Supporting Information

High-entropy Co-Zn-Cd-Cu-Mn sulfide ceramic nanoflowers as efficient microwave absorbers with photothermal performance

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Equations

The reflection loss (RL) values were obtained by transmission line theory, which could be summarized as the following equations:

$$Z_{in} = Z_0\sqrt{\mu_r/\varepsilon_r}\tanh\left[j(2\pi f d/c)\sqrt{\mu_r\varepsilon_r}\right] \quad \text{(S1)}$$

$$RL = 20\lg\left|(Z_{in} - Z_0)/(Z_{in} + Z_0)\right| \quad \text{(S2)}$$

where Z_{in} is the input impedance of the absorber, Z_0 is the impedance of free space, μ_r is the relative complex permeability ($\mu_r = \mu' - i\mu''$), ε_r is the complex permittivity ($\varepsilon_r = \varepsilon' - i\varepsilon''$), d is the thickness of absorber, c and f are velocity and frequency of light, respectively.

In general, the dielectric loss can be described by Debye's theory:

$$\varepsilon' = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + (\omega\tau_0)^2} \quad \text{(S3)}$$

where, ε_∞ is the relative dielectric permittivity in the high-frequency limit, τ is the polarization relaxation time, ω is the angular frequency, ε_s is the static permittivity, ε_0 is the dielectric constant of vacuum, σ is the electrical conductivity.

The attenuation constant (α) represents the attenuation capacity of electromagnetic, which is usually expressed as follows:

$$\alpha = \frac{\sqrt{2}\pi f}{c} \times \sqrt{(\mu''\varepsilon'' - \mu'\varepsilon') + \sqrt{(\mu''\varepsilon'' - \mu'\varepsilon')^2 + (\mu''\varepsilon' + \mu'\varepsilon'')^2}} \quad \text{(S4)}$$

For the relaxation losses, the Cole-Cole plots are used to analyze the polarization mechanism, according to the following equation:

$$\left(\varepsilon' - \frac{\varepsilon_s + \varepsilon_\infty}{2}\right)^2 + (\varepsilon'')^2 = \left(\frac{\varepsilon_s + \varepsilon_\infty}{2}\right)^2 \quad \text{(S5)}$$

Figures

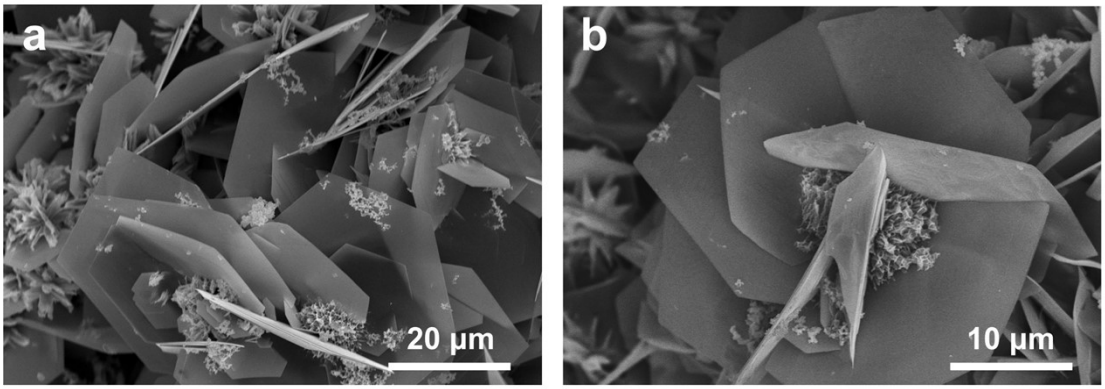

Fig. S1. (a, b) SEM images of CoZnCdCuMnS-500 at different magnifications.

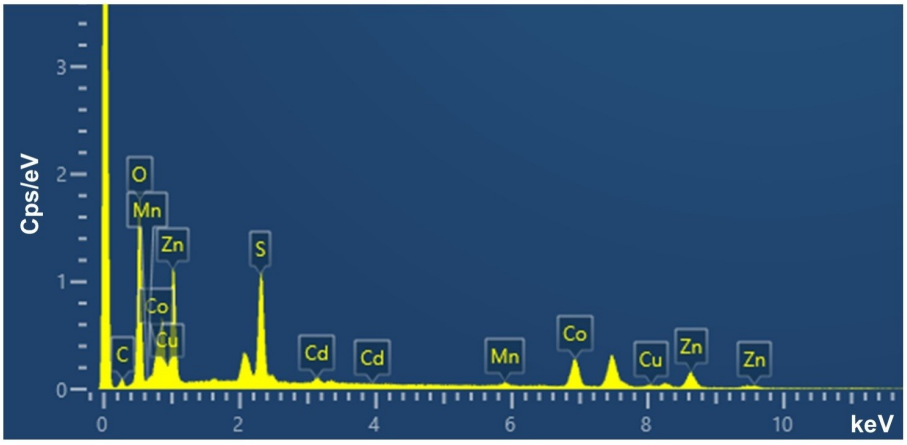

Fig. S2. The EDS spectrum of CoZnCdCuMnS-500.

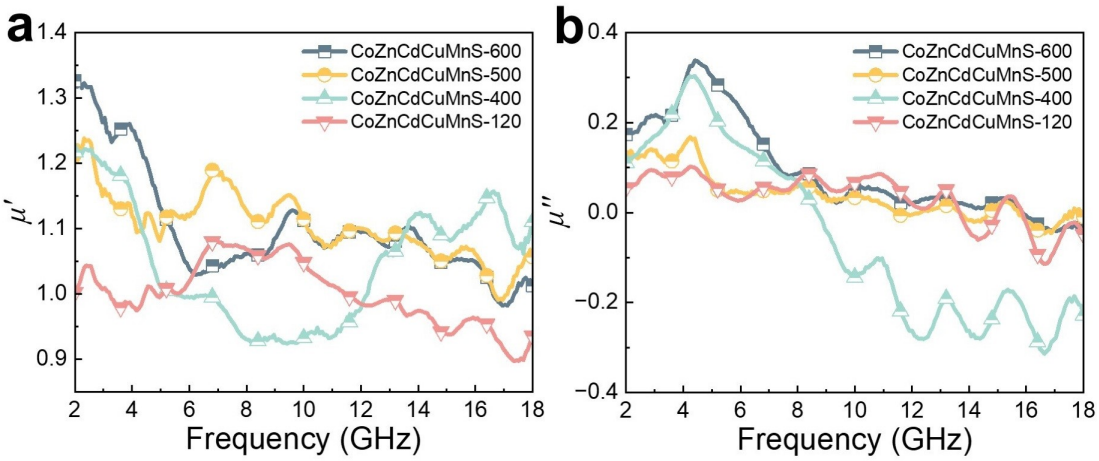

Fig. S3. (a) μ' and (b) μ'' of samples.

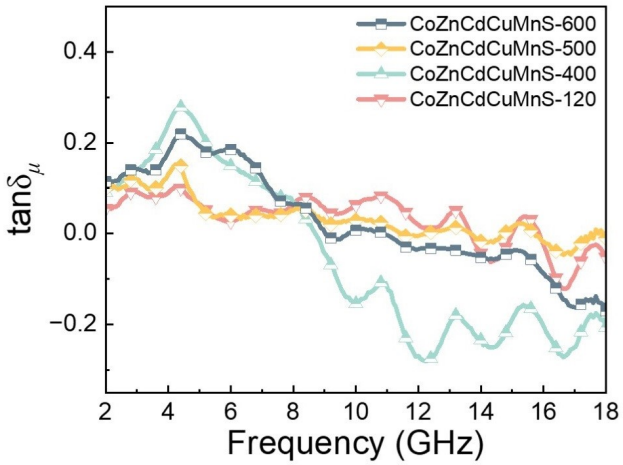

Fig. S4. The $tan\delta_{\mu}$ curves of samples.

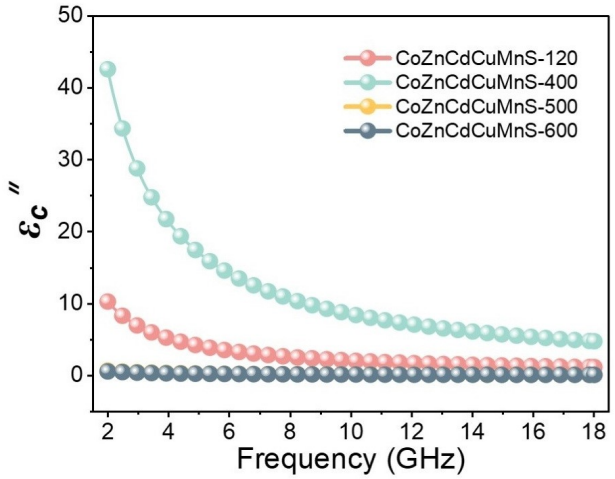

Fig. S5. The ε_c'' curves of samples.

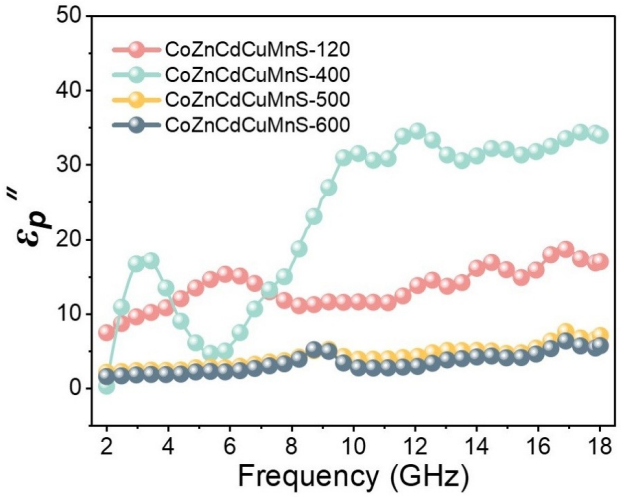

Fig. S6. The ε_p'' curves of samples.

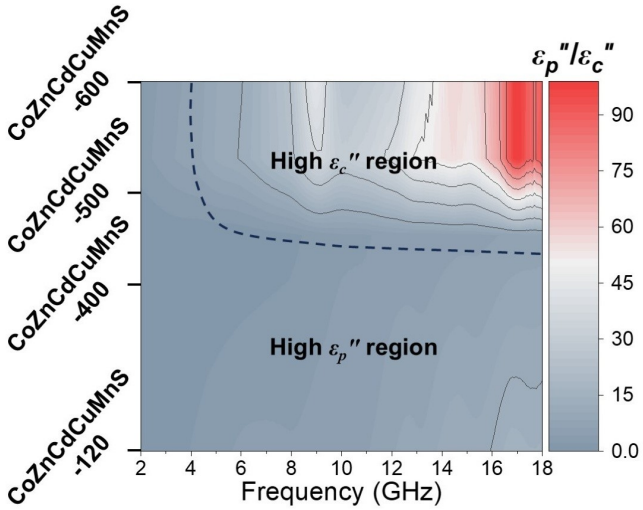

Fig. S7. Distribution of the $\varepsilon_p''/\varepsilon_c''$ ratio of samples.

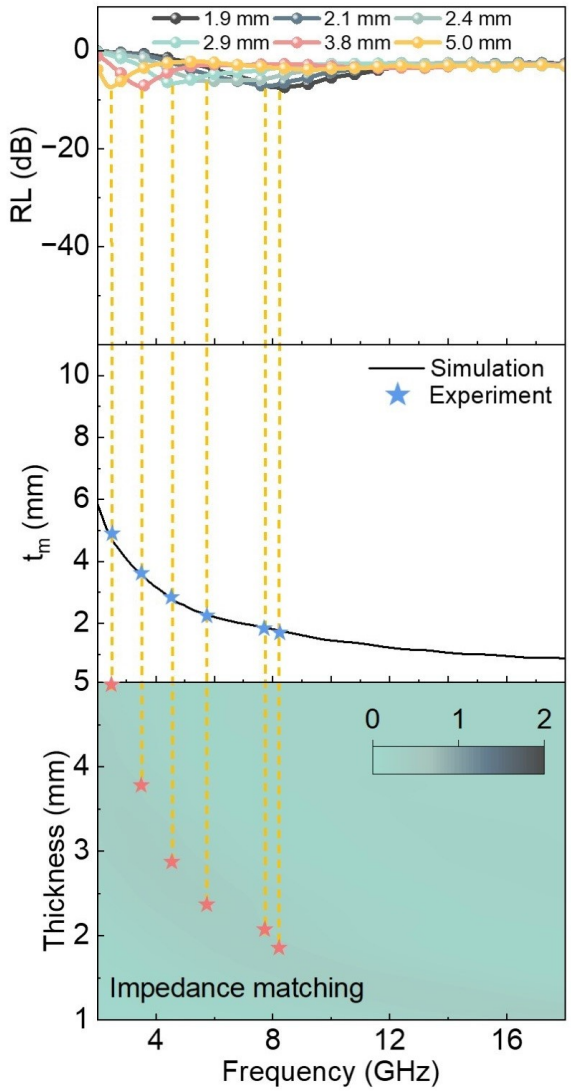

Fig. S8. The RL, dependence of t_m on f_m at $\lambda/4$ wavelength and impedance matching characteristics ($Z = Z_{in}/Z_0$) of CoZnCdCuMnS-120.

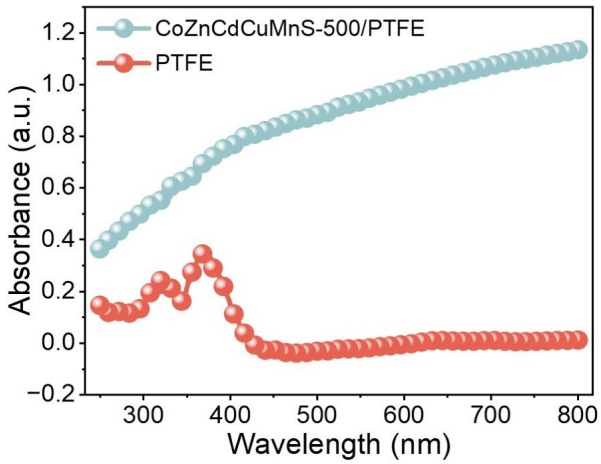

Fig. S9. The UV–vis-NIR diffuse reflectance spectra of samples.

Tables

Table S1 Semi-quantitative XPS analysis for CoZnCdCuMnS-500.

Component	BE (eV)	Mass conc.%	Error
S 2p	168.7	30.8	2.4
Zn 2p	1045.0	6.0	1.0
Co 2p	780.9	40.8	3.8
Cu 2p	932.1	7.9	1.7
Mn 2p	642.1	9.0	3.2
Cd 2p	405.2	5.4	1.1

Table S2 Performance comparison

Absorbers	RL_{min} (dB)	Thickness (mm)	Frequency (GHz)	Refs.
CuS/ZnS	−43.6	2.7	5.1	[32]
FeNi/Fe_3BO_5/ ZnS	−37.6	1.5	15.5	[33]
Carbon nanotube-CdS	−47.0	2.6	11.6	[34]
Hierarchical dandelion-like CoS_2	−47.3	3.3	11.8	[35]
Ni_3S_2@N	−46.9	2.0	17.1	[36]
Ni@Ni_3S_2	−50.7	3.6	12.5	[37]
CoZnCdCuMnS-500	**−50.8**	**2.4**	**9.3**	**This work**