Coherent control of magnon radiative damping with local photon states

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The collective excitation of ordered spins, known as spin waves or magnons, can in principle radiate by emitting travelling photons to an open system when decaying to the ground state. However, in contrast to the electric dipoles, magnetic dipoles contributed by magnons are more isolated from electromagnetic environment with negligible radiation in the vacuum, limiting their application in quantum communication by photons. Recently, strong interaction between cavity standing-wave photons and magnons has been reported, indicating the possible manipulation of magnon radiation via tailoring photon states. Here, with loading an yttrium iron garnet sphere in a one-dimensional circular waveguide cavity in the presence of both travelling and standing photon modes, we demonstrate an efficient photon emissions from magnon and a significant magnon radiative damping with radiation rate found to be proportional to the local density of states (LDOS) of photons. By modulating the LDOS including its magnitude and/or polarization, we can flexibly tune the photon emission and magnon radiative damping on demand. Our findings provide a general way in manipulating photon emission from magnon radiation for harnessing energy and angular momentum, generation, transfer and storage modulated by magnon in the waveguide quantum electrodynamics.

I. INTRODUCTION

Radiation in various systems arises when energy relaxes from excited states to the ground ones by emission of travelling photons that are fundamental information carriers [1-4]. Understanding and controlling the photon emission from radiation is one important objective in quantum optics and quantum information [5, 6] that would give rise to advanced applications ranging from quantum computation, optical communication, single photon source to display technologies [3, 4, 8-11]. However, unlike electric dipole that can strongly couple to the optical fields, the weak coupling between the magnetic dipole and electromagnetic field leads the radiation control of the long-lived spin degree of freedom to be relatively difficult [7, 12, 13]. Very recently, based on the collective spin excitations with quanta called magnon in magnetic material—yttrium iron garnet (YIG) with high spin density and extremely low damping [14], pioneering works demonstrate the high-cooperativity cavity QED (quantum electrodynamics) between coherently-coupled magnon and cavity photons [15-20], indicating a possible path to tune the magnon dynamics through photon states. So far, these works mainly focused on the coupling between the magnon and standing photon modes with emphasis on cavity magnon polariton [15, 22], while the magnon radiation at continuous wave range [23, 24] remains relatively unexplored.

Different from the cavity QED, the waveguide QED promises to transfer the emitted photons from radiation as a flying qubit in information processing [25, 27]. Due to possible strong coupling with microwave photon in a waveguide [23, 24], magnon could be an ideal candidate for the photon emission with extremely low intrinsic damping. The uniform spin excitation, i.e., the Kittel mode in a magnetic sphere is intrinsically circularly polarized [28, 29] that may allow to emit the unidirectional photon with particular chirality similar to the quantum dot [29, 30]. Moreover, the flexible tunability of the local electromagnetic environment in a microwave waveguide could also provide the possibility to tailor magnon radiation and hence its radiative damping in a precise fashion. In case the mechanism of tuning magnon radiation by local photon states could be demonstrated, various mechanisms that were used to tune photon emission by, for instance, quantum emitters, antennas and superconducting circuits could be realized with magnon that add functionality in magnonics [7, 29, 31, 32].

In this work, we address a general way to control the photon emission from magnon and magnon radiative damping by tuning the local electromagnetic environment. The radiative damping rate is demonstrated to be proportional to the local density of states (LDOS) of photons in a coupled magnon-photon system that is generated by placing an YIG sphere into a circular waveguide cavity resembling to a “clarinet” in shape [see Fig. 1(a)]. Similar to the sound physics of “clarinet”, due to the different transitions at the two terminals of the waveguide, the microwaves from the left terminal with particular wavevectors are totally reflected at the right terminal and vice versa, around which the standing waves form that are superposed on the continuous-wave background [33, 34]. By involving both the standing and continuous waves that coherently couple with the magnons in Kittel mode, we study the magnon radiative damping by measuring magnon linewidth $\Delta H$. A suppression of the radiative damping at standing-wave resonance is observed that seems to be different from the conventional Purcell effect [10, 11, 13]. We theoretically establish the relation between magnon radiative damping and the LDOS.
of microwave photons in a quantitative level that agrees with our measurements quite well. Our device allows us to tune the LDOS involving the magnitude and/or polarization to control the photon emission from magnon and magnon radiative damping. To the best of our knowledge, our work is the first convincing observation of the LDOS-tunable magnon radiative damping in a coupled magnon-photon system that paves a way to further explore interesting physics, e.g., the superradiant and subradiant states, by magnons.

II. RESULTS

A. Photon states construction

For clarifying the magnon radiative damping controlled by photon states, we first introduce the local electromagnetic environment inside the circular waveguide cavity as shown in Fig. 1(a). This waveguide consists of a 16 mm-diameter circular waveguide and two transitions at both ends that are rotated by a θ=±45°. The two transitions can smoothly transform TE_{10} mode of rectangular port to TE_{11} mode of circular waveguide, and vice versa. Specifically, the microwaves polarized in the \( \hat{x} \)- and \( \hat{x}' \)-directions are totally reflected at one end of the circular waveguide that allows to form the standing waves around specific microwave frequencies. While the microwaves polarized in \( \hat{y} \)- and \( \hat{y}' \)-directions can travel across the transitions and therefore form a continuum of travelling waves. Therefore, in our device the standing waves can form around particular wavevectors or frequencies that are superposed on the continuous-wave background [33, 34]. The continuous waves allow to transfer the information in the open system and the standing waves provide the ingredient to form the cavity magnon polariton. Thus, different from discrete modes in the conventional well-confined cavity, our circular waveguide cavity enables to add the ingredient of continuous modes to modify the photonic structure.

The modes in our device can be characterized by microwave transmission using a vector network analyzer (VNA) between port 1 and 2. A standing wave or “cavity” resonance mode at \( \omega_c/2\pi=12.14 \) GHz is clearly revealed in \( S_{21} \) with a loaded damping factor of \( 9 \times 10^{-3} \), as illustrated by the blue circles in Fig. 1(b). It is observed in the transmission spectrum that standing waves confined in the waveguide cause the dip in transmission spectrum at cavity resonance [33], while the travelling continuous waves that delivers photons from port 1 to 2 contributes a high transmission close to 1. Since continuous wave is not negligible in our device, photon modes thereby cannot be described via a single harmonic oscillator as in previous works [16, 20]. Hence the electromagnetic fields in our waveguide cavity are described by a large number of harmonic modes [33, 37, 38] in a wide frequency range and each mode has a certain coupling strength with magnon mode.

The following Fano-Anderson Hamiltonian describes the interaction between magnon and photon as [35, 36]

\[
H_0/h = \omega_m \hat{m}^\dagger \hat{m} + \sum_{k_z} \omega_k \hat{a}^\dagger_{k_z} \hat{a}_{k_z} + \sum_{k_z} g_{k_z} (\hat{m}^\dagger \hat{a}_{k_z} + \hat{m} \hat{a}^\dagger_{k_z}),
\]

where \( \hat{m}^\dagger (\hat{m}) \) is the creation (annihilation) operator for magnon in Kittel mode with frequency \( \omega_m \), \( \hat{a}^\dagger_{k_z} (\hat{a}_{k_z}) \) denotes the photon operator with wavevector \( k_z \) and frequency \( \omega_k \), and \( g_{k_z} \) represents the corresponding coupling strength between the magnon and microwave photon mode (see Supplementary Note 1). We visualize magnon Kittel mode as a single harmonic oscillator in Eq. (I). Magnon and photon modes have intrinsic dissipations originated from inherent property, but our cavity allows to build the coherent coupling between them [23, 25] as schematically shown in Fig. 1(c).

Due to the coherent coupling between magnon and photon, the energy of excited magnon would radiate to the photons that travel away from the magnetic sphere. This can be pictured as the “auto-ionization” of magnon into the propagating continuous states that induces the photon emission from magnon and hence magnon radiative damping [39, 40]. Such “additional” magnon dissipation induced by photon states can be rigorously calculated by the imaginary part of self-energy in magnon Green’s function that is expressed as \( \Delta E_m = \delta_m + \frac{\hbar}{\gamma} |h \hat{g}(\omega)|^2 D(\omega) \). Here, \( \delta_m \) is the intrinsic dissipation rate of magnon mode, \( D(\omega) \) represents the global density of states for the whole cavity that is a count of the number of modes per frequency interval. By further defining the magnon broadening in terms of magnetic field \( \Delta E = h \gamma \mu_0 \Delta H \), the magnon linewidth is expressed as (Supplementary Note 1)

\[
\mu_0 \Delta H = \mu_0 \Delta H_0 + \frac{\omega_c}{\gamma} + \frac{2\pi \kappa}{\gamma} R|\rho_1(d,\omega)|, \tag{2}
\]

in which \( \gamma \) is modulus of the gyromagnetic ratio and \( \mu_0 \) denotes the vacuum permeability. In Eq. (2), the first two terms are the linewidth related to inherent damping of magnon in which \( \mu_0 \Delta H_0 \) and \( \omega_c/\gamma \) come from the inhomogeneous broadening at zero frequency [41] and the intrinsic Gilbert damping, respectively. The last term describes the radiative damping induced by photon states in which \( |\rho_1(d,\omega)| \) represents the LDOS of magnetic fields with \( d \) and \( l \) denoting the position and photon polarization direction. Basically, \( |\rho_1(d,\omega)| \) counts both the local magnetic field strength and the number of electromagnetic modes per unit frequency and per unit volume. \( \kappa = \omega \mu_0 V_s \) with \( M_s \) and \( V_s \) being the saturated magnetization and volume of the loaded YIG sphere. \( R \) represents a fitting parameter that is mainly influenced by cavity design and cable loss in the measurement circuit.

Based on above theoretical analysis, we find that the radiative damping is exactly proportional to the LDOS \( \rho_1(d,\omega) \). To observe radiation as a dominant channel for the transfer of magnon angular momentum, it requires both low inherent damping of magnon and a large tun-
FIG. 1. (Color online) **Magnon radiative damping controlled by LDOS.** (a) Experimental set-up of coupled magnon-photon system in a circular waveguide cavity. (b) Transmission coefficient $|S_{21}|$ from measurement (circles) and simulation (solid lines), with insets showing normalized LDOS distribution for standing-wave resonance 12.14 GHz and continuous wave 11.64 GHz. (c) By coupling magnons with photons in a waveguide cavity, the radiative damping of magnon can be the dominant energy dissipation channel compared to its intrinsic damping. (d) Dispersion map for coupled magnon-photon states. $|S_{21}(H)|^2$ spectra is measured at fixed frequencies 11.64 GHz (e), 12.14 GHz (f) and 12.64 GHz (g), respectively, with the x-axis offset $H_m$ being the biased static magnetic field at magnon resonance.

able $|\rho_1(d, \omega)|$. In the following experiment, both conditions are satisfied by introducing a YIG sphere with low Gilbert damping, as well as by modifying photon mode density through tuning LDOS magnitude (Sec. II B 1), LDOS polarization (Sec. II B 2) and global cavity geometry (Sec. II B 3).

**B. Magnon radiation tunned by photon LDOS**

A highly polished YIG sphere with 1 mm diameter is loaded into the middle plane of waveguide cavity. Before immersing into experimental observations, it is instructive to understand the two-dimensional (2D) spatial distribution of LDOS in the middle plane, which is numerically simulated by CST (**Computer simulation technology**) at the center cross section that can well-reproduce $|S_{21}|$ as shown in Fig. 1(b). It can be seen that the hot spots for the continuous waves (11.64 GHz) and standing wave (12.14 GHz) are spatially separated, providing the possibility to control LDOS magnitude by tuning the positions of magnetic sample inside the cavity.

In our first configuration, we focus on the local position with $d=6.5$ mm as marked in Fig. 1(b). Such position enables the magnon mode not only to have overlapping with standing waves but also to couple to the continuous ones. More interestingly, as indicated by the insets in Fig. 1(b), LDOS at $d=6.5$ mm has smaller quantity at cavity resonance compared with the ones in the continuous-wave range, which is opposite to the LDOS enhancement at resonance in conventional well-confined cavity [10, 11, 13]. Therefore, according to Eq. (1), in contrast to magnon linewidth enhancement in previous works, we expect a totally different linewidth evolution


by varying frequency in measurement with linewidth suppression at cavity resonance $\omega_c$.

Concretely, the magnon linewidth can be measured from $|S_{21}|$ spectra in $\omega$-$H$ dispersion map. In our measurement, a static magnetic field $\mu_0H$ is applied along the $x$-direction to tune the magnon mode frequency (close to or away from the cavity resonance), which follows a linear dispersion $\omega_m = \gamma \mu_0 (H + H_A)$ with $\gamma = 2\pi \times 28 \text{ GHz/T}$ and $\mu_0H_A = 192 \text{ Gauss}$ being the specific anisotropy field.

For our YIG sphere, the saturated magnetization is $M_s = 10.175 \text{ T}$, the Gilbert damping $\alpha$ is measured to be $4.3 \times 10^{-5}$ by standard waveguide transmission with the fitted inhomogeneous broadening $\mu_0 \Delta H_0 = 0.19 \text{ Gauss}$. As $\omega_m$ is tuned to approach the cavity resonance $\omega_c$, a hybrid state is generated with the typical anticrossing dispersion as displayed in Fig. 1(d). A coupling strength of 16 MHz can be found from rabi splitting at zero detuning condition that indicates the coherent energy conversion between magnon and photon.

Magnon linewidth (HWHM) is characterized by a lineshape fitting of $|S_{21}(H)|^2$ that is obtained from the measured transmission at fixed frequency and different magnetic fields. Here, we focus on $|S_{21}(H)|^2$ at three different frequencies with one being at the cavity resonance $\omega_c$ and the other two chosen at continuous wave frequencies above and below $\omega_c$ (11.64 GHz and 12.64 GHz, respectively). As photon frequency is tuned from continuous wave range to the cavity resonance $\omega_c$, the lineshape of $|S_{21}(H)|^2$ varies from asymmetry to symmetry, accompanied by an obvious linewidth suppression from 2.0 Gauss/1.5 Gauss to 1.0 Gauss as shown in Fig. 1(c)-(g).

It is worth noticing that the magnon linewidth $\mu_0 \Delta H$ shows a clear suppression at cavity resonance rather than the linewidth enhancement in conventional coupled magnon-photon system in the cavity [20, 42]. Such suppression of magnon linewidth qualitatively follows the LDOS magnitude, which also shows smaller quantity at cavity resonance. This qualitatively agrees with our theoretical expectation from Eq. (2). In the following subsections, it is necessary to study the relation between linewidth and LDOS in a quantitative level by using both the theoretical calculation and experimental verification.

1. Magnon radiation controlled by LDOS magnitude

In this subsection, we show a quantitative control of magnon radiative damping by tuning the LDOS magnitude over a broadband. The spacial variation of the magnetic field in our waveguide cavity allows us to realize different LDOS spectra by simply choosing different positions. Similar to the experimental settings in the above section with $d=6.5 \text{ mm}$, we display a broadband view of LDOS for per polarization by using simulation in Fig. 2. Although $\rho_x(\omega)$ in Fig. 2(a) shows a typical resonance behaviour, its contribution to the magnon radiation is negligible here according to the well-known fact that only photon polarization that perpendicular to the external static magnetic field $H$ drives the magnon dynamics. Following this consideration, we further simulate $\rho_\perp = \sqrt{\rho_{0x}^2 + \rho_{0z}^2}$ that plays a dominant important role in the magnon-photon interaction as displayed in Fig. 2(b). $\rho_\perp(\omega)$ shows a dip at the cavity resonance in the frequency dependence.

It is clearly seen that due to the enhancement of global density of states at the mode cut-off of the waveguide, continuous wave LDOS becomes more and more significant when frequency goes lower to approach the cut-off frequency (around 9.5 GHz). This phenomenon can be viewed as a Van Hove singularity effect in the density of states for photons (see independent observa-

![FIG. 2. (Color online) LDOS magnitude dependence.](attachment:image)

(a) and (b), Simulated $\rho_x$ and $\rho_\perp$ at $d=6.5 \text{ mm}$. (c) Measured $\mu_0 \Delta H$-$\omega$ relation (squares) with calculated lines from model (the green line) at $d=6.5 \text{ mm}$. (d) and (e), Simulated $\rho_x$ and $\rho_\perp$ at $d=0 \text{ mm}$. (f) Measured $\mu_0 \Delta H$-$\omega$ relation (squares) with calculated lines from model (the green line) at $d=0 \text{ mm}$. Black circles and lines indicate the measured and fitted intrinsic linewidth, respectively. (g) $\mu_0 \Delta H$ evolution with tuning positions for different frequencies.
magnon radiation, the magnetic sphere is moved to the by standing waves. Showing that radiative power emission induced by con-
is coherently controlled by LDOS magnitude, especially the fitting parameter quantity $\rho$ respectively. The effective LDOS $\mu$ served in Fig. 2(c) that the measured $\mu \Delta H$-ω relation (squares) and calculated results (solid lines) for different angles $\varphi = 0^\circ$, $45^\circ$ and $90^\circ$, respectively. As such singularity effect is involved in the coupled magnon-photon dynamics, we obtain larger coupling with magnon at cavity resonance. While as continuous waves become more and continuous waves can unambiguously exceed that induced by standing waves.

To create a different LDOS magnitude to tune the magnon radiation, the magnetic sphere is moved to the center of the cross section with $d=0$ mm. The simulated LDOS $\rho_x$ and $\rho_\perp$ are illustrated in Fig. 2(d) and (e), respectively. The effective LDOS $\rho_\perp$ shows an enhancement at cavity resonance but suppressions at continuous-wave range. Similar to the frequency dependence of the LDOS magnitude, the magnon linewidth is clearly observed to be enhanced at cavity resonance but suppressed at continuous waves. This relation between the magnon width and LDOS is again quantitatively verified by the good agreement between measurement and calculated results from Eq. 2 as shown in Fig. 2(f). Particularly, as continuous wave LDOS is suppressed to nearly zero, the radiative damping from LDOS thereby becomes negligibly small. In this case, it can be found that the magnon linewidth exactly returns to its intrinsic damping $\mu_0 \Delta H_0 + \alpha \omega/\gamma$ measured in an independent standard waveguide.

Finally, at a detailed level, to continuously tune the ratio of standing/continuous-wave LDOS magnitude, the position of the YIG sphere is moved with $d$ varied from 0 mm to 6.5 mm. Typically for three different frequency detunings with 0 MHz, -10 MHz and -45 MHz, our results in Fig. 2(g) shows that the magnon linewidth can be controlled with enhancement, suppression or negligible variation in the position dependence. As shown in Fig. 2(g), these results showing good agreement with the theoretical calculation suggests that magnon linewidth can be controlled on demand by tuning the LDOS magnitude. Moreover, the photon emission efficiency from magnon radiation can in principle be significantly enhanced with a larger magnetic sphere and smaller waveguide in cross section. For example, a magnetic sphere in 2-mm diameter and a waveguide with half radius would enhance the radiation rate by 16 times (Supplementary Note 1).

### 2. Magnon radiation controlled by LDOS Polarization

Having shown the relation between the magnon radiative damping in $\mu_0 \Delta H$ and the LDOS magnitude, here we would like to introduce LDOS polarization as a new degree of freedom to control the magnon radiation. In our experiment, by placing the YIG sphere at $d=2.3$ mm, the tuning of effective LDOS polarization $\rho_\perp$ for the magnon to feel can be simply achieved by varying the direction of external static magnetic field $H$ with a relative angle $\varphi$ to the $x$-direction as shown in Fig. 3(a). Please note that compared with the complicated operation to vary the position of YIG sphere inside a cavity, here the LDOS was controlled continuously in a large range simply by rotating the orientation of the static magnetic field. Based on the orthogonal decomposition of LDOS for photons, $\rho_\perp$ is simulated for three typical angles $\varphi$, i.e., $0^\circ$, $45^\circ$, and $90^\circ$ as shown in Fig. 3(b). For $\varphi = 0^\circ$ with $H$ being exactly in the $x$-direction, the LDOS is dominated by standing-wave component, which could provide largest coupling with magnon at cavity resonance. While as $\varphi$ goes close to $90^\circ$, continuous waves become more and more dominant in the contribution to the LDOS, caus-

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**FIG. 3.** (Color online) LDOS polarization dependence. (a) Schematic of tuning orientation of external magnetic field $H$ relative to the $x$-direction in the plane of waveguide cross section (b) Simulated photon LDOS perpendicular to external magnetic field $H$ with relative angle $\varphi = 0^\circ$, $45^\circ$ and $90^\circ$, respectively. (c) Measured magnon linewidth spectra, i.e., $\mu_0 \Delta H$-ω relation (squares) and calculated results (solid lines) for different angles $\varphi = 0^\circ$, $45^\circ$ and $90^\circ$, respectively.
ing a peak-to-dip flip for LDOS around $\omega_c$ in Fig. 3(b).

Accordingly, in our experiment, we obtain a magnon linewidth enhancement at $\varphi = 0^\circ$ as shown in Fig. 3(c) by red squares. As $\varphi$ is tuned towards 90°, we thereby anticipate and indeed obtain a linewidth suppression at cavity resonance with blue squares, showing good agreement with the linewidth scaling of $\rho_\perp$ in Eq (2). The theoretically calculated linewidth $\mu_0 \Delta H$ is plotted for each $\varphi$ in Fig. 3(c) with $\kappa R$ being consistent with the previous subsection. The good agreement between experimental and theoretical findings suggest a flexible control of magnon radiation via LDOS polarization. Moreover, not restricted to tune relative angle between $H$ and LDOS polarization in 2D plane, more possibility of magnon radiation engineering may be realized by pointing $H$ to arbitrary direction in the whole 3D space.

3. Magnon radiation controlled by cavity geometry

Our device allows us to tune the LDOS magnitude and polarization together by simply rotating the relative angle $\theta$ between the two transitions [33], i.e., the global geometry in our circular waveguide cavity. This can again validate and rich our observations that the same magnon harmonic mode radiates a different amount of power depending on the surrounding photon environments. In this subsection, we insert a rotating part in the middle plane of cavity, so that the relative angle $\theta$ between two transitions can be smoothly adjusted. By tuning angle $\theta$ from 45 degree to 5 degree, our system allows a significant change in photon transmission as illustrated in Fig. 4(a), accompanied by significant enhancements in cavity quality factor and global density of states [43, 44]. In addition, cavity resonance shows red shift to 11.79 GHz due to the increase of cavity length. The YIG sphere is placed at cavity center cross section with $d=6$ mm and the external magnetic field is applied in the $\hat{x}$-direction. Such experimental conditions provide stable magnon-photon coupling strength when $\theta$ is tuned, as shown by the nearly unchanged mode splitting in Fig. 4(b).

Our hybrid system now readily allows the investigation of magnon radiation tunable by cavity geometry. In particular, tuning $\theta$ from 45 degree to 5 degree leads to a redistribution of photon states in cavity that greatly enhances the LDOS near $\omega = \omega_c$ and controls the continuous wave LDOS in an opposite way, as illustrated by the simulated $\rho_\perp$ in Fig. 4(c). Based on the theoretical model, we expect magnon linewidth can quantitatively follow the geometry-controlled $\rho_\perp$. Results from measurements under different $\theta$ are shown in Fig. 4(d) and we indeed obtain linewidth $\mu_0 \Delta H$ with similar behavior to the simulated $\rho_\perp$. As is evident in Fig. 4(e) and (f), we find that the linewidth is well reproduced by our theoretical model with $\kappa R$ adjusted to $4.3 \times 10^{22}$ m$^3$/s$^2$. By tuning LDOS via $\theta$, the experimental linewidth is enhanced by twenty-fold at cavity resonance in comparison with the intrinsic damping of magnon as illustrated by the dashed lines.

III. DISCUSSION

Along a rapid development of communication applications, magnetic insulators have drawn extensive attractions in magnonics. Compared with electronic device, magnetic insulators are appealing because they could keep low conductive losses in high quality material such as YIG that shows the lowest recorded magnetic damping ($\sim 10^{-5}$) [14]. Meanwhile, YIG has high spin density, containing in total $\sim 10^{19}$ ordered spins aligned in one direction by exchange interaction in a 1-mm–diameter YIG sphere [22]. Due to extremely low intrinsic damping and large spin density in YIG [14, 18, 19], high cooperativity can be achieved in a coupled magnon-photon states.
providing an efficient way to tune magnon dynamics via photon states. In particular, compared with the small intrinsic damping, such coupled states enables an “additional” damping by radiating photon to stand out in angular momentum transfer process. Understanding and controlling photon emission by magnon and magnon radiative damping can provide a flexible way to enhance or suppress the angular momentum transfer for various applications, such as coherent spin current manipulation and unidirectional photon transport [13, 30].

In conclusion, we observe and show the ability to control photon emission from magnon and magnon radiative damping in the hybrid magnon-photon system, bridging their relation to the tunable photon LDOS. Compared with conventional enhancement of magnon damping at cavity resonance in well-confined magnon-photon system, we report that the magnon linewidth at cavity resonance can be even suppressed by photon LDOS engineering. One quantitative method to design and tune the radiation efficiency of magnon is provided based on tailoring photon LDOS including LDOS magnitude and/or polarization, thereby leading to a general technique of tuning magnon relaxation on demand. Our study introduces a novel mechanism to coherently manipulate magnon dynamics by local photon states and suggests a promising potential towards the development of magnon-based hybrid devices and related quantum information processing.

IV. METHODS

A. Device description

Our waveguide cavity is made up of a cylindrical waveguide and two circular rectangular transitions coaxially connected at both ends. Through the transition, a smooth change between TE$_{10}$ mode of rectangular waveguide port and TE$_{11}$ one of cylindrical waveguide can be established. Via coaxial cables, the cavity is connected to the input/output ports of an vector network analyzer (VNA). With an input power of 0 dBm, the transmission signals can be precisely picked up by VNA. YIG sphere is fixed firmly inside the cavity with scotch tape, with its location tunable on demand to couple with different microwave magnetic fields. YIG and the scotch tape, as dielectric materials, can slightly influence the microwave fields distribution in our experiment. We neglect the small dielectric influence in our theoretical treatment.

B. Theoretical description

In Supplementary Note 1, the theory of magnon spontaneous radiation in the waveguide including the derivation of the magnon linewidth induced by the LDOS is provided.

V. DATA AVAILABILITY

All relevant data are available from the authors.

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VII. AUTHOR CONTRIBUTIONS

B.M.Y. and Y.S.G. set up the hybrid system, conducted the experiment as well as analyzed the data. T.Y., in discussions with B.M.Y. and C.-M.H., developed the theory part. J.W.R. and Y.T.Z. contributed to the design of the cavity parts. B.M.Y. and T.Y. prepared all the figures as well as the supplementary material part. T.Y., L.W. and C.-M.H. together supervised the work. All authors contribute to the paper writing.