappa_a}, \tag{12}$$

$$a_{ws} = \frac{E_w - iGb_s}{i\Delta_{0w} + \kappa_w}, \tag{13}$$

$$b_s = \frac{E_{dpw} - iJa_s - iGa_{ws}}{i\Delta_{0p} + \kappa_p}, \tag{14}$$

where $\Delta_a = \Delta_{0a} - g|a_s|^2$ is defined as the effective detuning of the optical cavity. Also, the subscript "s" denotes the steady-state mean value.

IV. DYNAMICS OF THE FLUCTUATIONS

We consider each operator as a sum of its steady-state value with a small fluctuation with zero mean value, e.g., $O(t) = O_s + \delta O(t)$. Therefore, from Eqs. (2)–(6), one can obtain

$$\delta\dot{Q} = \omega_m \delta P, \tag{15}$$

$$\delta\dot{P} = -\omega_m \delta Q - \gamma_m \delta P + g_a(a_s \delta a^\dagger + a_s^* \delta a) + \xi(t), \tag{16}$$

$$\delta\dot{a} = -(i\Delta_a + \kappa_a)\delta a + i g_a a_s \delta Q - iJ\delta b + \sqrt{2\kappa_a}\delta a_{in}(t), \tag{17}$$

$$\delta\dot{a_w} = -(i\Delta_{0w} + \kappa_w)\delta a_w - iG\delta b + \sqrt{2\kappa_w}\delta a_{in,w}(t), \tag{18}$$

$$\delta\dot{b} = -(i\Delta_{0p} + \kappa_p)\delta b - iJ\delta a - iG\delta a_w + \sqrt{2\kappa_p}\delta b_{in}(t). \tag{19}$$

To study entanglement properties of the system, we define quadratures of optical ($\delta x_a = (\delta a + \delta a^\dagger)/\sqrt{2}$, $\delta y_a = i(\delta a^\dagger - \delta a)/\sqrt{2}$), microwave [$\delta x_w = (\delta a_w + \delta a_w^\dagger)/\sqrt{2}, \delta y_w = i(\delta a_w^\dagger - \delta a_w)/\sqrt{2}$], and plasmonic [$\delta x_b = (\delta b + \delta b^\dagger)/\sqrt{2}$, $\delta y_b = i(\delta b^\dagger - \delta b)/\sqrt{2}$] fields and Hermitian input noise operators $\delta x_a^{in} = (\delta a_{in} + \delta a_{in}^\dagger)/\sqrt{2}$, $\delta y_a^{in} = i(\delta a_{in}^\dagger - \delta a_{in})/\sqrt{2}$, $\delta x_w^{in} = (\delta a_{in,w} + \delta a_{in,w}^\dagger)/\sqrt{2}$, $\delta y_w^{in} = i(\delta a_{in,w}^\dagger - \delta a_{in,w})/\sqrt{2}$, $\delta x_b^{in} = (\delta b_{in} + \delta b_{in}^\dagger)/\sqrt{2}$, and $\delta y_b^{in} = i(\delta b_{in}^\dagger - \delta b_{in})/\sqrt{2}$ to rewrite Eqs. (15)–(19) as the following compact form:

$$\dot{u}(t) = Au(t) + n(t), \tag{20}$$

where, $u^T(t) = (\delta Q, \delta P, \delta x_a, \delta y_a, \delta x_b, \delta y_b, \delta x_w, \delta y_w)$, $n^T(t) = [0, \xi(t), \sqrt{2\kappa_a}\delta x_a^{in}, \sqrt{2\kappa_a}\delta y_a^{in}, \sqrt{2\kappa_p}\delta x_b^{in}, \sqrt{2\kappa_p}\delta y_b^{in}, \sqrt{2\kappa_w}\delta x_w^{in}, \sqrt{2\kappa_w}\delta y_w^{in}]$ (the superscript T denotes the transpose matrix), and

$$A = \begin{pmatrix} 0 & \omega_m & 0 & 0 & 0 & 0 & 0 & 0 \\ -\omega_m & -\gamma_m & \frac{1}{\sqrt{2}}g(a_s + a_s^*) & \frac{-i}{\sqrt{2}}g(a_s - a_s^*) & 0 & 0 & 0 & 0 \\ \frac{i}{\sqrt{2}}g(a_s - a_s^*) & 0 & -\kappa_a & \Delta_a & 0 & J & 0 & 0 \\ \frac{1}{\sqrt{2}}g(a_s + a_s^*) & 0 & -\Delta_a & -\kappa_a & -J & 0 & 0 & 0 \\ 0 & 0 & 0 & J & -\kappa_p & \Delta_{0p} & 0 & G \\ 0 & 0 & -J & 0 & -\Delta_{0p} & -\kappa_p & -G & 0 \\ 0 & 0 & 0 & 0 & 0 & G & -\kappa_w & \Delta_{0w} \\ 0 & 0 & 0 & 0 & -G & 0 & -\Delta_{0w} & -\kappa_w \end{pmatrix}. \tag{21}$$

If all eigenvalues of the drift matrix A possess negative real parts, the system is stable and reaches a steady state. The stability conditions of the system can be obtained by applying Routh-Hurwitz criteria [27], however, they are not reported here. Because of the Gaussian nature of the noise terms in Eq. (20), the dynamics of the fluctuations is determined by a continuous-variable Gaussian state, given by a 8×8 correlation matrix (CM) as

$$V_{ij} = \sum_{k,l} \int_0^\infty dt \int_0^\infty dt' M_{ik}(t) M_{jl}(t') \Phi_{kl}(t - t'), \tag{22}$$

where $M(t) = \exp(At)$ and $\Phi_{kl}(t - t') = \langle [n_k(t) n_l(t') + n_k(t') n_l(t)] \rangle / 2$ is the matrix of stationary noise correlation functions. In Eq. (20), except $\xi(t)$, all the input noise terms have Gaussian natures. Also, $\xi(t)$ is not a δ correlated function. However, for a mechanical resonator with a high quality factor, $Q = \frac{\omega_m}{\gamma_m} \to \infty$, it can be assumed as a δ correlated function, whose correlation relation is given by $\langle \xi(t)\xi(t') + \xi(t')\xi(t) \rangle \simeq 2\gamma_m(2\bar{n}_m + 1)\delta(t - t')$, where $\bar{n}_m = [\exp(\hbar\omega_m/k_B T) - 1]^{-1}$ is the mean thermal excitation number of the oscillating mirror. Consequently, one can obtain $\Phi_{kl}(t - t') = D_{kl}\delta(t - t')$ with $D = \mathrm{Diag}\{0, \gamma_m(2\bar{n}_m + 1), \kappa_a, \kappa_a, \kappa_p, \kappa_p, \kappa_w[2N(\omega_{0w}) + 1], \kappa_w [2N(\omega_{0w}) + 1]\}$ being the diffusion matrix. Therefore, V in Eq. (22) becomes

$$V = \int_0^\infty dt M(t) D M(t)^T. \tag{23}$$

In a stable regime ($M(\infty) = 0$), Eq. (23) is equivalent to the first theorem Lyapunov equation, which is given by

$$MV + VM^T = -D. \tag{24}$$

Equation (24) is linear in V and can be solved straightforwardly, however, the explicit expression of the solution will not be reported here.

V. ENTANGLEMENT PROPERTIES

To investigate the entanglement properties of the system, we use the logarithmic negativity. The proposed system in this paper is formed of four subsystems. There are six possible bipartite subsystems where the correlation matrix of each bipartite subsystem (V_{bp}) is obtained by neglecting rows and columns of the uninteresting modes. The logarithmic negativity is defined as $E_{\mathcal{N}} = \max[0, -\ln(2\eta^-)]$, where $\eta^- \equiv 2^{(-1/2)}[\Sigma(V_{bp}) - \sqrt{\Sigma(V_{bp})^2 - 4 \det V_{bp}}]^{1/2}$ and $\Sigma(V_{bp}) = \det B + \det B' - 2\det C$. Note that, B, B', and C are 2×2 block matrices which form bipartite correlation matrix (V_{bp}) as

$$V_{bp} = \begin{bmatrix} B & C \\ C^T & B' \end{bmatrix}. \tag{25}$$

To analyze the entanglement properties of the system, we use experimentally realizable values for the parameters as $\omega_c = 1.785\,45 \times 10^{15}$ Hz ($\lambda_c = 1055$ nm), $\omega_m/2\pi = 21.9$ MHz, $m = 6.8 \times 10^{-16}$ kg, $Q = 1.2 \times 10^5$, $P_a = 10\ \mu$W (power of the input optical field), $P_{dpw} = 10\ \mu$W (input power to the plasmonic wave), $\Delta_a = -\omega_m$, $\kappa_a = 0.2\omega_m$, $J = 1.5\kappa_a$, $\kappa_p = 0.2\omega_m$, $\omega_{dpw}/2\pi = 100$ THz, $G = 4.5\kappa_a$, $\Delta_{0p} = 2\omega_m$, $\kappa_w = 0.06\omega_m$, $\omega_{0w}/2\pi = 10$ GHz, $P_w = 10\ \mu$W (power of the input microwave signal).

The main problem in entanglement between microwave signals and optical photons in optomechanics is the destructive effect of the reservoir temperature on this entanglement. Regarding this problem, the presented system in this paper shows a different way to employ optomechanics for creating a significant and stable entanglement between microwave and optical photons. The obtained results show that, with an increase of the temperature of the environment, not only the entanglement between the optical mode and microwave signal decreases, but we also see a considerable increase in it. Figure 2 shows logarithmic negativities of the three bipartite subsystems: (a) MC-OC, (b) MC-MR, and (c) OC-MR, versus normalized detuning of the microwave cavity Δ_w/ω_m at different temperatures: $T = 30$ mK (dotted blue lines), $T = 3$ K (dashed red lines), and $T = 8$ K (solid black lines). We see that [Fig. 2(a)] with the increase of the temperature, an increase occurs in the entanglement between the microwave and optical photons. Also, as can be seen in Figs. 2(b) and 2(c), the two other bipartite subsystems experience increased entanglements for increasing temperatures. However, the presented logarithmic negativities do not behave in the same way, but increasing the temperature of the environment of the system has no destructive effect on the entanglement between optical and microwave photons in the range $T < 8$ K. Note that the system is stable in the chosen parameters regime in Fig. 2. The physical concept behind results presented in Fig. 2 can be explained as follows. With the increase of the temperature, the thermal energy of the movable mirror increases, leading to increased energy transfer from the oscillating mirror to the optical mode. But in our system, the plasmonic wave moderates the energy transfer rate between optical, mechanical, and microwave modes. Indeed, the plasmonic wave acts as a buffer, which decreases effect of the thermal noise on entanglement between different subsystems of our proposed scheme. If we continue increasing the temperature, i.e., $T > 8$ K, logarithmic negativities of the three bipartite subsystems, MC-OC, MC-MR, and OC-MR, continue to increase and become higher than $E_{\mathcal{N}} = 1$ at some values of Δ_w/ω_m, which are not stable regions. But in this situation, one can find some regions for Δ_w/ω_m which are stable and give significant and nonzero entanglements between the optical mode and microwave signal. We tried high temperatures to see the behaviors of the three bipartite subsystems. Figure 3 shows logarithmic negativities of the three bipartite subsystems, MC-OC (a), MC-MR (b), and OC-MR (c), as functions of normalized detuning of the microwave cavity at $T = 203$ K. As can be seen, there are some detuning regions of the microwave cavity in which entanglement between microwave and optical photons is significant. In comparison with Ref. [16], we see a different effect of the temperature on the entanglement in our system, i.e., with the increase of the temperature, entanglements of the three bipartite subsystems, MC-OC, MC-MR, and OC-MR, intensify. Consequently, our system is a good candidate for detecting reflected microwave signals from a low-reflecting object at high temperatures by assisting a plasmonic wave and a developed optomechanical system. In spite of the presented system in Ref. [16], in our system, the microwave signal and the oscillating mirror are not directly coupled together. Therefore, it is possible to detect microwave signals with low powers which are reflected from a low-reflecting object.

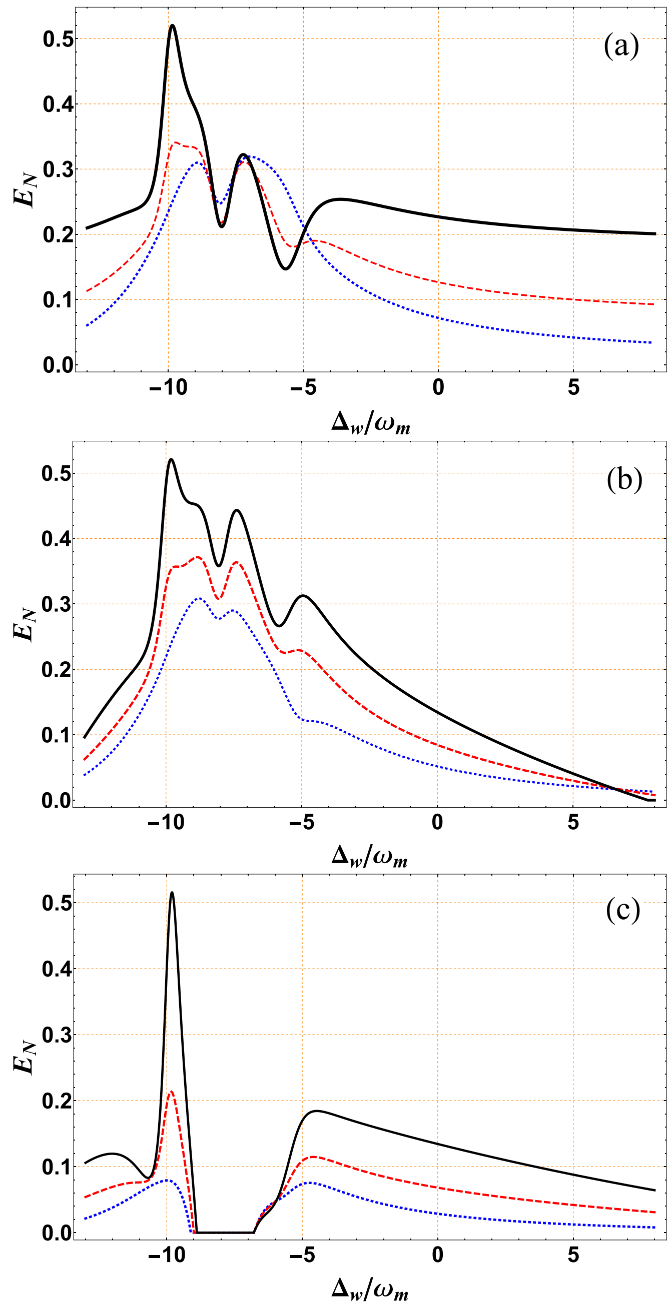

FIG. 2. Performance of our quantum optical detector at different temperatures. Plots show logarithmic negativities of the three bipartite subsystems, (a) MC-OC, (b) MC-MR, and (c) OC-MR, as functions of the normalized detuning of the microwave cavity (Δ_w/ω_m) at $T = 30$ mK (dotted blue lines), $T = 3$ K (dashed red lines), and $T = 8$ K (solid black lines). Other parameters are considered as $\omega_c = 1.78545 \times 10^{15}$ Hz ($\lambda_c = 1055$ nm), $\omega_m/2\pi = 21.9$ MHz, $m = 6.8 \times 10^{-16}$ kg, $Q = 1.2 \times 10^5$, $P_a = 10\ \mu$W, $P_{dpw} = 10\ \mu$W, $\Delta_a = -\omega_m$, $\kappa_a = 0.2\omega_m$, $J = 1.5\kappa_a$, $\kappa_p = 0.2\omega_m$, $\omega_{dpw}/2\pi = 100$ THz, $G = 4.5\kappa_a$, $\Delta_{0p} = 2\omega_m$, $\kappa_w = 0.06\omega_m$, $\omega_{0w}/2\pi = 10$ GHz, $P_w = 10\ \mu$W.

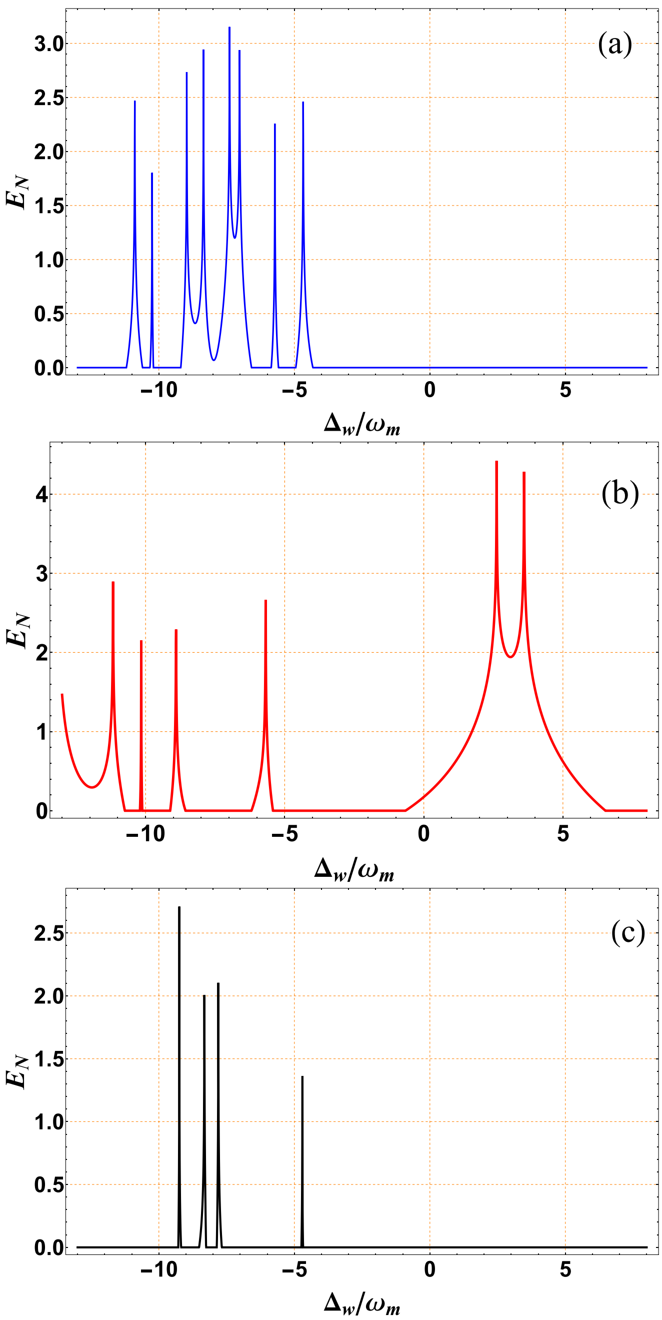

FIG. 3. Performance of proposed quantum optical device at high-temperature regime. Graphs present logarithmic negativities of the bipartite subsystems, (a) MC-OC, (b) MC-MR, and (c) OC-MR, versus normalized detuning of the microwave cavity at $T = 203$ K. The rest of the parameters are considered as $\omega_c = 1.78545 \times 10^{15}$ Hz ($\lambda_c = 1055$ nm), $\omega_m/2\pi = 21.9$ MHz, $m = 6.8 \times 10^{-16}$ kg, $Q = 1.2 \times 10^5$, $P_a = 10\ \mu$W, $P_{dpw} = 10\ \mu$W, $\Delta_a = -\omega_m$, $\kappa_a = 0.2\omega_m$, $J = 1.5\kappa_a$, $\kappa_p = 0.2\omega_m$, $\omega_{dpw}/2\pi = 100$ THz, $G = 4.5\kappa_a$, $\Delta_{0p} = 2\omega_m$, $\kappa_w = 0.06\omega_m$, $\omega_{0w}/2\pi = 10$ GHz, $P_w = 10\ \mu$W.

If the microwave cavity and oscillating mirror are coupled directly, i.e., direct interaction between radiation pressure of the microwave field and the oscillations of the oscillating mirror, sufficient power of the microwave field is needed to affect on the position of the oscillating mirror, while reflected microwave signals from a low-reflecting object are so weak that they have a weak radiation pressure. Also, according to our results, the existence of the optomechanical interaction in our system is necessary to obtain a considerable and significant entanglement between microwave and optical photons. If we omit optomechanical terms from the Hamiltonian of the system [Eq. (1)], i.e., replace the oscillating mirror with a fixed one, we see an insignificant entanglement between the microwave signal and the optical mode as depicted in Fig. 4.

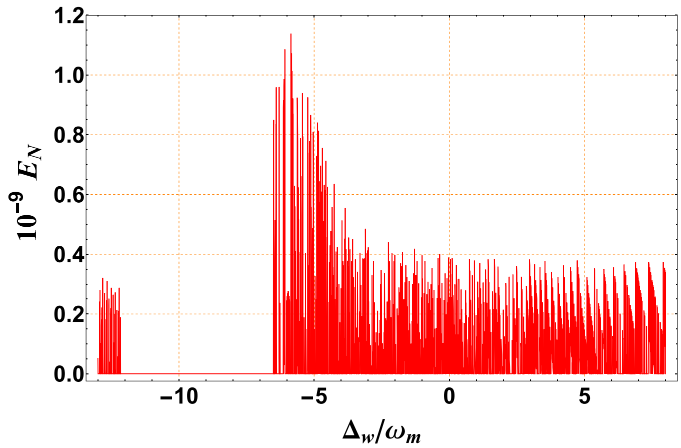

FIG. 4. Plot of the logarithmic negativity of the bipartite subsystem MC-OC in the fixed optical cavity regime, i.e., both sides of the optomechanical cavity are fixed, as a function of normalized detuning of the microwave cavity at $T = 30$ mK. Other parameters are considered as $\omega_c = 1.78545 \times 10^{15}$ Hz ($\lambda_c = 1055$ nm), $\omega_m/2\pi = 21.9$ MHz, $m = 6.8 \times 10^{-16}$ kg, $Q = 1.2 \times 10^5$, $P_a = 10\ \mu$W, $P_{dpw} = 10\ \mu$W, $\Delta_a = -\omega_m$, $\kappa_a = 0.2\omega_m$, $J = 1.5\kappa_a$, $\kappa_p = 0.2\omega_m$, $\omega_{dpw}/2\pi = 100$ THz, $G = 4.5\kappa_a$, $\Delta_{0p} = 2\omega_m$, $\kappa_w = 0.06\omega_m$, $\omega_{0w}/2\pi = 10$ GHz, $P_w = 10\ \mu$W.

VI. CONCLUSIONS

We have introduced an optomechanical scheme for detection of reflected microwave signals from a low-reflecting object which can perform at high temperatures. The proposed scheme performs based on coupling between microwave signals and a plasmonic wave which propagates through the fixed side of the optomechanical cavity. We have shown that with the increase of the temperature of the environment of the system, the entanglement between the microwave signal and the optical mode increases for temperatures below $T = 8$ K. It has been seen that, even for the temperatures higher than $T = 8$ K, e.g., $T = 203$ K, it is possible to find some regions of the detuning of the microwave cavity in which the system shows nonzero and significant logarithmic negativities for the bipartite subsystem MC-OC, where the system is stable in these regions. Also, we have shown that the existence of the oscillating mirror and consequently the presence of optomechanical interactions are necessary to create a significant and considerable entanglement between the optical mode and microwave signals. As a final conclusion, our system is an appropriate candidate in detection of reflected microwave signals from a low-reflecting object, which can perform at high temperatures.

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