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Low-Temperature Formation of YIG and Its Structural Evolution Upon Copper Incorporation for Terahertz Applications

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INTRODUCTION & AIM

- Yttrium iron garnet (YIG) is an attractive candidate for microwave applications due to its magnetic and dielectric properties. Its widely used for high frequency electronic devices and possesses potential negative permeability
- Conventional synthesis of YIG requires high temperatures (>1000 °C).
- This study focuses on low-temperature synthesis of YIG (600 °C) and investigates how Cu incorporation (20–30 wt%) affects its structure and morphology.
- Taking chemical stability and preparation cost into consideration, the copper as an excellent conductor could offer conduction electrons for negative.
- Aim: To evaluate the impact of copper on crystallinity, porosity, and microstructure of YIG for potential microwave device applications.

METHOD

Y_2O_3 and Fe_2O_3 powders were mixed in a stoichiometric ratio of 3:5 and annealed at different temperatures (600- 1300 °C) for 6 h to form YIG precursor.

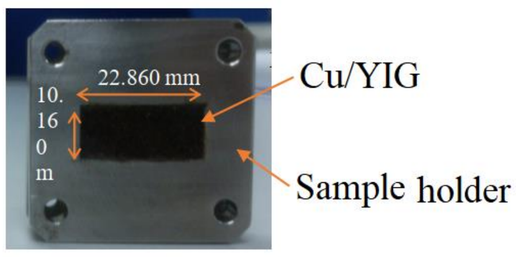
• Nano-sized YIG powder was sintered at 600 °C, then mixed with different CuO contents (20, 25, 30, 35 wt%) in ethanol and ball-milled for 10 h at 300 rpm (BPR = 20:1).

• The slurry was vacuum-dried at 353 K (80 °C), sieved, and pressed under 30 MPa into pellets (22.86 × 10.16 × 2 mm^3).

• Pellets were sintered at 1050 °C for 1 h and annealed in H_2 (99.9%) at 500 °C for 3 h.

• S-parameters (S_{11}, S_{21}) were measured in the 5–12 THz range using a vector network analyzer (VNA).

• The complex permittivity (ε_r) and permeability (μ_r) were extracted from S-parameters via the Nicolson–Ross–Weir (NRW) algorithm implemented in MATLAB.



The rectangular Cu/YIG sample inside the sample holder

CONCLUSION

YIG phase was successfully formed at 600 °C. Copper incorporation improved crystallinity and particle growth. The CY30 composite exhibited simultaneous negative ε′ and μ′ near 5.5 THz, confirming dual-negative behavior suitable for microwave applications.

FUTURE WORK / REFERENCES

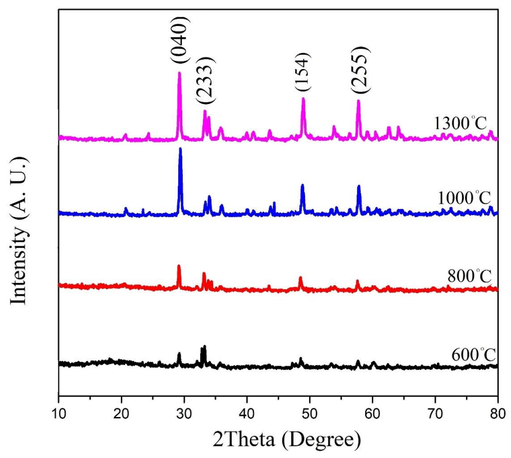
Further investigations will focus on tuning Cu concentration, exploring similar metallic dopants, and optimizing annealing conditions to enhance the electromagnetic response and extend the negative-index bandwidth.

[1] K. Sun *et al.*, *RSC Adv.*, **5** (2015) 61155–61160.
[2] R. Gholipur, A. Bahari, *Opt. Mater.*, **50** (2015) 175–183.
[3] R. Gholipur, A. Bahari, *Mater. Lett.*, **180** (2016) 123–126.
[4] R. Gholipur, A. Bahari, *Electron. Mater. Lett.*, **13** (2017) 179–183.
[5] P. Xie *et al.*, *Adv. Compos. Hybrid Mater.*, **5** (2022) 679–695.

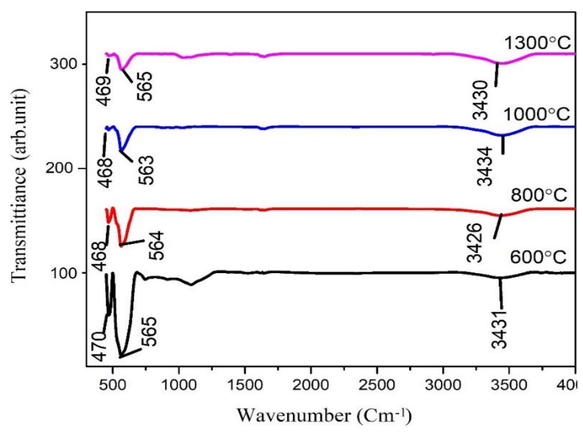
RESULTS & DISCUSSION

YIG powders were prepared via solid-state reaction using Y_2O_3 and Fe_2O_3 at 600–1300 °C for 6 h.

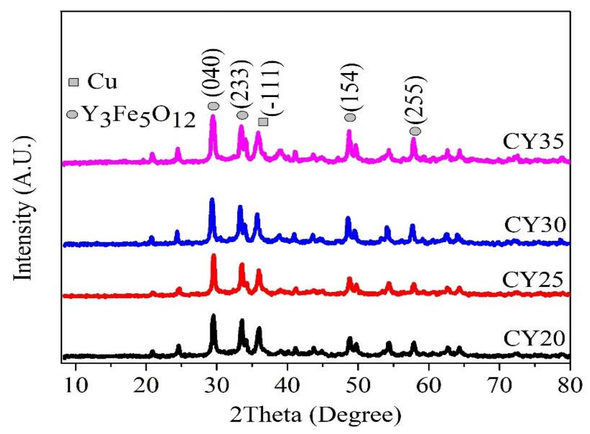
According to the XRD patterns and corresponding data table, the YIG structure was successfully obtained even at the calcination temperature of 600 °C.



Calcination temperature ℃	2θ ICDD standard	2θ Analyzed samples	d-spacing (A°) Analyzed sample	Size (nm)	Miller indices (h k l)
600	28/88	29/20	3/05	24	(040)
	34/00	33/92	2/63	44	(233)
	47/66	48/67	1/87	30	(154)
	54.53	54.23	1.69	49	(255)
800	28/88	29/35	3.04	24	(040)
	34/00	34/04	2.63	34	(233)
	47/66	48/80	1.86	30	(154)
	54.53	57.84	1.59	23	(255)
1000	28/88	29/19	3/05	34	(040)
	34/00	34.36	2/60	59	(233)
	47/66	47/30	1/92	62	(154)
	54.53	54/07	1.69	64	(255)
1300	28/88	29/20	3/05	34	(040)
	34/00	33/15	2/70	28	(233)
	47/66	48/58	1/87	22	(154)
	54.53	57/72	1/59	15	(255)

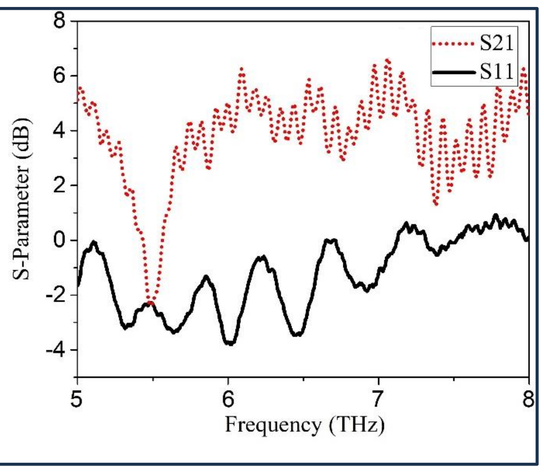


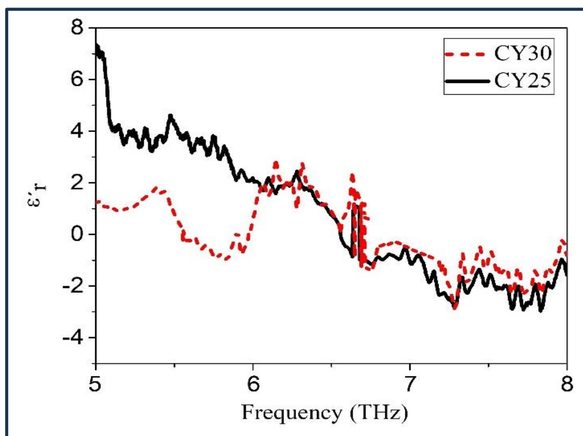
As shown in the FTIR spectra, the characteristic Fe–O stretching bands of YIG appeared around 470 and 565 cm^{-1}, indicating that the YIG phase was formed even at 600 °C.

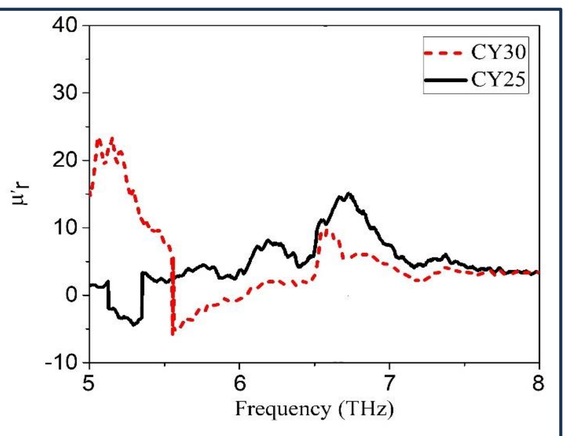


XRD patterns of Cu/YIG (CYx) composites show improved crystallinity with increasing Cu content. The growth of the Cu (−111) peak and particle size suggests the formation of Cu networks within the YIG matrix.

The S-parameters (S_{11} and S_{21}) reported by the VNA for the CY30 sample show a clear resonance around 5.5 THz, where both curves decrease, indicating strong absorption and the onset of plasmonic or metamaterial behavior. Multiple oscillations between 6–8 THz suggest complex electromagnetic interactions within the Cu/YIG composite.







The real parts of permittivity (ε'_r) and permeability (μ'_r) of CY25 and CY30 samples are presented. Both parameters become negative simultaneously around 5.5 THz, with the CY30 sample showing a stronger dual-negative (DNG) response compared to CY25.