

Magneto-dynamic response of YIG ceramics: Influence of secondary phases

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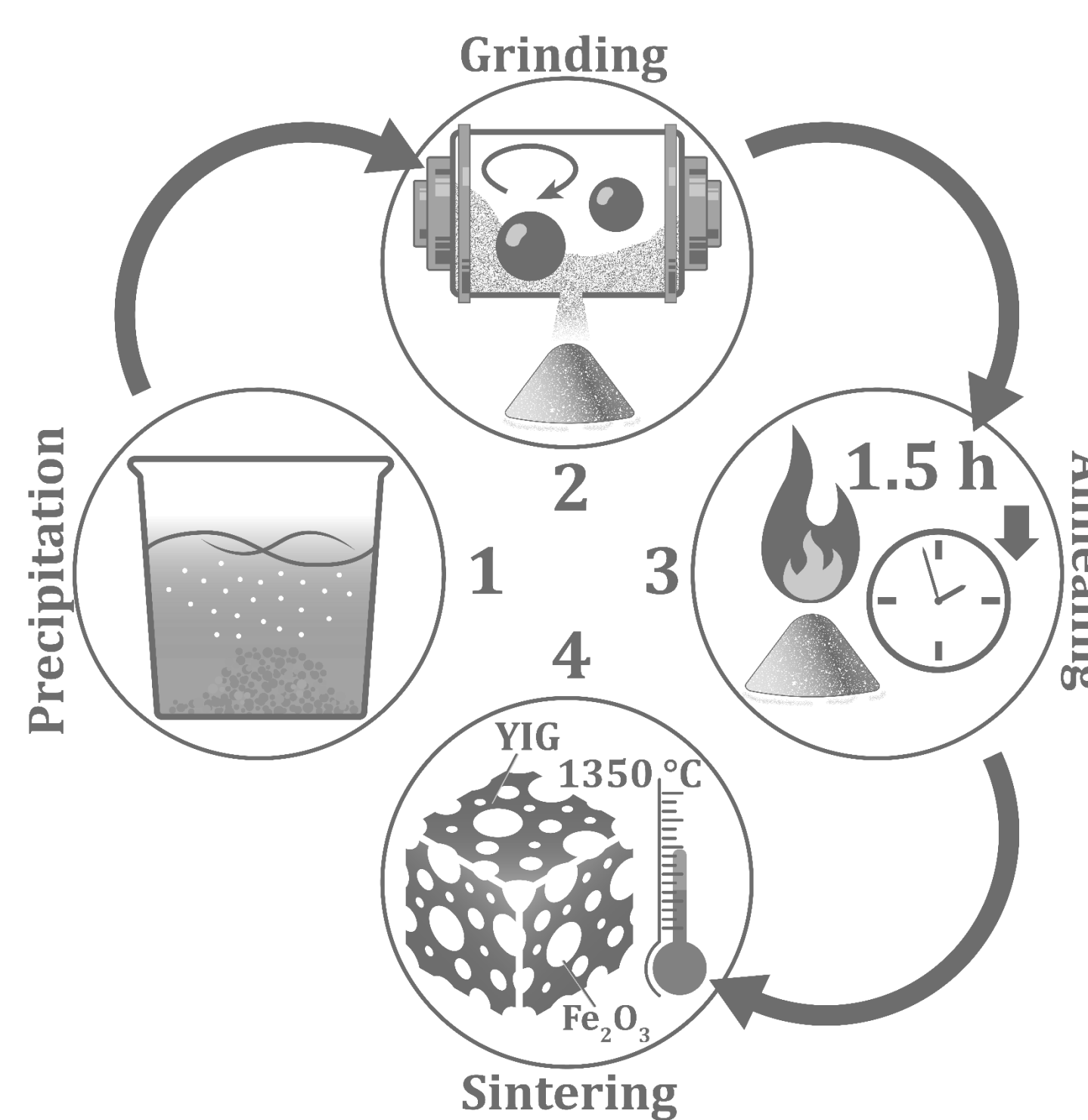
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Abstract

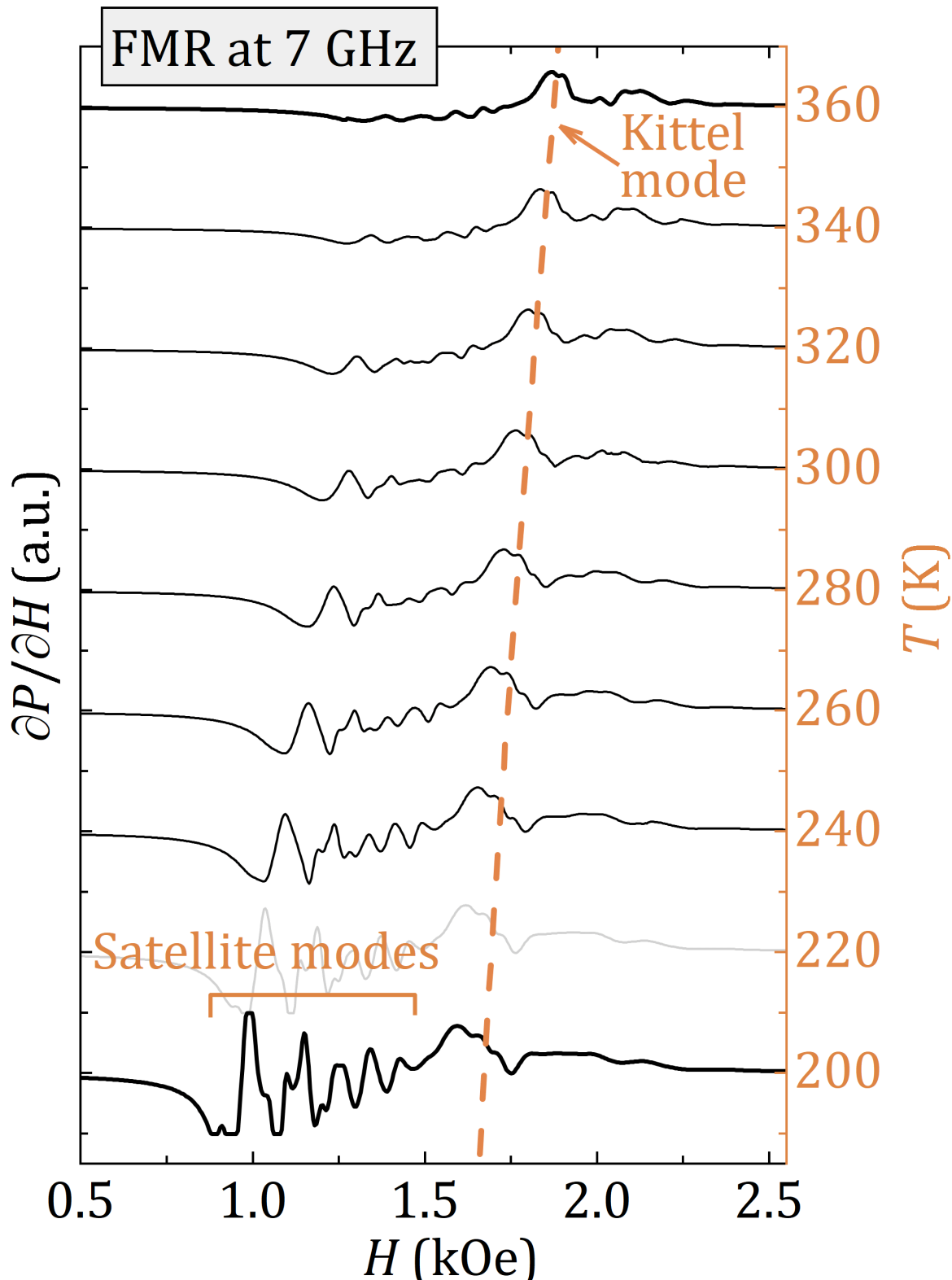
Doping garnet-based ceramics with magnetic and non-magnetic ions such as Co, Ni, Al, Sm, and Gd is a well-established strategy for tailoring their electromagnetic properties to demands of microwave electronics and spintronics. Previous studies demonstrated that substitution of Fe³⁺ with non-magnetic Al³⁺ cations not only enhances dielectric permittivity but also significantly reduces effective magnetic anisotropy. However, both Al-doped and undoped yttrium iron garnet (YIG) ceramics exhibited non-trivial FMR behavior, including additional signals and non-uniform broadening of the main mode. One of the reasons may be the formation of nano- and microscale inclusions of secondary phases within the polycrystalline YIG matrix. Intermediate phases such as hematite (α -Fe₂O₃), yttrium oxide (Y₂O₃), and orthoferrite (YFeO₃) may form and persist in the resulting product depending on stoichiometry and thermal conditions.

- Bulk YIG ceramics was synthesized via co-precipitation in aqueous solution with reduced annealing time. As a result, residual secondary phases may persist in the fabricated ceramics. Secondary phases modify sample microstructure, which may be responsible for the observed satellite modes.

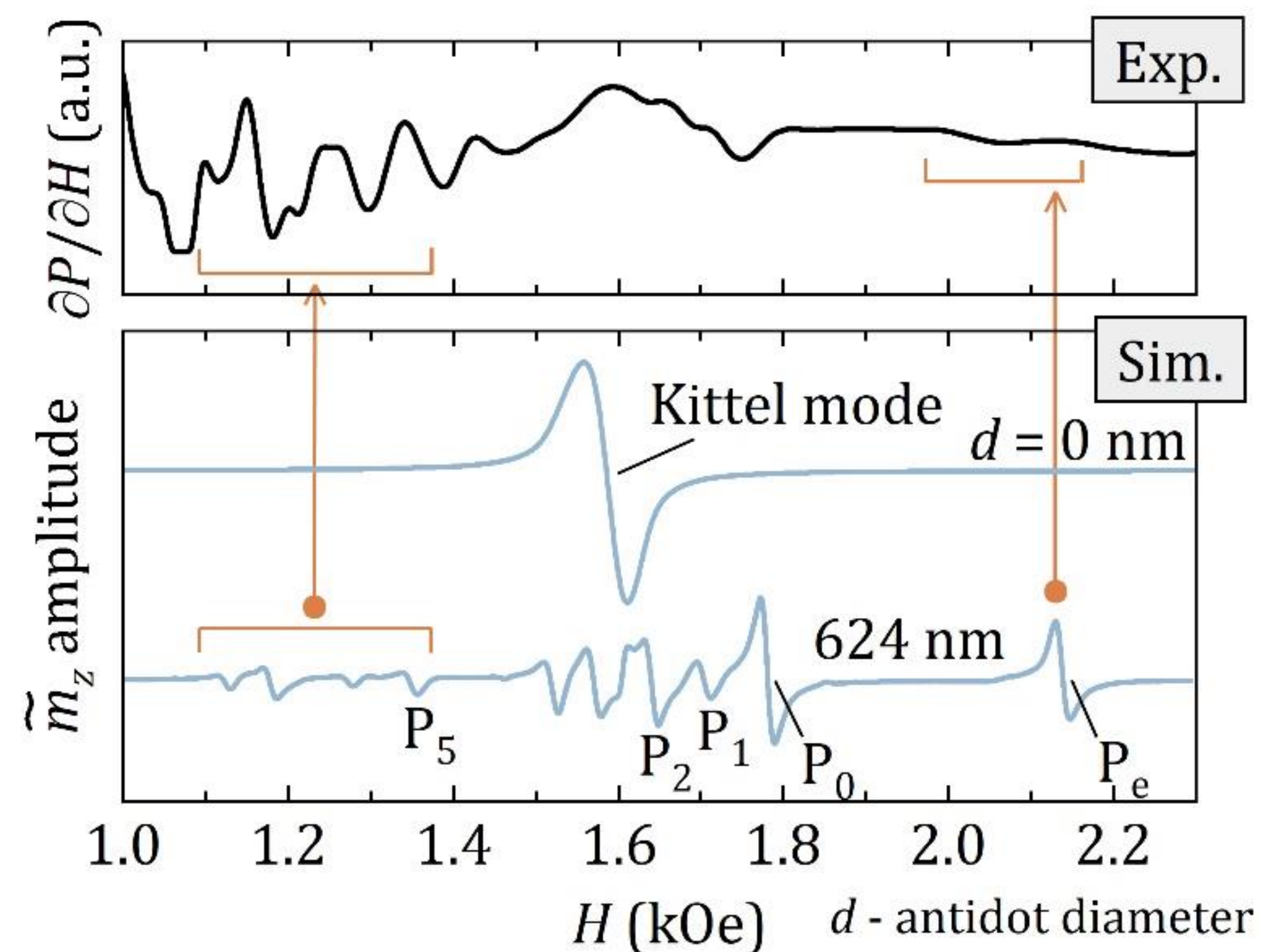
Schematic illustration of the garnet ceramics fabrication procedure



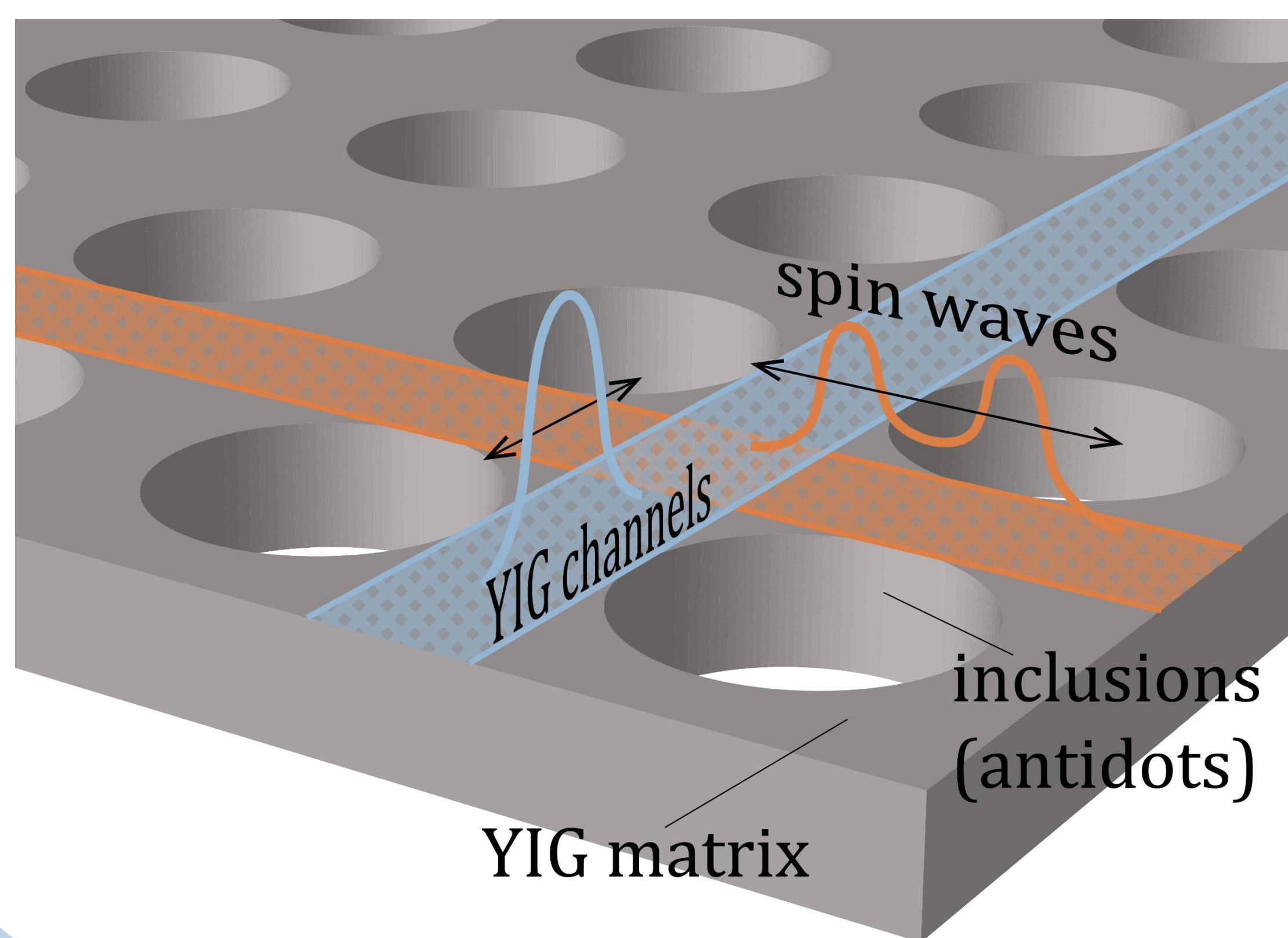
Temperature transformation of the FMR spectrum in synthesized bulk YIG



Comparison of the experimental FMR spectrum with micromagnetic calculations of an infinite film ($d = 0$ nm) and an antidot array ($d = 624$ nm); d – antidot diameter. Panel below shows power maps of the selected spin-wave modes.



Schematic illustration of the antidot array model. Weak-ferromagnetic inclusions act as circular holes in the YIG matrix, creating inhomogeneous fields necessary for spin-wave excitation.



- Our PXRD and SEM/EDS data confirm the formation of a predominant YIG matrix with a minor fraction (<2%) of α -Fe₂O₃ phase. Such a small amount cannot generate detectable signals in the CPW-FMR. However, hematite impurities take the form of microscopic inclusions with 0.5–5 μ m size distribution, which may induce inhomogeneous internal fields necessary for spin-wave excitation.

Discussion

- The inclusions impose boundary conditions and inhomogeneous internal fields profile, promoting excitation of higher-order modes within the YIG matrix itself – in the narrow channels between antidots.
- Micromagnetic simulations on an idealized model of a closely-packed antidot array provide good correspondence with the multimode spectrum at 624-nm antidot diameter, which falls within 0.5–5 μ m inclusions size distribution.
- Morin transition in hematite ($T_M \sim 260$ K) may explain the elevated intensities of the low-field modes, strongly dependent on internal fields localization.

Summary

YIG ceramics synthesized with reduced annealing time exhibit a multimode microwave spectrum in the GHz range. Structural analysis reveals residual hematite inclusions (0.5–5 μ m) embedded within the YIG matrix. These inclusions may form narrow YIG channels, promoting higher-order spin-wave excitations. Micromagnetic simulations on an idealized antidot array model successfully reproduce the multimode behavior, matching the experimental size distribution of hematite inclusions.

Acknowledgment

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