

LIST OF FIGURES

Figure	Page	
1	Crystal structure of cerium oxide.	4
2	Diagram of microemulsion, (a) oil in water (O/W) (b) water in oil (W/O)	7
3	The formation mechanism of nano-sized metal particle obtained from microemulsion method.	8
4	Schematic representation of synthesis of nanoparticles in microemulsion.	10
5	Diagram of interfacial tension, (a) in a bulk phase (b) at liquid/liquid interface and (c) when a microemulsion is formed.	11
6	Addition of surfactant(S) to the liquid/liquid interface.	11
7	Diagram of creaming.	12
8	Diagram of flocculation.	13
9	Diagram of coalescence.	13
10	Diagram of Ostwald ripening.	14
11	HRTEM of as-prepared samples annealed at (a)623 K and (b) 873K	19
12a	TEM micrograph of CTAB-coated CeO ₂ nanoparticles annealed at 200°C.	21
12b	HRTEM photograph of CTAB-coated CeO ₂ nanoparticles annealed at 500°C.	21
13	Experiment flow chart of preparation of nano-sized CeO ₂ by microemulsion method.	24
14	The formation mechanism of nano-sized cerium particle obtained from microemulsion method.	25
15	Experiment flow chart of preparation of nano-sized CeO ₂ by combined methods of homogeneous precipitation and microemulsion.	26

LIST OF FIGURES (cont'd)

Figure		Page
16	The formation mechanism of ceriumoxalate hydrate obtained from combined methods of homogeneous precipitation and microemulsion.	27
17	Experiment flow chart of preparation of nano-sized CeO ₂ by microemulsion method.	29
18	The formation mechanism of cerium hydroxide obtained from mixing of two microemulsions.	30
19	TEM Image of Ce particles in microemulsion obtained from Ce(NO ₃) ₃ ·6H ₂ O as a cerium source and PE4LE as a surfactant using microemulsion method (50,000x magnification).	34
20	TEM Image of Ce particles in microemulsion obtained from (NH ₄) ₂ Ce(NO ₃) ₆ as a cerium source and PE4LE as a surfactant using microemulsion method (100,000x magnification).	34
21	TEM Image of Ce particles in microemulsion obtained from CeCl ₃ ·7H ₂ O as a cerium source and PE4LE as a surfactant using microemulsion method (20,000x magnification).	35
22	TEM Image of Ce particles in microemulsion obtained from Ce(NO ₃) ₃ ·6H ₂ O as a cerium source and Brij96V as a surfactant using microemulsion method (100,000x magnification).	35
23	TEM Image of Ce particles in microemulsion obtained from (NH ₄) ₂ Ce(NO ₃) ₆ as a cerium source and Brij96V as a surfactant using microemulsion method (100,000x magnification).	36
24	TEM Image of Ce particles in microemulsion obtained from CeCl ₃ ·7H ₂ O as a cerium source and Brij96V as a surfactant using microemulsion method (50,000x magnification).	36

LIST OF FIGURES (cont'd)

Figure		Page
25	TEM Image of Ce particles in microemulsion obtained from $\text{Ce}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ as a cerium source, CTAB as a surfactant and butanol as a cosurfactant using microemulsion method (50,000x magnification).	37
26	TEM Image of Ce particles in microemulsion obtained from $(\text{NH}_4)_2\text{Ce}(\text{NO}_3)_6$ as a cerium source, CTAB as a surfactant and butanol as a cosurfactant using microemulsion method (100,000x magnification).	37
27	TEM Image of Ce particles in microemulsion obtained from $\text{CeCl}_3 \cdot 7\text{H}_2\text{O}$ as a cerium source, CTAB as a surfactant and butanol as a cosurfactant using microemulsion method (50,000x magnification).	38
28	TEM Image of Ce particles in microemulsion obtained from $\text{Ce}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ as a cerium source and PE4LE as a surfactant using combined methods of homogeneous precipitation and microemulsion (100,000x magnification).	38
29	TEM Image of Ce particles in microemulsion obtained from $(\text{NH}_4)_2\text{Ce}(\text{NO}_3)_6$ as a cerium source and PE4LE as a surfactant using combined methods of homogeneous precipitation and microemulsion (100,000x magnification).	39
30	TEM Image of Ce particles in microemulsion obtained from $\text{CeCl}_3 \cdot 7\text{H}_2\text{O}$ as a cerium source and PE4LE as a surfactant using combined methods of homogeneous precipitation and microemulsion (50,000x magnification).	39

LIST OF FIGURES (cont'd)

Figure		Page
31	TEM Image of Ce particles in microemulsion obtained from $\text{Ce}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ as a cerium source, CTAB as a surfactant and butanol as a cosurfactant using combined methods of homogeneous precipitation and microemulsion (50,000x magnification).	40
32	TEM Image of Ce particles in microemulsion obtained from $(\text{NH}_4)_2\text{Ce}(\text{NO}_3)_6$ as a cerium source, CTAB as a surfactant and butanol as a cosurfactant using combined methods of homogeneous precipitation and microemulsion (100,000x magnification).	40
33	TEM Image of Ce particles in microemulsion obtained from $\text{CeCl}_3 \cdot 7\text{H}_2\text{O}$ as a cerium source, CTAB as a surfactant and butanol as a cosurfactant using combined methods of homogeneous precipitation and microemulsion (30,000x magnification).	41
34	TEM Image of Ce particles in microemulsion obtained from $\text{Ce}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ as a cerium source and PE4LE as a surfactant by mixing of two microemulsions (50,000x magnification).	41
35	TEM Image of Ce particles in microemulsion obtained from $(\text{NH}_4)_2\text{Ce}(\text{NO}_3)_6$ as a cerium source and PE4LE as a surfactant by mixing of two microemulsions (100,000x magnification).	42
36	TEM Image of Ce particles in microemulsion obtained from $\text{CeCl}_3 \cdot 7\text{H}_2\text{O}$ as a cerium source and PE4LE as a surfactant by mixing of two microemulsions (100,000x magnification).	42
37	TEM Image of Ce particles in microemulsion obtained from $\text{Ce}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ as a cerium source, CTAB as a surfactant and butanol as a cosurfactant by mixing of two microemulsions (250,000x magnification).	43

LIST OF FIGURES (cont'd)

Figure		Page
38	TEM Image of Ce particles in microemulsion obtained from $(\text{NH}_4)_2\text{Ce}(\text{NO}_3)_6$ as a cerium source, CTAB as a surfactant and butanol as a cosurfactant by mixing of two microemulsions (250,000x magnification).	43
39	TEM Image of Ce particles in microemulsion obtained from $\text{CeCl}_3 \cdot 7\text{H}_2\text{O}$ as a cerium source, CTAB as a surfactant and butanol as a cosurfactant by mixing of two microemulsions (80,000x magnification).	44
40	EDS spectrum of microemulsion obtained from different methods (a) microemulsion method (b) combined methods of homogeneous precipitation with microemulsion and (c) mixing of two microemulsions	45
41	TEM Image of CeO_2 obtained from $\text{Ce}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ as a cerium source and PE4LE as a surfactant using microemulsion method (120,000x magnification).	47
42	TEM Histograms of CeO_2 particles: $\text{Ce}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ as a cerium source, PE4LE as a surfactant using microemulsion method (120,000x magnification).	47
43	TEM Image of CeO_2 obtained from $(\text{NH}_4)_2\text{Ce}(\text{NO}_3)_6$ as a cerium source and PE4LE as a surfactant using microemulsion method (120,000x magnification).	48
44	TEM Histograms of CeO_2 particles: $(\text{NH}_4)_2\text{Ce}(\text{NO}_3)_6$ as a cerium source, PE4LE as a surfactant using microemulsion method (120,000x magnification).	48
45	TEM Image of CeO_2 obtained from $\text{CeCl}_3 \cdot 7\text{H}_2\text{O}$ as a cerium source and PE4LE as a surfactant using microemulsion method (50,000x magnification).	49

LIST OF FIGURES (cont'd)

Figure		Page
46	TEM Histograms of CeO ₂ particles: CeCl ₃ ·7H ₂ O as a cerium source, PE4LE as a surfactant using microemulsion method (50,000x magnification).	50
47	TEM Image of CeO ₂ obtained from Ce(NO ₃) ₃ ·6H ₂ O as a cerium source and Brij96V as a surfactant using microemulsion method (100,000x magnification).	51
48	TEM Histograms of CeO ₂ particles: Ce(NO ₃) ₃ ·6H ₂ O as a cerium source, Brij96V as a surfactant using microemulsion method (100,000x magnification).	51
49	TEM Image of CeO ₂ obtained from (NH ₄) ₂ Ce(NO ₃) ₆ as a cerium source and Brij96V as a surfactant using microemulsion method (100,000x magnification).	52
50	TEM Histograms of CeO ₂ particles: (NH ₄) ₂ Ce(NO ₃) ₆ as a cerium source, Brij96V as a surfactant using microemulsion method (100,000x magnification).	52
51	TEM Image of CeO ₂ obtained from CeCl ₃ ·7H ₂ O as a cerium source and Brij96V as a surfactant using microemulsion method (100,000x magnification).	53
52	TEM Histograms of CeO ₂ particles: CeCl ₃ ·7H ₂ O as a cerium source, Brij96V as a surfactant using microemulsion method (100,000x magnification).	53
53	TEM Image of CeO ₂ obtained from Ce(NO ₃) ₃ ·6H ₂ O as a cerium source, CTAB as a surfactant and butanol as a cosurfactant using microemulsion method (100,000x magnification).	54
54	TEM Histograms of CeO ₂ particles: Ce(NO ₃) ₃ ·6H ₂ O as a cerium source, CTAB as a surfactant and butanol as a cosurfactant using microemulsion method (100,000x magnification).	55

LIST OF FIGURES (cont'd)

Figure		Page
55	TEM Image of CeO ₂ obtained from (NH ₄) ₂ Ce(NO ₃) ₆ as a cerium source, CTAB as a surfactant and butanol as a cosurfactant using microemulsion method (100,000x magnification).	55
56	TEM Histograms of CeO ₂ particles: (NH ₄) ₂ Ce(NO ₃) ₆ as a cerium source, CTAB as a surfactant and butanol as a cosurfactant using microemulsion method (100,000x magnification).	56
57	TEM Image of CeO ₂ obtained from CeCl ₃ ·7H ₂ O as a cerium source, CTAB as a surfactant and butanol as a cosurfactant using microemulsion method (100,000x magnification).	56
58	TEM Histograms of CeO ₂ particles: CeCl ₃ ·7H ₂ O as a cerium source, CTAB as a surfactant and butanol as a cosurfactant using microemulsion method (100,000x magnification).	57
59	X-Ray diffraction pattern of CeO ₂ powders obtained from microemulsion method (a) Ce(NO ₃) ₃ ·6H ₂ O as a cerium source (b) (NH ₄) ₂ Ce(NO ₃) ₆ as a cerium source.	58
60	EDS of CeO ₂ powders obtained from microemulsion method (a) Ce(NO ₃) ₃ ·6H ₂ O (b) (NH ₄) ₂ Ce(NO ₃) ₆ (c) CeCl ₃ ·7H ₂ O as a cerium source.	59
61	TEM Image of CeO ₂ obtained from Ce(NO ₃) ₃ ·6H ₂ O as a cerium source and PE4LE as a surfactant using combined methods of homogeneous precipitation and microemulsion (100,000x magnification).	61
62	TEM Histograms of CeO ₂ particles: Ce(NO ₃) ₃ ·6H ₂ O as cerium source, PE4LE as a surfactant using combined methods of homogeneous precipitation and microemulsion (100,000x magnification).	61

LIST OF FIGURES (cont'd)

Figure		Page
63	TEM Image of CeO ₂ obtained from (NH ₄) ₂ Ce(NO ₃) ₆ as a cerium source and PE4LE as a surfactant using combined methods of homogeneous precipitation and microemulsion (100,000x magnification).	62
64	TEM Histograms of CeO ₂ particles: (NH ₄) ₂ Ce(NO ₃) ₆ as a cerium source, PE4LE as a surfactant using combined methods of homogeneous precipitation and microemulsion (100,000x magnification).	62
65	TEM Image of CeO ₂ obtained from CeCl ₃ ·7H ₂ O as a cerium source and PE4LE as a surfactant using combined methods of homogeneous precipitation and microemulsion (100,000x magnification).	63
66	TEM Histograms of CeO ₂ particles: CeCl ₃ ·7H ₂ O as a cerium source, PE4LE as a surfactant using combined methods of homogeneous precipitation and microemulsion (100,000x magnification).	63
67	TEM Image of CeO ₂ obtained from Ce(NO ₃) ₃ ·6H ₂ O as a cerium source, CTAB as a surfactant and butanol as a cosurfactant using combined methods of homogeneous precipitation and microemulsion (100,000x magnification).	64
68	TEM Histograms of CeO ₂ particles: Ce(NO ₃) ₃ ·6H ₂ O as a cerium source, CTAB as a surfactant and butanol as a cosurfactant using combined methods of homogeneous precipitation and microemulsion (100,000x magnification).	65

LIST OF FIGURES (cont'd)

Figure		Page
69	TEM Image of CeO ₂ obtained from (NH ₄) ₂ Ce(NO ₃) ₆ as a cerium source, CTAB as a surfactant and butanol as a cosurfactant using combined methods of homogeneous precipitation and microemulsion (250,000x magnification).	65
70	TEM Histograms of CeO ₂ particles: (NH ₄) ₂ Ce(NO ₃) ₆ as a cerium source, CTAB as a surfactant and butanol as a cosurfactant using combined methods of homogeneous precipitation and microemulsion (250,000x magnification).	66
71	TEM Image of CeO ₂ obtained from CeCl ₃ ·7H ₂ O as a cerium source, CTAB as a surfactant and butanol as a cosurfactant using combined methods of homogeneous precipitation and microemulsion (100,000x magnification).	66
72	TEM Histograms of CeO ₂ particles: CeCl ₃ ·7H ₂ O as a cerium source, CTAB as a surfactant and butanol as a cosurfactant using combined methods of homogeneous precipitation and microemulsion (100,000x magnification).	67
73	TEM Image of CeO ₂ obtained from Ce(NO ₃) ₃ ·6H ₂ O as a cerium source and PE4LE as a surfactant by mixing of two microemulsions (100,000x magnification).	68
74	TEM Histograms of CeO ₂ particles: Ce(NO ₃) ₃ ·6H ₂ O as a cerium source, PE4LE as a surfactant by mixing of two microemulsions (100,000x magnification).	69
75	TEM Image of CeO ₂ obtained from (NH ₄) ₂ Ce(NO ₃) ₆ as a cerium source and PE4LE as a surfactant by mixing of two microemulsions (100,000x magnification).	69

LIST OF FIGURES (cont'd)

Figure		Page
76	TEM Histograms of CeO ₂ particles: (NH ₄) ₂ Ce(NO ₃) ₆ as a cerium source, PE4LE as a surfactant by mixing of two microemulsions (100,000x magnification).	70
77	TEM Image of CeO ₂ obtained from CeCl ₃ ·7H ₂ O as a cerium source and PE4LE as a surfactant by mixing of two microemulsions (50,000x magnification).	70
78	TEM Histograms of CeO ₂ particles: CeCl ₃ ·7H ₂ O as a cerium source, PE4LE as a surfactant by mixing of two microemulsions (50,000x magnification).	71
79	TEM Image of CeO ₂ obtained from Ce(NO ₃) ₃ ·6H ₂ O as a cerium source, CTAB as a surfactant and butanol as a cosurfactant by mixing of two microemulsions (250,000x magnification).	72
80	TEM Histograms of CeO ₂ particles: Ce(NO ₃) ₃ ·6H ₂ O as a cerium source, CTAB as a surfactant and butanol as a cosurfactant by mixing of two microemulsions (250,000x magnification).	72
81	TEM Image of CeO ₂ obtained from (NH ₄) ₂ Ce(NO ₃) ₆ as a cerium source, CTAB as a surfactant and butanol as a cosurfactant by mixing of two microemulsions (100,000x magnification).	73
82	TEM Histograms of CeO ₂ particles: (NH ₄) ₂ Ce(NO ₃) ₆ as a cerium source, CTAB as a surfactant and butanol as a cosurfactant by mixing of two microemulsions (100,000x magnification).	73
83	TEM Image of CeO ₂ obtained from CeCl ₃ ·7H ₂ O as a cerium source, CTAB as a surfactant and butanol as a cosurfactant by mixing of two microemulsions (100,000x magnification).	74
84	TEM Histograms of CeO ₂ particles: CeCl ₃ ·7H ₂ O as a cerium source, CTAB as a surfactant and butanol as a cosurfactant by mixing of two microemulsions (100,000x magnification).	74

LIST OF FIGURES (cont'd)

Figure		Page
85	Variation of the average size of CeO ₂ particles with different techniques using Ce(NO ₃) ₃ ·6H ₂ O as a cerium source	78
86	Variation of the average size of CeO ₂ particles with different techniques using (NH ₄) ₂ Ce(NO ₃) ₆ as a cerium source.	78
87	Variation of the average size of CeO ₂ particles with different techniques using CeCl ₃ ·7H ₂ O as a cerium source.	79
88	TEM Image of CeO ₂ obtained from Ce(NO ₃) ₃ ·6H ₂ O as a cerium source, methyl oxalate as a precipitant material and PE4LE as a surfactant by mixing of two microemulsions (100,000x magnification).	80
89	Variation of the average size of CeO ₂ particles with different cerium sources using microemulsion method.	81
90	Variation of the average size of CeO ₂ particles with different cerium sources using combined methods of homogeneous precipitation and microemulsion.	81
91	Variation of the average size of CeO ₂ particles with different cerium sources by mixing of two microemulsions.	82
92	Variation of the average size of CeO ₂ particles with different surfactants using microemulsion method.	84
93	Variation of the average size of CeO ₂ particles with different surfactants using combined methods of homogeneous precipitation and microemulsion.	84
94	Variation of the average size of CeO ₂ particles with different surfactants by mixing of two microemulsions.	85