Comparison of spin-wave transmission in parallel and antiparallel magnetic configurations

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Abstract **Parallel (P) and antiparallel (AP) configurations are widely applied in magnetic heterostructures and have significant impacts on the spin-wave transmission in magnonic devices. In the present study, a theoretical investigation was conducted into the transmission of exchange-dominated spin waves with nanoscale wavelengths in a type of heterostructure including two magnetic media, of which the magnetization state can be set to the P (AP) configuration by ferromagnetic (antiferromagnetic) interfacial exchange coupling (IEC). In the P configuration, a critical angle θ_c always exists and has a significant influence on the transmission. Spin waves are refracted and reflected when the incident angle θ_i is smaller than the critical angle ($\theta_i < \theta_c$), while total reflection occurs as $\theta_i > \theta_c$. In the AP configuration, the spin-wave polarizations of mediums 1 and 2 are inverse, that is, right handed (RH) and left handed (LH), leading to the total reflection being independent of θ_i. As demonstrated by the difference in spin-wave transmission properties between the P ($\theta_i < \theta_c$) and AP cases, there is a polarization-dependent scattering. However, as θ_i exceeds θ_c, the P ($\theta_i > \theta_c$) case exhibits similarities with the AP case, where the transmitted waves are found to be evanescent in medium 2 and their decay lengths are investigated. In both the P ($\theta_i > \theta_c$) and AP cases, the Goos-Hänchen (GH) shift of the total reflection waves are calculated and shown as a function of the frequency and incident angle. The relationship between the decay lengths and GH shifts is also explored. Furthermore, as the number of media exceeds two, spin waves are scattered by multiple interfaces, resulting in the resonant transmission effect in the P ($\theta_i < \theta_c$) case. At the same time, there is a tunneling effect and a resonant tunneling effect in the P ($\theta_i > \theta_c$) and AP cases, which are attributed to the evanescent waves. The influences of the IEC strength on all of the aforementioned findings are investigated in detail.**

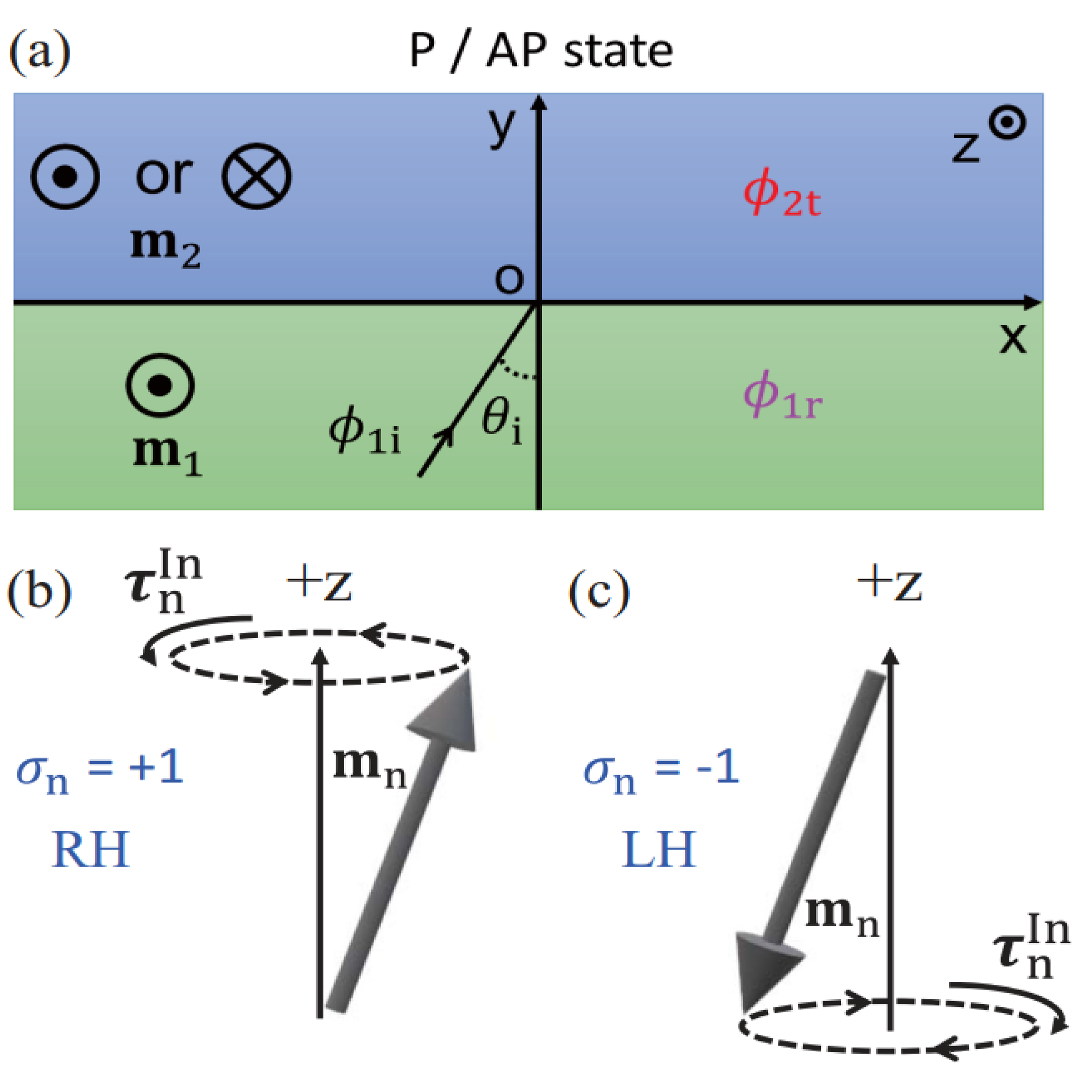

FIG. 1. (a) The schematic diagram of the two medium system in the P or AP state. (b) and (c) The RH and LH spin-wave polarizations, corresponding to $\sigma_n = +1$ and -1, respectively.

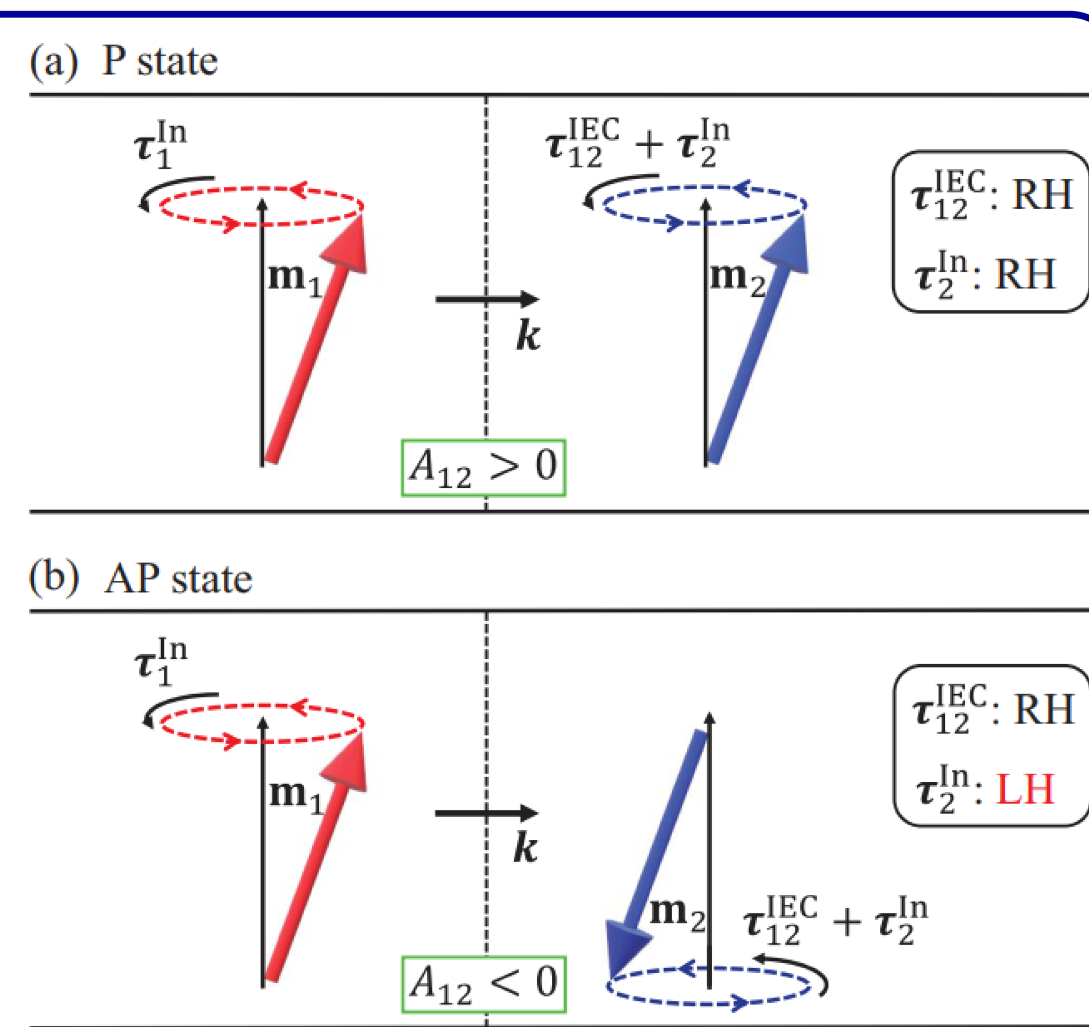

FIG. 2. (a) The precession details of $\mathbf{m}_1$ (red) and $\mathbf{m}_2$ (blue) at the interface between two magnetic media with the P configuration, where the type of IEC is ferromagnetic ($A_{12} > 0$). (b) The case of IEC is antiferromagnetic ($A_{12} < 0$).

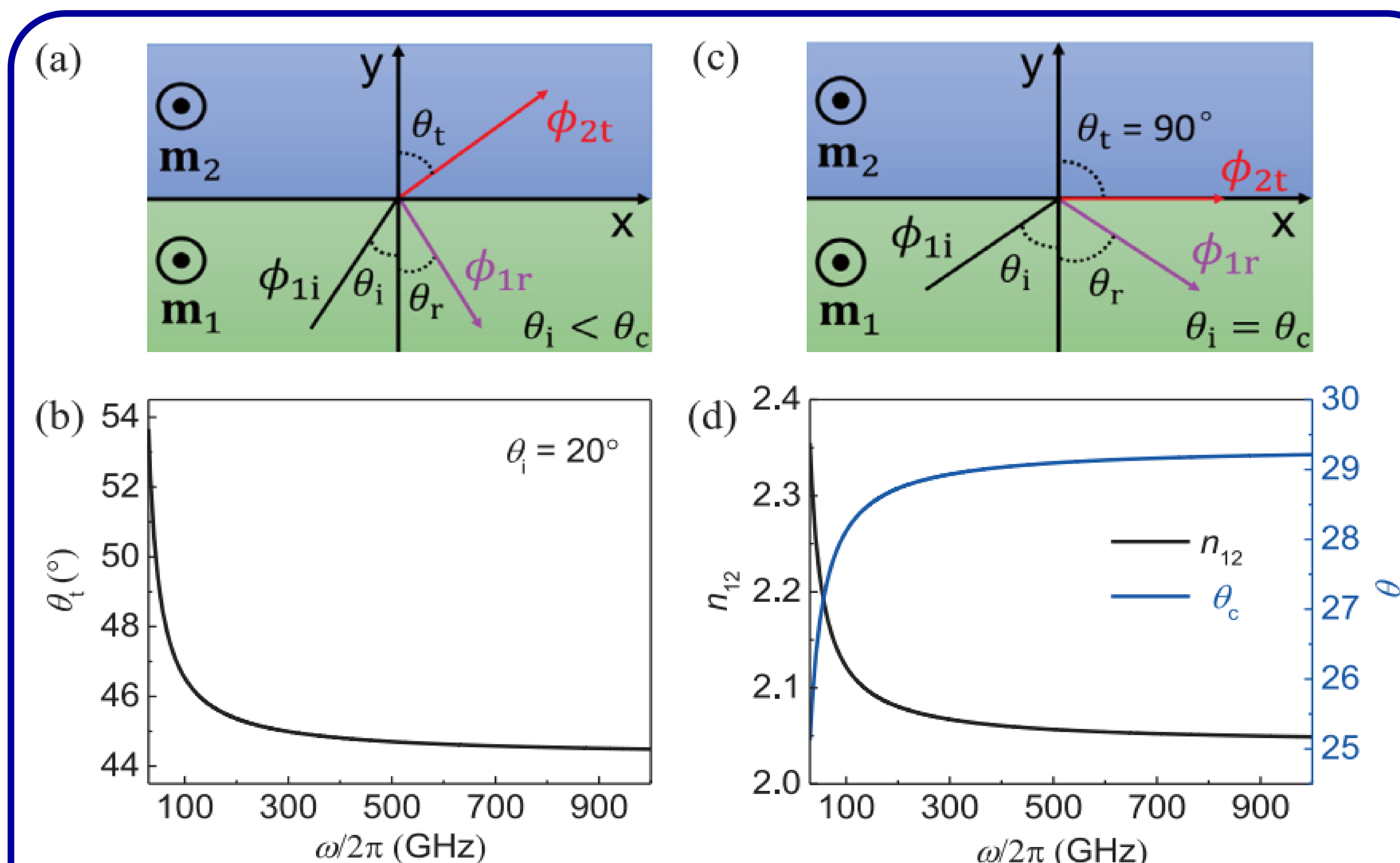

FIG. 3. The spin-wave transmission and reflection at the interface between YIG ($\mathbf{m}_1$) and GdIG ($\mathbf{m}_2$) with the P configuration. (a) When the incident angle is less than critical angle ($\theta_i < \theta_c$). The frequency-dependent refracted angle θ_t is shown in (b) at $\theta_i = 20°$. (c) As θ_i is increased to θ_c, spin waves are all reflected. (d) The frequency dependence of magnetic refractive index n_{12} (black) and critical angle θ_c (blue).

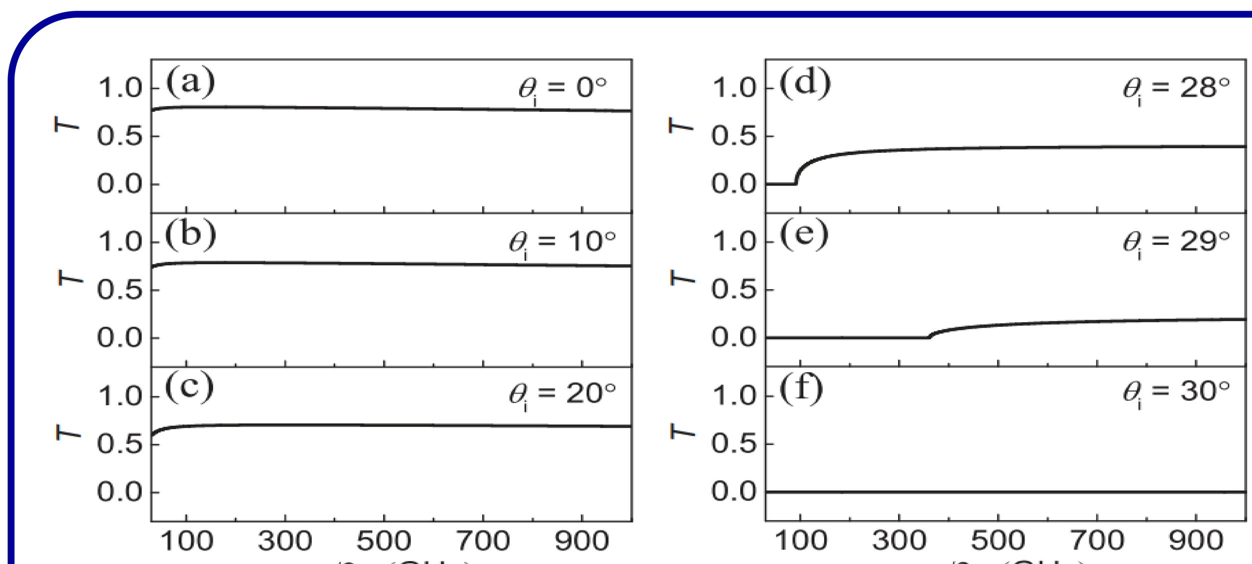

FIG. 4. The transmission spectra of spin waves in YIG ($\mathbf{m}_1$)/GdIG ($\mathbf{m}_2$) heterojunction with the P configuration. (a)–(f) The cases of θ_i = 0°, 10°, 20°, 28°, 29°, and 30°.

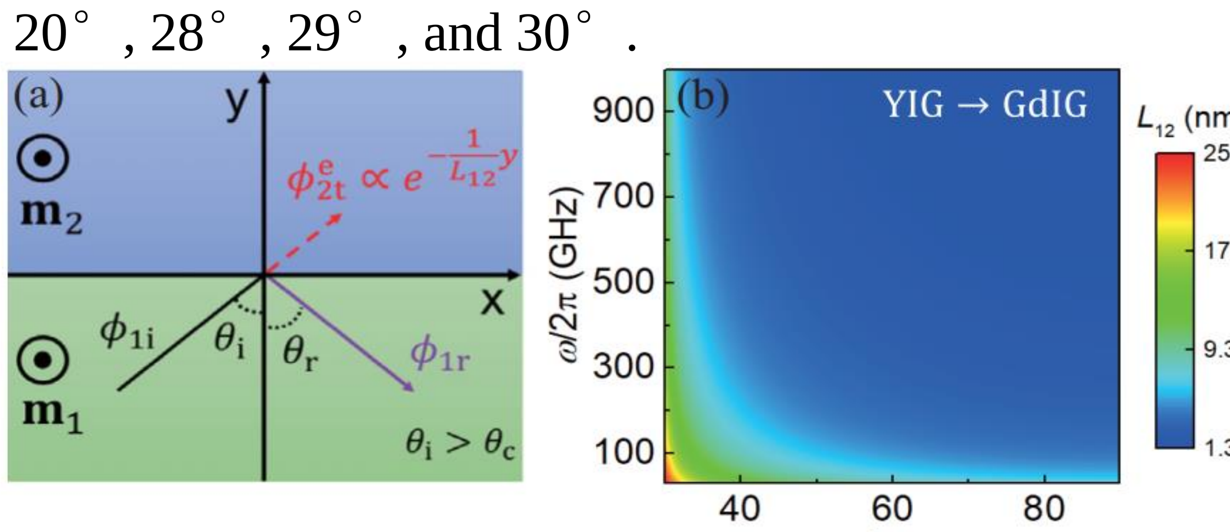

FIG. 5. The decay lengths of evanescent waves in the case of $\theta_i > \theta_c$. (a) As the incident angle θ_i exceeds the critical angle θ_c, spin waves are all reflected back. (b) The calculation result of the decay length L_{12}.

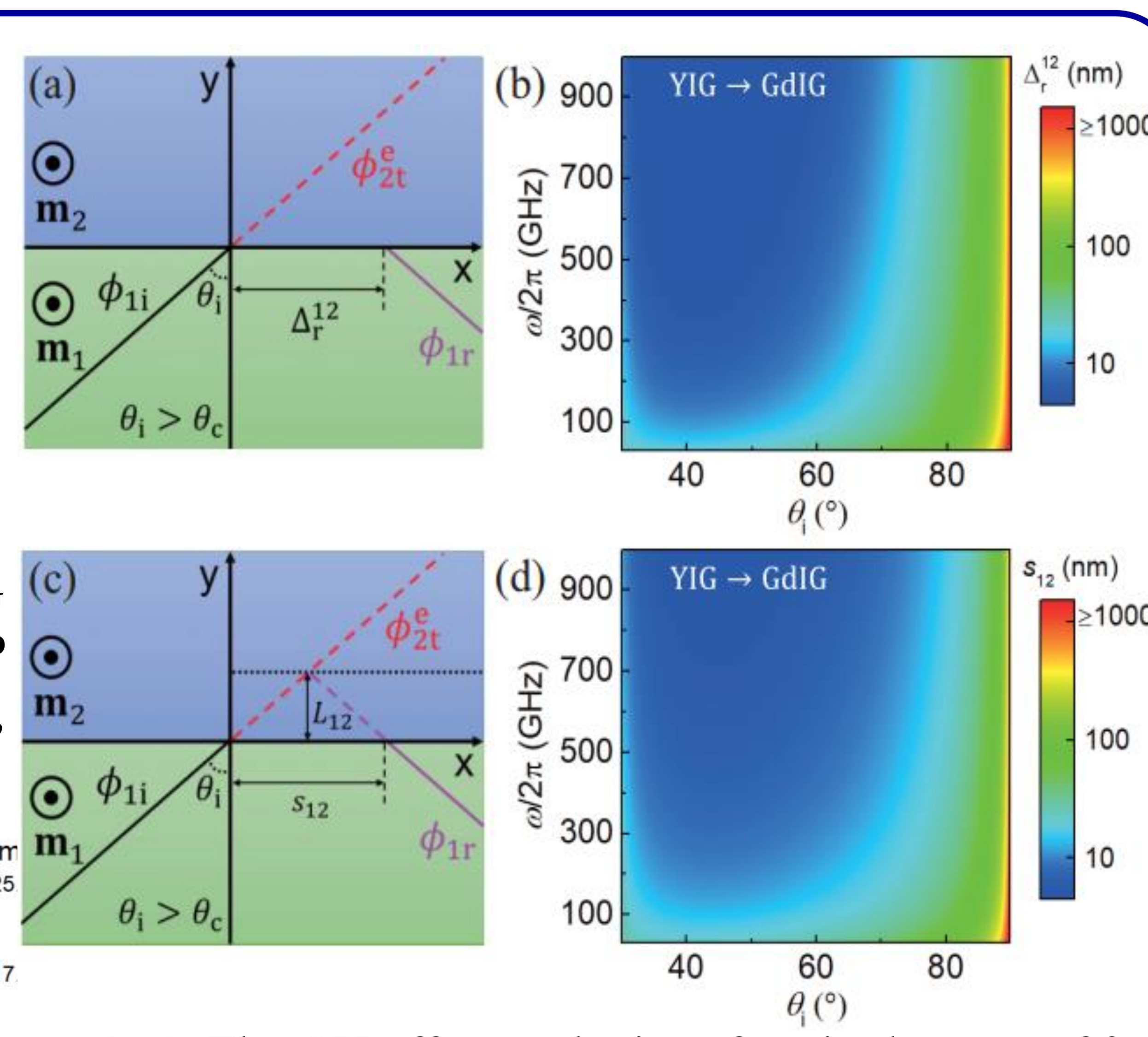

FIG. 6. The GH effect at the interface in the case of $\theta_i > \theta_c$. (a) The GH shift of the reflected waves, marked with Δ_r^{12}. (b) The result of Δ_r^{12} calculated by Eq. (25). (c) The relationship between the lateral shift s_{12} and decay length L12. The black dotted line represents the effective reflecting interface. (d) The result of s_{12} calculated by Eq. (26). The color bars in (b) and (d) are shown in the log scale

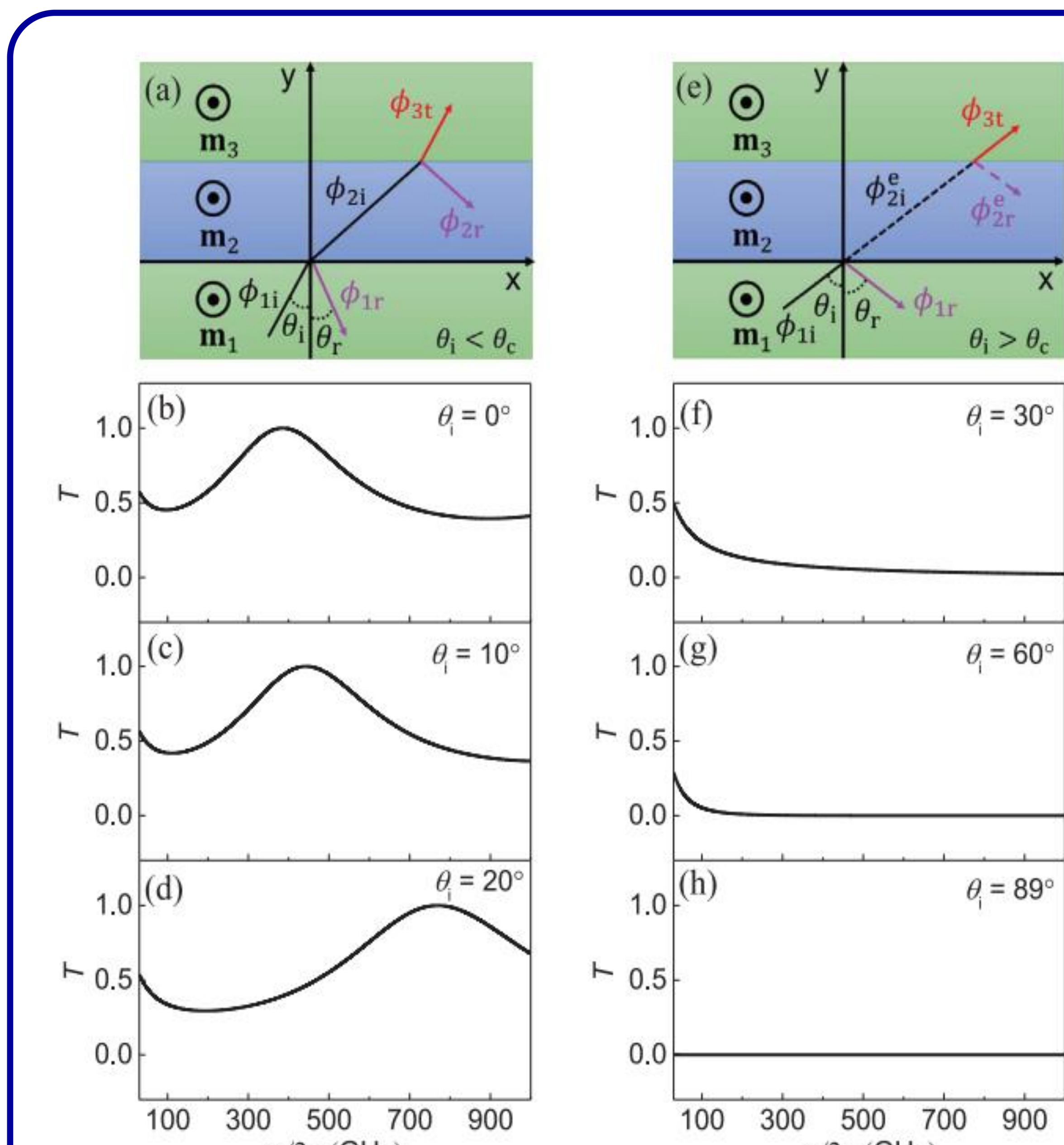

FIG. 7. The transmission spectra of spin waves in YIG ($\mathbf{m}_1$)/GdIG ($\mathbf{m}_2$)/YIG ($\mathbf{m}_3$) with the P configuration. (a)–(d) and (e)–(h) correspond to the cases of $\theta_i < \theta_c$ and $\theta_i > \theta_c$, respectively. The thickness of GdIG ($\mathbf{m}_2$) is 10 nm .

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