Heat Generation Ability for Fine Mg-type Substitution Ferrite Particle in the AC Magnetic Field.

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Background

Thermal coagulation therapy that utilizes an AC magnetic field is attracting attention as a new treatment method that reduces the need for invasive surgical approaches in the treatment of cancer tumors (Fig.1).

In order to put this therapy into practical use, there is a need to develop magnetic particles that have excellent heat-generating ability in AC magnetic fields.

A new cancer treatment method: "AC magnetic field ablation"

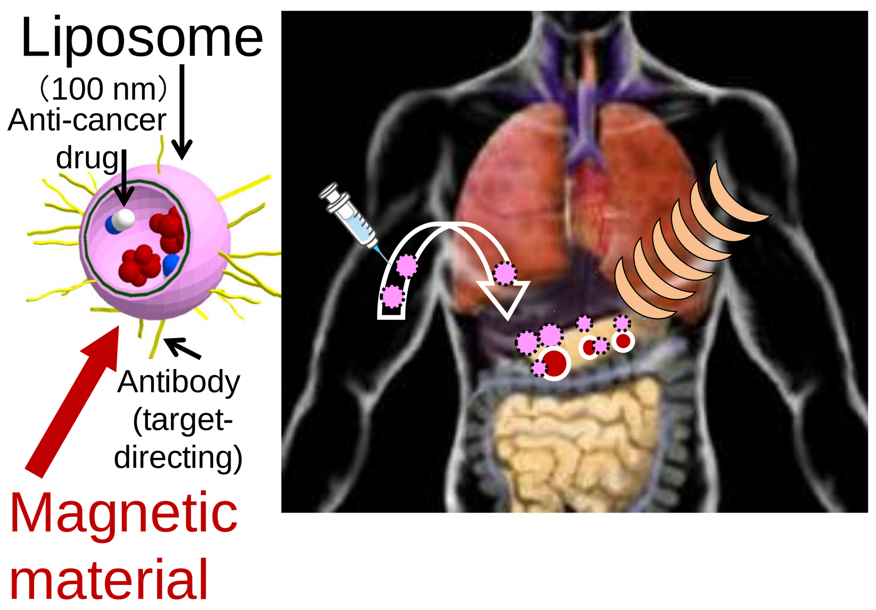

Fig.1 Outline of new cancer treatment using AC magnetic field.

1. Liposomes are injected into the body using a catheter, Placed in or near a cancer tumor
2. Apply an alternating magnetic field
3. The heat generated causes tumor necrosis (over 42.5°C)

Purpose

In our previous studies, we found that the $MgFe_2O_4$ having highest heat generation ability in various ferrite powders [1]. Moreover, we then reported that the ion substitution into spinel type ferrite structure was effective to improve the heat generation ability in the AC magnetic field.

In this study, we tried to develop the fine $Mg_{1-X}M_XFe_2O_4$ powder (M: Ca, Zn) by solvothermal method and to clarify the mechanism of heat generation ability in the AC magnetic field.

Previous research

The $MgFe_2O_4$ sample with the best heat generation ability was synthesized at 210°C without the addition of sodium acetate, moreover the concentration of metal nitrates was 0.10 mol/L.

From these results, the improvement in heating capacity was not thought to be due to hysteresis loss besides Néel relaxation.

Sample preparation

1. $Mg(NO_3)_2$- $6H_2O$, and $Fe(NO_3)_3$-$9H_2O$ was dissolved in ethylene glycol
2. Heated in autoclave at 210℃ (solvothermal synthesis)
3. Washed in pure water and ethanol, after that dried using constant temperature dryer

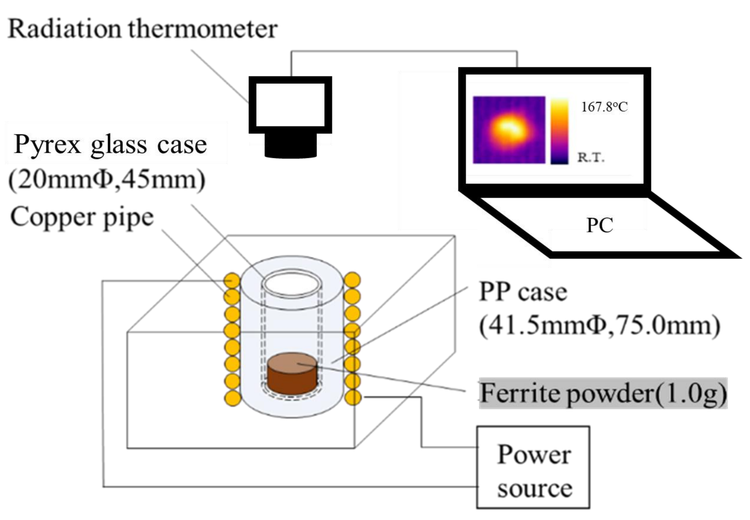

Fig.2 Heat generation device using AC magnetic field(370kHz, 2.65kA/m)

Research method

The ion substitution such as Ca or Zn is expected to produce crystal distortion, which increases hysteresis loss and increasing heat generation ability in the AC magnetic field.

I. Part of the staring material magnesium nitrate hexahydrate was changed to calcium nitrate tetrahydrate.

II. Part of the starting material magnesium nitrate hexahydrate was changed to zinc nitrate hexahydrate

Results and Discussion

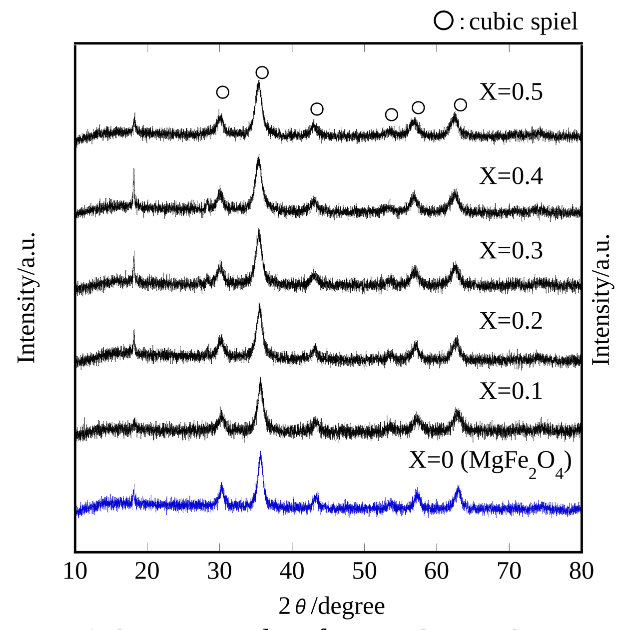

Fig3.XRD results of $Mg_{1-X}Ca_XFe_2O_4$ powder prepared by solvothermal synthesis.

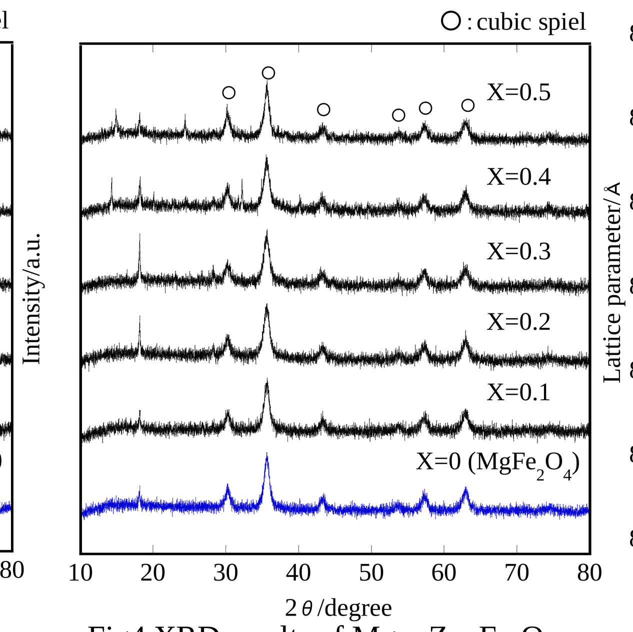

Fig4.XRD results of $Mg_{1-X}Zn_XFe_2O_4$ powder prepared by solvothermal synthesis.

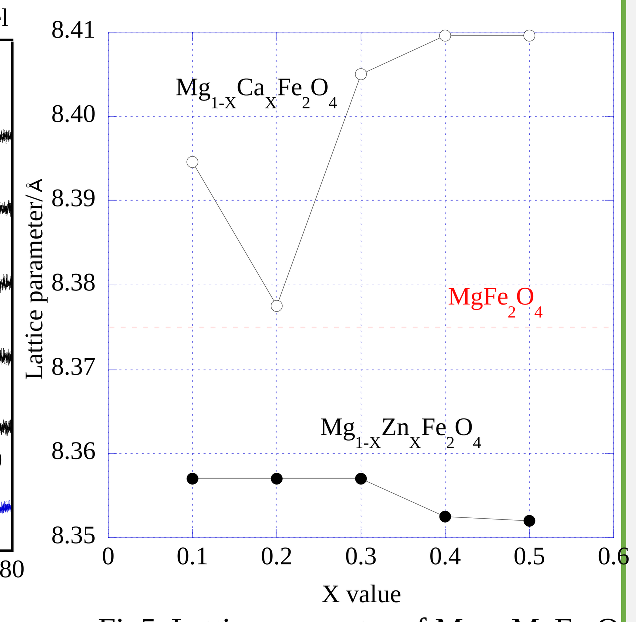

Fig5. Lattice parameter of $Mg_{1-X}M_XFe_2O_4$ sample calculated from XRD results.

Spinel type cubic peaks were observed in almost all of the samples, it suggests that Zn and Ca ions are substituted into the spinel structure.(Fig.3,4)
The shift of the peaks due to ion substitution was shown from XRD patterns, which confirms the change in the lattice parameter due to ion substitution.(Fig.3,4)
The lattice constants change significantly with the amount of ion substitution X. In particular, the crystal lattice is greatly distorted when Ca ions are substituted.(Fig.5)

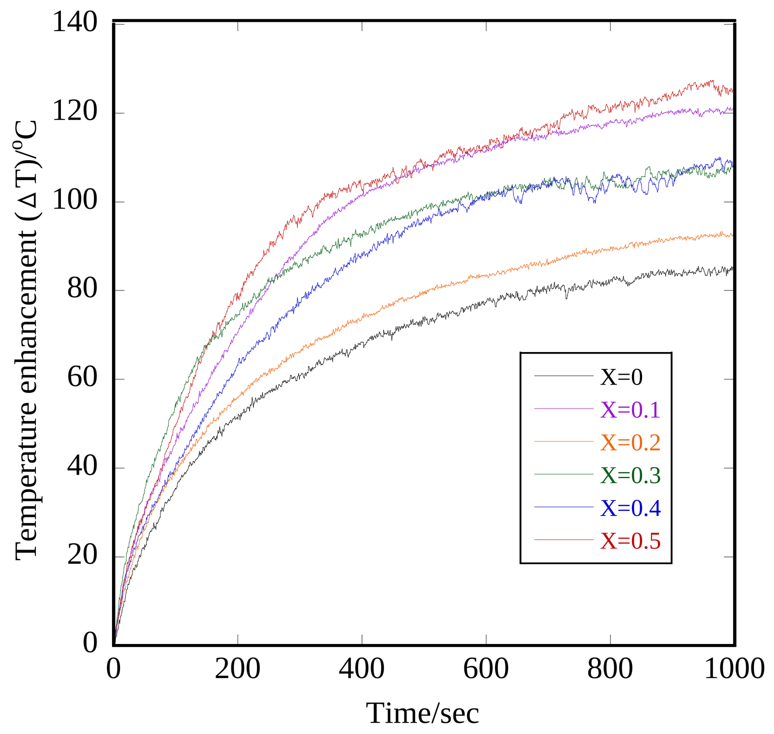

Fig.6 Temperature enhancement(ΔT) in the AC magnetic field of $Mg_{1-X}Ca_XFe_2O_4$ powder prepared by solvothermal synthesis.

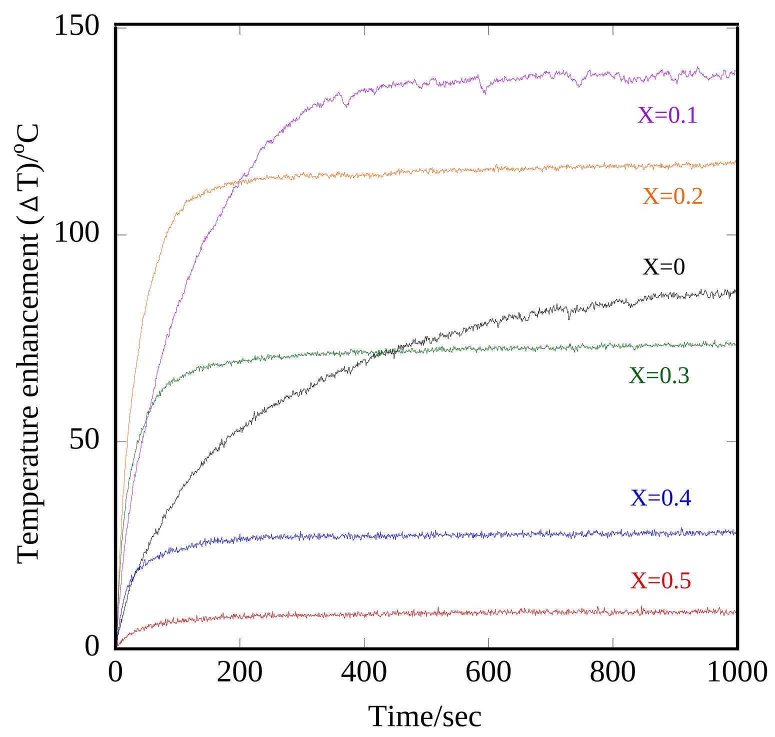

Fig.7 Temperature enhancement(ΔT) in the AC magnetic field of $Mg_{1-X}Zn_XFe_2O_4$ powder prepared by solvothermal synthesis.

The heat generation ability for $Mg_{1-X}Ca_XFe_2O_4$ was improved for all substitution sample, especially the highest heat generation ability ca. 120°C was obtained at X=0.5 sample. (Fig.6)
On the other hand, the Zn-substituted $MgFe_2O_4$ sample with X=0.1 showed the highest heat generation ability ca.140.6°C, however the heat generation ability was decreased with increase the Zn substitution.

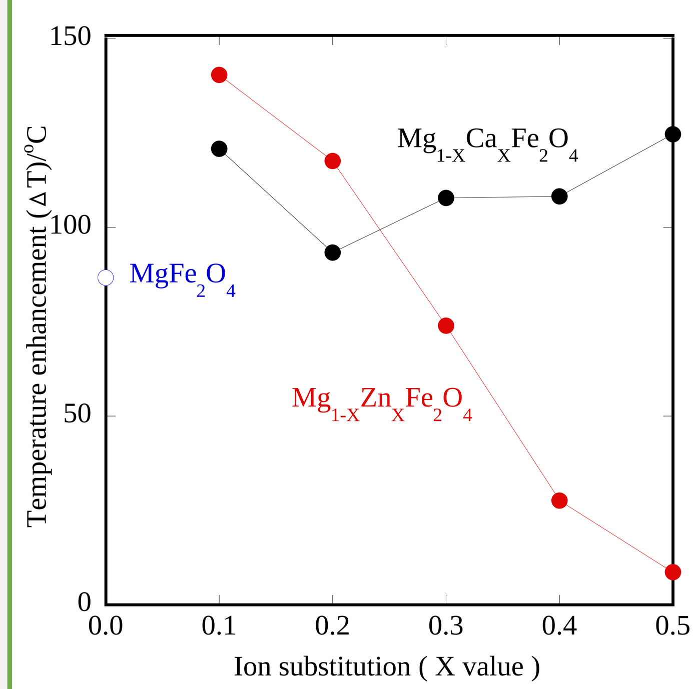

Fig.8 Temperature enhancement of $Mg_{1-X}M_XFe_2O_4$ (M=Ca, Zn)ferrite powder prepared by solvothermal synthesis. ΔT value was plotted after 1000sec in the AC magnetic field.

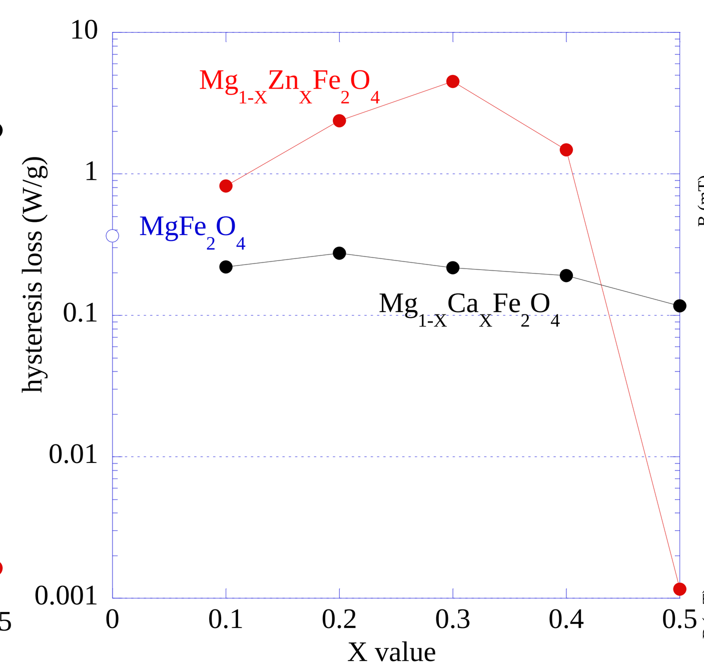

Fig.9 Heat generation ability in the AC magnetic field of $Mg_{1-X}M_XFe_2O_4$ (M=Ca, Zn) ferrite powder prepared by solvothermal synthesis.

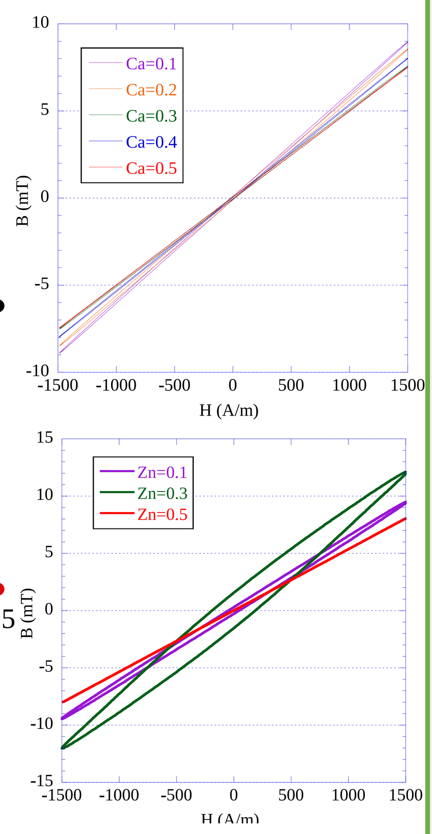

Fig.10 Hysteresis loops of $Mg_{1-X}M_XFe_2O_4$ (M=Ca, Zn) ferrite powder prepared by solvothermal synthesis.

The heat generation ability for all the Ca-substituted ferrites was increased from $MgFe_2O_4$, however the hysteresis loss value was decreased.(Fig.8, 9 and 10)
In Zn-substituted ferrite, the heat generation ability increased at X=0.1 and 0.2, while it tended to decrease at X=0.3 and above. However, hysteresis loss showed a different tendency from heat generation results, thus there was no clear dependence between heating capacity and hysteresis loss. (Fig.8, 9 and 10)

Conclusion

In this study, substituted Mg ferrites were synthesized by the solvothermal method, and the following findings were obtained

- As a result of synthesizing substituted ferrite by the solvothermal method, the single phase of cubic ferrite was observed, suggesting that it is substituted within the crystal.
- The heat generation ability was improved for all Ca-substituted sample, the highest heat generation ability was confirmed at X=0.5 sample.
- The highest heating ability was obtained at $Mg_{0.9}Zn_{0.1}Fe_2O_4$, there was no correlation between hysteresis loss and heat generation capacity.

References

[1] Maehara, T. *et al.*, Selection of Ferrite Powder for Thermal Coagulation Therapy with Alternating Magnetic Field, J. Mater. Sci., **40**(1), 135 (2005).
[2] J. Nonkumwong *et al.*, "Phase formation, morphology and magnetic properties of $MgFe_2O_4$nanoparticles synthesized by hydrothermal technique", J. Magn. Magn. Mater., **381** (2015) 226.

Acknowledgments

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