Controlling magnetic anisotropy via cation exchange and the development of ferromagnetic mini-Torquer

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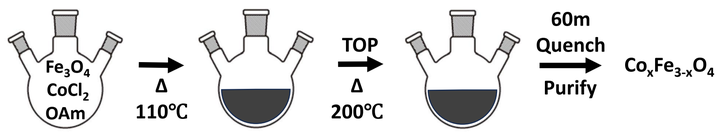
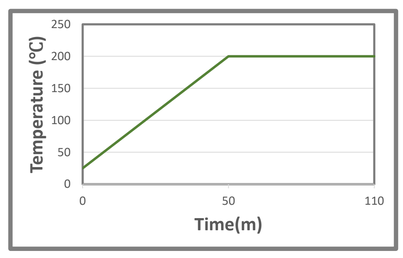
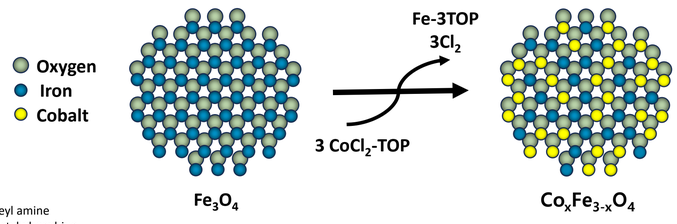
Scheme

Ⅰ. Synthesis of $Co_xFe_{3-x}O_4$ from 17 nm Fe_3O_4





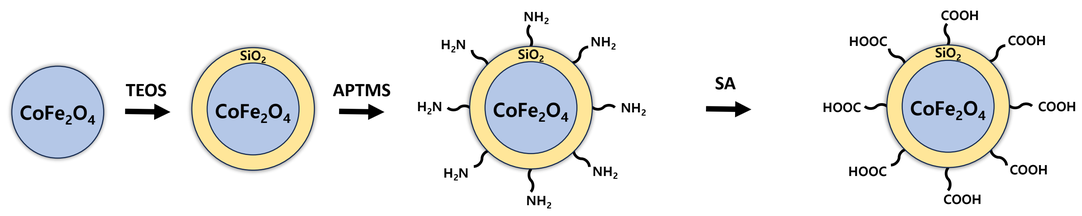
Ⅱ. Cobalt Cation Exchange



OAm : Oleyl amine
TOP : trioctyl phosphine

Fe_3O_4	$CoCl_2$	OAm	TOP
30mg	0.03125 mmol	21mL	0.03125 mmol
	0.125 mmol		0.125 mmol
	0.25 mmol		0.25 mmol
	0.375 mmol		0.375 mmol
	0.5 mmol		0.5 mmol
	1 mmol		1 mmol
	2 mmol		2 mmol

Ⅰ. Workflow of surface modification with 30 nm $CoFe_2O_4$



TEOS : Tetraethyl orthosilicate
APTMS : (3-Aminopropyl)trimethoxy silane
SA : Succinic anhydride
EDC : 1-ethyl-3-(3-dimethylaminopropyl)carbodiimide
NHS : N-Hydroxy succinimide
PEG : Polyethylene glycol

Ⅱ. Application as m-Torquer

Results

Ⅰ. Structural Properties

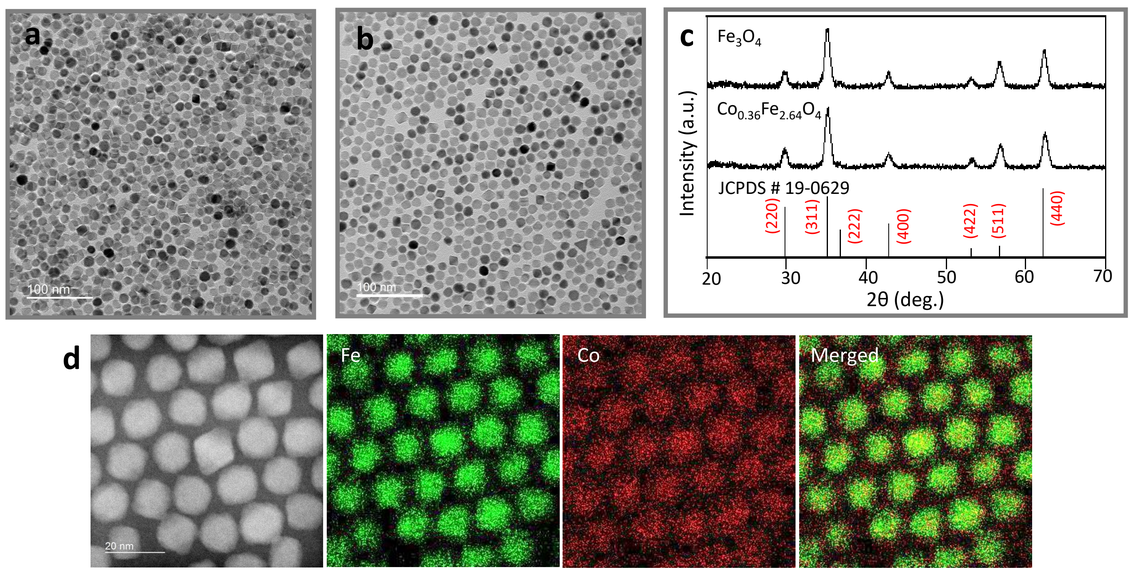
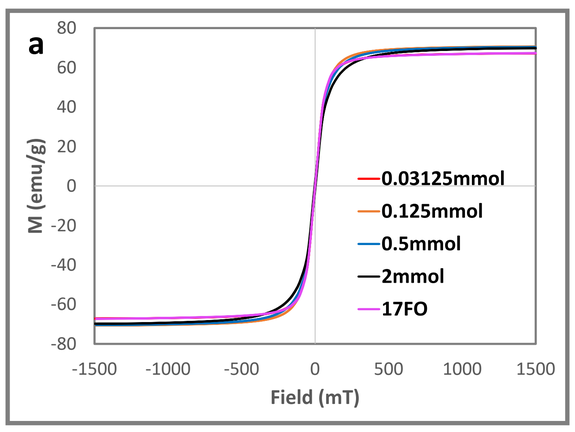
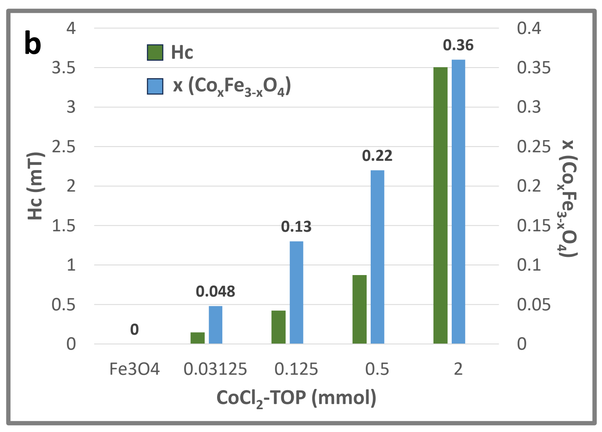
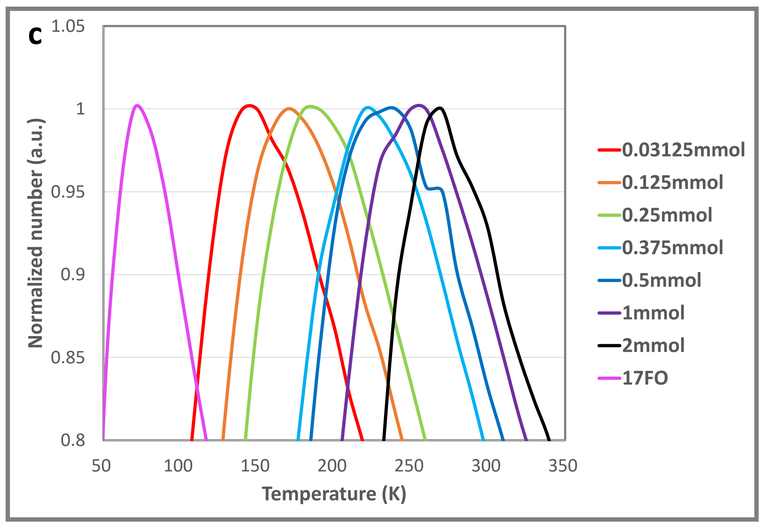


Fig1. Structural properties before & after cation exchange. (a) TEM image of 17 nm Fe_3O_4 before cation exchange. (b) TEM image after cation exchange with 2mmol $CoCl_2$-TOP. (c) XRD analysis of Fe_3O_4 and $Co_xFe_{3-x}O_4$. (d) Energy dispersive X-ray spectroscopy (EDS) image of $Co_{0.36}Fe_{2.64}O_4$.

Ⅱ. Magnetic Properties







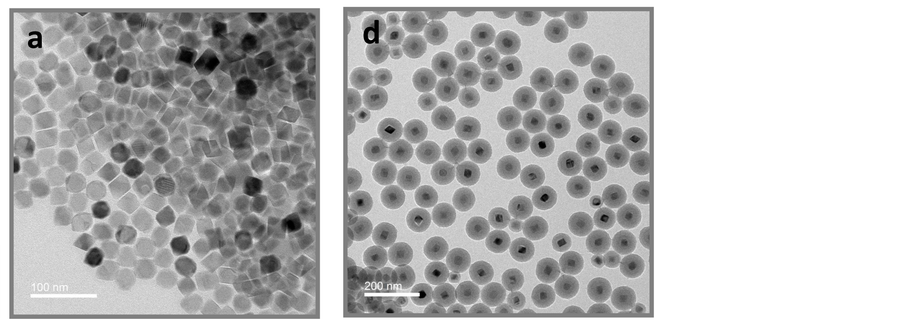
d Precursor (mmol)	T_b (K)	K_{eff} (J/m^3)
-	70	9604
0.03125	150	20580
0.125	170	23324
0.25	190	26068
0.375	220	30184
0.5	240	32928
1	250	34300
2	270	37044

e

$$T_b = \frac{K_{eff} V}{k_B \ln(\tau_m/\tau_0)}$$

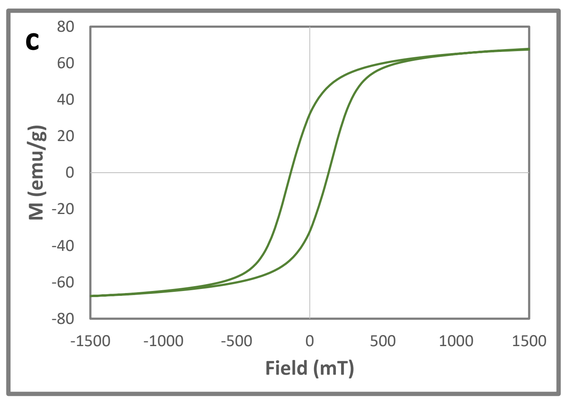
Fig2. Magnetic properties after cation exchange. (a) Magnetic hysteresis loops. (b) Changes of coercivity and the cobalt doping level x depending on precursor amount when the experimental conditions are 200℃. (c) Zero field cooling curves. (d) Table of Blocking temperature & magnetic anisotropy K_{eff}. (e) Equation that express the relationship between blocking temperature and anisotropy.

Ⅰ. 100 nm m-Torquer



b

Hc (mT)	Ms (emu/g)
128.95	67.55



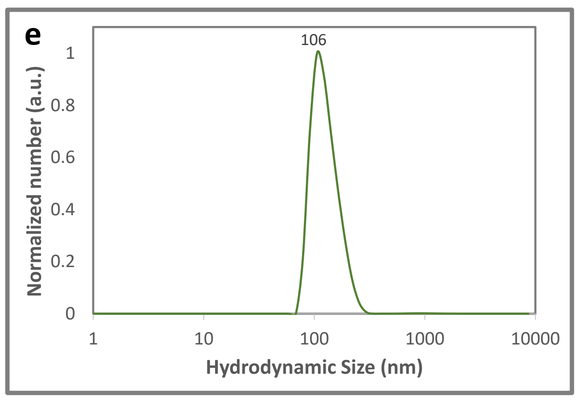
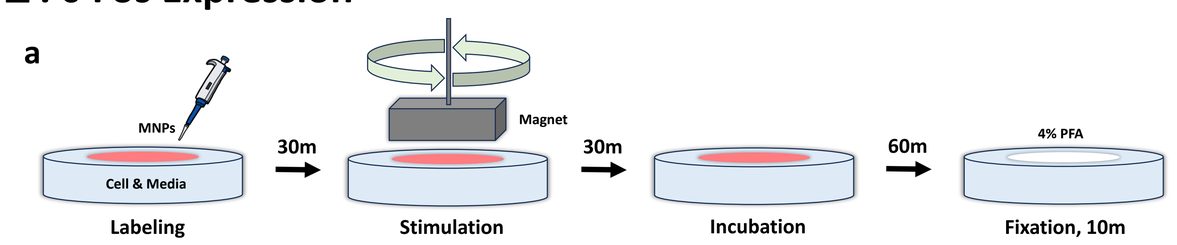
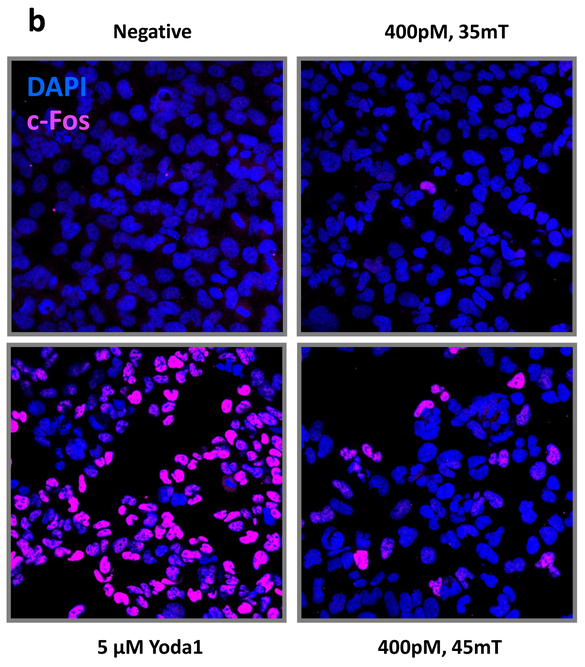


Fig3. Analysis of particle size. (a) TEM image of 30 nm $CoFe_2O_4$ before surface modification. (b) Coercivity and Saturated Magnetization values of 30 nm $CoFe_2O_4$. (c) Magnetic hysteresis loop of 30 nm $CoFe_2O_4$ before surface modification. (d) TEM image of 100 nm m-Torquer after surface modification with 250μL. (e) DLS analysis of 100nm m-Torquer Hydrodynamic size.

Ⅱ. c-Fos Expression





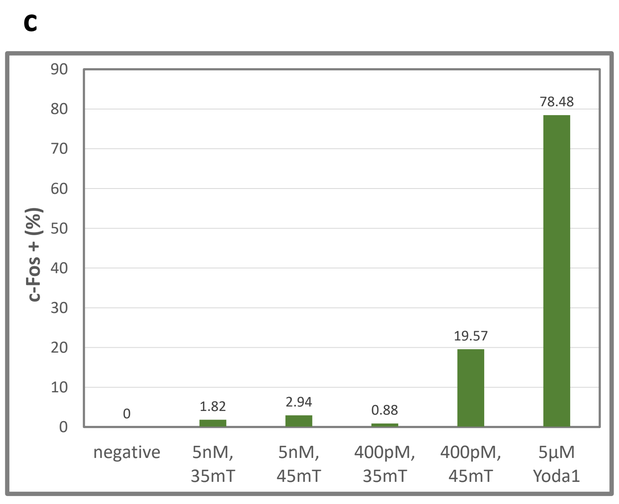


Fig4. Analysis of expression of c-Fos (c-Fos +).
(a) Procedure of cell preprocessing.
(b) Confocal microscopy images.
(c) Quantitative analysis of c-Fos +

Conclusion & Further Study

In this study, we attempted to control the anisotropy of magnetic nanoparticles without changing the crystal structure through cation exchange method. As the amount of complex participating in the reaction increased, the cobalt doping level and coercivity tended to increase. Accordingly, the blocking temperature of each magnetic nanoparticle also tends to increase, and as a result, we can control the magnetic properties of the particle by adjusting the amount of reactant. It would have been good to carry out surface modification with particles created through cation exchange, but due to time constraints, the two experiments could not be conducted consecutively. Surface modification was performed to see whether single magnetic nanoparticles, rather than assemblies, could be used as m-Torquer. The size has been reduced by nearly half to 100 nm scale, and it appears to be able to generate enough force to open the mechanosensitive ion channel, Piezo1. In fact, since it is still a one-time result, more accurate results may be obtained if the experiment is repeated for reproducibility. Surface modification is also in progress with 40nm core-shell cobalt ferrite particles that maximize coercivity, and I would like to continue this study by changing magnetic properties of the particles several times.

Reference

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