

Contents

TOPICS		Page No.
List of Figures		(i-vii)
List of Tables		(ix-x)
Preface		(xi-xvii)
Chapter I	Introduction and Literature Review	1-40
1.1	Fuel Cell	1
	1.1.1 Activation polarization	2
	1.1.2 Ohmic polarization	3
	1.1.3 Concentration polarization	3
1.2	Why Fuel Cells	4
1.3	Types of Fuel Cells	4
	1.3.1 Polymer electrolyte membrane fuel cells (PEMFC)	5
	1.3.2 Alkaline fuel cells (AFC)	5
	1.3.3 Phosphoric acid fuel cell (PAFC)	5
	1.3.4 Molten carbonate fuel cell (MCFC)	6
	1.3.5 Solid oxide fuel cells (SOFCs)	6
1.4	Solid Oxide Fuel Cell	6
1.5	Working Principle of SOFC	7
1.6	Design of SOFC	9
	1.6.1 Planer SOFC	9
	1.6.2 Tubular SOFC	10
1.7	Components of SOFC	11
	1.7.1 Electrolyte	11
	1.7.2 Anode	11
	1.7.3 Cathode	13
	1.7.4 Interconnect	13
	1.7.5 Sealing	14
1.8	Solid Oxide Electrolytes	14
1.9	High Temperature Electrolytes	15
	1.9.1 Zirconia based electrolytes	15
1.10	Intermediate Temperature Electrolytes	15
	1.10.1 Bi ₂ O ₃ -based electrolytes	16
	1.10.2 LaGaO ₃ -based electrolytes	16
	1.10.3 Doped and co-doped ceria	17
1.11	Enhancement in Grain Boundaries Conductivity of Co-Doped Ceria	19

1.12	Conduction Mechanism and Temperature Dependence of of Ionic Conductivity, Activation Energy and Pre-Exponential Factor	21
1.13	Dual Phase Ceria Based Composites	26
	1.13.1 Ceria-hydrate composites	26
	1.13.2 Ceria-perovskite oxide composites	26
	1.13.3 Ceria-salt based composites	27
1.14.	Nanocomposite Idea	27
1.15	Effect of Carbonate Composition and Concentration	29
1.16	Stability of SOFCs Based on Ceria/Carbonate Composite	33
	1.16.1 Materials thermal and chemical stability	33
	1.16.2 Electrochemical stability	35
1.17	Applications of SOFCs Technology	35
	1.17.1 Stationary power generation	36
	1.17.1 Transportation	36
	1.17.3 In Military sector	38
1.18	Advanced Applications of SOFC Based on Dual Phase Ceria Based Electrolytes	38
	1.18.1 Solid oxide electrolysis cell	38
	1.18.2 Direct carbon fuel cell (DCFC)	38
	1.18.5 Synthesis of ammonia	39
	1.18.6 CO ₂ separation	39
Chapter II Objective of the Work		41-45
Chapter III Experimental Work		46-62
3.1	Preparation of Materials	47
	3.1.1 Preparation of nitrates	47
	3.1.2 Synthesis of ceria powders by citrate-nitrate gel auto-combustion method	47
	3.1.3 Preparation of nanocomposites	49
3.2	Pellet Formation and Sintering	50
3.3	Characterizations	51
	3.3.1 Thermal analysis	51
	3.3.2 Powder X-ray diffraction	52
	3.3.3 Density and porosity measurements	54
	3.3.4 Field emission scanning electron microscope equipped with energy dispersive X-ray spectroscopy	55
	3.3.5 Coefficient of thermal expansion (CTE) using dilatometer	57
	3.3.6 Complex plane impedance analysis	58

Chapter IV	La and Sr Co-Doped Ceria, $Ce_{1-x-y}La_xSr_yO_{2-\delta}$ (Fixed Oxygen Vacancies) and its Nanocomposites	63-115
4.1	La and Sr Co-Doped Ceria, $Ce_{1-x-y}La_xSr_yO_{2-\delta}$	63
	4.1.1 Introduction	63
	4.1.2 Results and Discussion	64
	(a) Thermal analysis	64
	(b) Crystal structure and phases	65
	(c) Microstructure	69
	(d) Electrical conductivity	72
	4.1.3 Conclusion	90
4.2	Nanocomposites of La and Sr Co-Doped Ceria, $Ce_{1-x-y}La_xSr_yO_{2-\delta}$	90
	4.2.1 Introduction	90
	4.2.2 Results and Discussion	92
	(a) Thermal analysis	92
	(b) Crystal structure and phases	93
	(c) Microstructure	94
	(d) Thermal expansion	96
	(e) Electrical conductivity	97
	4.2.3 Conclusion	114
Chapter V	La and Sr Co-Doped Ceria, $Ce_{0.85}La_{0.15-x}Sr_xO_{2-\delta}$ and its Nanocomposites	116-159
5.1	La and Sr Co-Doped Ceria	116
	5.1.1 Introduction	116
	5.1.2 Results and Discussion	117
	(a) Crystal structure and phases	117
	(b) Microstructure	120
	(c) Electrical conductivity	124
	5.1.3 Conclusion	139
5.2	Nanocomposites of La and Sr Co-Doped Ceria	140
	5.2.1 Introduction	140
	5.2.2 Results and Discussion	141
	(a) Thermal analysis	141
	(b) Crystal structure and phases	141
	(c) Thermal expansion	143
	(d) Microstructure	144
	(e) Electrical conductivity	146
	5.2.3 Conclusion	159

Chapter VI	Sm and Sr Co-Doped Ceria and its Nanocomposites	160-205
6.1	Sm and Sr Co-Doped Ceria	160
	6.1.1 Introduction	160
	6.1.2 Results and Discussion	161
	(a) Crystal structure and phases	161
	(b) Microstructure	164
	(c) Electrical conductivity	167
	6.1.3 Conclusion	185
6.2	Nanocomposites of Sm and Sr Co-Doped Ceria	185
	6.2.1 Introduction	185
	6.2.2 Results and Discussion	186
	(a) Thermal analysis	186
	(b) Crystal structure and phases	187
	(c) Microstructure	188
	(d) Thermal expansion	190
	(e) Electrical conductivity	191
	6.2.3 Conclusion	205
Chapter VII	Ca and Sr co-doped ceria and its nanocomposites	206-248
7.1	Ca and Sr co-doped ceria	206
	7.1.1 Introduction	206
	7.1.2 Results and Discussion	207
	(a) Thermal analysis	207
	(b) Crystal structure and phases	208
	(c) Microstructure	209
	(d) Electrical conductivity	212
	7.1.3 Conclusion	228
7.2	Nanocomposites of Ca and Sr co-doped ceria	229
	7.2.1 Introduction	229
	7.2.2 Results and Discussion	229
	(a) Thermal analysis	229
	(b) Crystal structure and phases	230
	(c) Microstructure	231
	(d) Thermal expansion	233
	(e) Electrical conductivity	234
	7.2.3 Conclusion	248
Chapter VIII	Mg and Sr co-doped ceria and its nanocomposites	249-297
8.1	Mg and Sr co-doped ceria	249
	8.1.1 Introduction	249

8.1.2	Results and Discussion	251
	(a) Crystal structure and phases	251
	(b) Microstructure	252
	(c) Electrical conductivity	255
8.1.3	Conclusion	277
8.2	Nanocomposites of Mg and Sr co-doped ceria	277
8.2.1	Introduction	277
8.2.2	Results and Discussion	278
	(a) Thermal analysis	278
	(b) Crystal structure and phases	279
	(c) Thermal expansion	280
	(d) Microstructure	282
	(e) Electrical conductivity	284
8.2.3	Conclusion	297
Chapter IX	Conclusion and Scope for the Future Work	298-300
9.1	Conclusion	298
9.2	Scope for the future work	300
References		301-322

Outcomes of the thesis

- (a) List of Publications in International Journals
- (b) List of Research Papers in International and National Conferences

LIST of FIGURES

FIGURES

		Page No.
Chapter I	Introduction and Literature Review	1-40
Fig. 1.1	Working principle of fuel cell	1
Fig. 1.2	Polarization curve of fuel cell	2
Fig. 1.3	Working principle of SOFC	8
Fig. 1.4	Planer SOFC	9
Fig. 1.5	Tubular SOFC	10
Fig. 1.6	Temperature dependence of electrical conductivity of oxide ion electrolytes	14
Fig. 1.7	Crystal structure of ceria	17
Fig. 1.8	EDXM spectra of a grain and grain boundary in CeO ₂ :6 mol% Gd ₂ O ₃ sample.	21
Fig. 1.9	Variation of association energy against the dopant concentration for various rare earth cation doped ceria	23
Fig. 1.10	Log σT and Log A vs E _a plot of yttria-doped ceria	24
Fig. 1.11	Log σT and Log A vs E _a plot of gadolinia-doped ceria	25
Fig. 1.12	(a) TEM images and (b) SEM images of ceria/carbonate nanocomposites	28
Fig. 1.13	Variation of ionic conductivity of composites electrolyte with carbonate compositions	29
Fig. 1.14	Variation of conductivity with carbonate content at 650 °C	30
Fig. 1.15	Electrical field at the interfaces between two constituent phase particles	32
Fig. 1.16	Conducting highways at the interfaces of two phase particles resulting in interfacial superionic conduction	33
Fig. 1.17	(a) Time dependence of electrical conductivity of GDC/(Li-K) ₂ CO ₃ composite at 600 °C in air under OCV condition (b) Evaluation of cell performances vs. time for ceria/carbonate composite electrolytes based SOFC at 550 °C	34
Fig. 1.18	Basic building block for automobile APUs	36
Fig. 1.19	500 W battery charging system concept	37
Fig. 1.20	Portable SOFC system	37
Fig. 1.21	Multi-ion conduction and advanced applications of ceria/carbonates nanocomposites	39

Chapter III	Experimental Work	46-62
Fig. 3.1	Flow chart for preparation of nitrates	48
Fig. 3.2	Flow chart for synthesis of ceria powders	49
Fig. 3.3	Flow chart of the preparation of nanocomposites	50
Fig. 3.4	Optimization of load	51
Fig. 3.5	NETZSCH Gerate Bau DTA/TGA	52
Fig. 3.6	Schematic diagram of X-ray diffractometer	54
Fig. 3.7	Working principle of FE-SEM	56
Fig. 3.8	Image of FEI NOVA NANOSEM	57
Fig. 3.9	Image of push rod dilatometer	58
Fig. 3.10	A schematic representation of impedance plot of a polycrystalline solid electrolyte with an equivalent circuit	61
Fig. 3.11	A schematic diagram of sample cell used in impedance measurements	61
Chapter IV	La and Sr Co-Doped Ceria, $Ce_{1-x-y}La_xSr_yO_{2-\delta}$ (Fixed Oxygen Vacancies) and its Nanocomposites	63-115
Fig. 4.1	DTA/TGA plot of the ash of composition CLO15	65
Fig. 4.2	Powder X-ray diffraction patterns of sintered powders for various compositions (a) CLO15 (b) CL11S2 (c) CL7S4 (d) CL3S6 in the system $Ce_{1-x-y}La_xSr_yO_{2-\{x/2+y\}}$	66
Fig. 4.3	Variation of lattice parameter as a function of Sr^{2+} concentration in the system $Ce_{1-x-y}La_xSr_yO_{2-\{x/2+y\}}$	69
Fig. 4.4	SEM micrographs of various compositions (a) CLO15 (b) CL11S2 (c) CL7S4 (d) CL3S6 in the system $Ce_{1-x-y}La_xSr_yO_{2-\{x/2+y\}}$	70
Fig. 4.5	EDS spectrum of the composition CLO15 at three different points	71
Fig. 4.6	EDS spectrum of the composition CL7S4 at three different points	72
Fig. 4.7	Complex plane impedance plots of the composition CLO15 at different temperatures	74
Fig. 4.8	Complex plane impedance plots of the composition CL11S2 at different temperatures	77
Fig. 4.9	Complex plane impedance plots of the composition CL7S4 at different temperatures	80
Fig. 4.10	Complex plane impedance plots of the composition CL3S6 at different temperatures	83
Fig. 4.11	Brick layer model of polycrystalline material	86

Fig. 4.12	Arrhenius plots of all the compositions for the grain, grain boundaries and total ionic conductivity in the system $Ce_{1-x-y}La_xSr_yO_{2-\delta}$	87
Fig. 4.13	DTA plots of all the CL7S4/LNCO nanocomposite powders	92
Fig. 4.14	XRD patterns of all the sintered powders: (a) CL7S4/35 LNCO (b) CL7S4/30 LNCO (c) CL7S4/20 LNCO and (d) CL7S4	93
Fig. 4.15	SEM micrograph of all the compositions (a) CL7S4: after polishing and thermal etching (b) CL7S4/20 LNCO: fractured sample (c) CL7S4/30 LNCO: fractured sample (d) CL7S4/35LNCO: fractured sample	95
Fig. 4.16	EDS spectrum of the composition CL7S4/35LNCO at two different points	96
Fig. 4.17	Thermal expansion curves for all the CL7S4/LNCO nanocomposites	97
Fig. 4.18	Complex plane impedance plots of the composition CL7S4/20LNCO at different temperatures	99
Fig. 4.19	Complex plane impedance plots of the composition CL7S4/30LNCO at different temperatures	102
Fig. 4.20	Complex plane impedance plots of the composition CL7S4/35LNCO at different temperatures	105
Fig. 4.21	Complex plane impedance plots of the composition LNCO at different temperatures	108
Fig. 4.22	Arrhenius plots of total conductivity for all the compositions	111
Fig. 4.23	Archie plot for the composite in the system CL7S4/LNCO	113
Chapter V	La and Sr Co-Doped Ceria, $Ce_{0.85}La_{0.15-x}Sr_xO_{2-\delta}$ and its Nanocomposites	116-159
Fig. 5.1	Powder X-ray diffraction patterns of the sintered powders in the system $Ce_{0.85}La_{0.15-x}Sr_xO_{\{2-(0.075+x/2)\}}$ for (a) $x = 0.0$, (b) $x = 0.025$, (c) $x = 0.050$ and (d) $x = 0.075$	118
Fig. 5.2	Variation of lattice parameter with concentration of Sr in the system $Ce_{0.85}La_{0.15-x}Sr_xO_{\{2-(0.075+x/2)\}}$	119
Fig. 5.3	BFTEM images of the compositions (i) CLO15 (ii) CL125S025 (iii) CL10S5 (iv) CL075S075	121
Fig. 5.4	SEM micrographs of different compositions in the system $Ce_{0.85}La_{0.15-x}Sr_xO_{\{2-(0.075+x/2)\}}$ (a) CLO15 (b) CL125S025 (c) CL10S5 and (d) CL075S075	122
Fig. 5.5	EDS spectrum of the composition CL125S025 at three different points: (a) in the grain (b) at the grain boundary (c) at triple point	123

Fig. 5.6	Complex plane impedance plots of the composition CL125S025 at different temperatures	125
Fig. 5.7	Complex plane impedance plots of the composition CL10S5 at different temperatures	129
Fig. 5.8	Complex plane impedance plots of the composition CL075S075 at different temperatures	132
Fig. 5.9	Arrhenius plots for the grain, grain boundaries and total ionic conductivity in the system $Ce_{0.85}La_{0.15-x}Sr_xO_{2-(0.075+x/2)}$	136
Fig. 5.10	DTA plots of all the composite samples of CL125S025/LNCO	141
Fig. 5.11	Powder XRD patterns of various compositions (a)CL125S025 (b) CL125S025/20LNCO (c) CL125S025/30LNCO and (d) CL125S025/35LNCO sintered powders	142
Fig. 5.12	Thermal expansion curves for CL125S025/LNCO composites	143
Fig. 5.13	Scanning electron micrograph of all the fractured samples (a) CL125S025 (b) CL125S025/20LNCO (c) CL125S025/30LNCO and (d) CL125S025/35 LNCO	144
Fig. 5.14	EDS spectrum of the composition CL125S025/35LNCO at two different points	145
Fig. 5.15	Complex plane impedance plots of CL125S025/20LNCO at different temperatures	147
Fig. 5.16	Complex plane impedance plots of CL125S025/30LNCO at different temperatures	150
Fig. 5.17	Complex plane impedance plots of CL125S025/35LNCO at different temperatures	153
Fig. 5.18	Arrhenius plots of total conductivity for all the compositions	156
Fig. 5.19	Arhie plot of the system CL125S025/LNCO	158
Chapter VI Sm and Sr Co-Doped Ceria and its Nanocomposites		160-205
Fig. 6.1	Powder XRD patterns of the sintered samples in the system $Ce_{1-x-y}Sm_xSr_yO_{1.90}$ system with (a) SDC (b) 2SrSDC (c) 4SrSDC and (d) 6SrSDC	162
Fig. 6.2	Variation of lattice parameter with Sr content in the system $Ce_{1-x-y}Sm_xSr_yO_{1.90}$	163
Fig. 6.3	SEM micrographs of thermally etched samples (a) SDC (b) 2SrSDC (c) 4SrSDC and (d) 6SrSDC	165
Fig. 6.4	EDS spectrum of the composition SDC at three different points	166
Fig. 6.5	EDS spectrum of the composition 2SrSDC at three different points	166

Fig. 6.6	Complex plane impedance plots of the composition SDC at different temperatures	168
Fig. 6.7	Complex plane impedance plots of the composition 2SrSDC at different temperatures	171
Fig. 6.8	Complex plane impedance plots of the composition 4SrSDC at different temperatures	174
Fig. 6.9	Complex plane impedance plots of the composition 6SrSDC at different temperatures	177
Fig. 6.10	Arrhenius plots for grains, grain boundaries and total conductivity of all the compositions in the system $Ce_{1-x-y}Sm_xSr_yO_{1.90}$	182
Fig. 6.11	Plots of variation of activation energy with dopant concentration for $Ce_{1-x-y}Sm_xSr_yO_{1.90}$ system	184
Fig. 6.12	DTA plots of all the samples in the system SSDC/LNCO	186
Fig. 6.13	Powder X-ray diffraction patterns of various compositions (a) Pure LNCO (b) SSDC (c) SSDC/20 LNCO (d) SSDC/30 LNCO (e) SSDC/35 LNCO	187
Fig. 6.14	Scanning electron micrograph of all the compositions (i) SSDC (ii) SSDC/20 LNCO (iii) SSDC/30 LNCO (iv) SSDC/35 LNCO	189
Fig. 6.15	EDS spectrum of the composition SSDC/35LNCO at two different points	190
Fig. 6.16	Thermal expansion curves for SSDC/LNCO composites	191
Fig. 6.17	Complex plane impedance plots of the composition SSDC/20LNCO at different temperatures	193
Fig. 6.18	Complex plane impedance plots of the composition SSDC/30 LNCO at different temperatures	196
Fig. 6.19	Complex plane impedance plots of the composition SSDC/35 LNCO at different temperatures	199
Fig. 6.20	Arrhenius plots of all the compositions in the system SSDC/LNCO	202
Fig. 6.21	Archie plot for SSDC/LNCO system	204

Chapter VII Ca and Sr co-doped ceria and its nanocomposites **206-248**

Fig. 7.1	DTA/TGA plots of the as prepared ash of composition CCO5	207
Fig. 7.2	Powder X-ray diffraction patterns of various compositions (a) CCO5 (b) CC5S2 (c) CC5S2 (d) CC5S3 sintered at 1350 °C	208
Fig. 7.3	SEM micrographs of various compositions (a) CCO5 (b) CC5S1 (c) CC5S2 (d) CC5S3 thermally etched at 1250 °C	210
Fig. 7.4	EDS spectrum of the composition CCO5 at three different points	211

Fig. 7.5	EDS spectrum of the composition CC5S2 at three different Points	211
Fig. 7.6	Complex plane impedance plots of the composition CCO5 at different temperatures	213
Fig. 7.7	Complex plane impedance plots of the composition CC5S1 at different temperatures	216
Fig. 7.8	Complex plane impedance plots of the composition CC5S2 at different temperatures	219
Fig. 7.9	Complex plane impedance plots of the composition CC5S3 at different temperatures	222
Fig. 7.10	Arrhenius plots of all the compositions in the system $Ce_{0.95-x}Ca_{0.05}Sr_xO_{1.95-x}$	226
Fig. 7.11	DTA plots of all the samples in the system CC5S2/LNCO	230
Fig. 7.12	Powder X-ray diffraction patterns of various compositions (a) CC5S2 (b) CC5S2 /20 LNCO (c) CC5S2 /30 LNCO and (d) CC5S2 /35LNCO	231
Fig. 7.13	Scanning electron micrograph of all the fractured samples (a) CC5S2 (b) CC5S2 /20 LNCO (c) CC5S2/30 LNCO and (d) CC5S2/35 LNCO	232
Fig. 7.14	EDS spectrum of the composition CC5S2/LNCO at two different points	233
Fig. 7.15	Thermal expansion curves for CC5S2/LNCO composites	234
Fig. 7.16	Complex plane impedance plots of the composition CC5S2/20LNCO at different temperatures	236
Fig. 7.17	Complex plane impedance plots of the composition CC5S2/30LNCO at different temperatures	239
Fig. 7.18	Complex plane impedance plots of the composition CC5S2/35LNCO at different temperatures	242
Fig. 7.19	Arrhenius plots of total conductivity for all the compositions	246
Fig. 7.20	Archie plot for the system CC5S2/LNCO	247
Chapter VIII Mg and Sr co-doped ceria and its nanocomposites		249-297
Fig. 8.1	Powder X-ray diffraction patterns of the sintered powders of compositions (a) CMO10 (b) CM8S2 (c) CM6S4 and (d) CM4S6 in the system $Ce_{0.90}Mg_{0.10-x}Sr_xO_{1.90}$	251
Fig. 8.2	SEM micrograph of the fractured samples in the system $Ce_{0.90}Mg_{0.10-x}Sr_xO_{1.90}$ for (a) CMO10 (b) CM8S2 (c) CM6S4 and (d) CM4S6	253

Fig. 8.3	EDX spectrum of the composition CMO10 at two different points: Spectrum 1 (in the grain) Spectrum 2 (at the grain boundary)	254
Fig. 8.4	EDX spectrum of the composition CM6S4 at two different points: (a) in the grain (b) at the grain boundary (c) at triple point	255
Fig. 8.5	Complex plane impedance plots of the composition CMO10 at different temperatures	257
Fig. 8.6	Complex plane impedance plots of the composition CM8S2 at different temperatures	261
Fig. 8.7	Complex plane impedance plots of the composition CM6S4 at different temperatures	265
Fig. 8.8	Complex plane impedance plots of the composition CM4S6 at different temperatures	269
Fig. 8.9	Arrhenius plots of all the compositions in the system $Ce_{0.90}Mg_{0.10-x}Sr_xO_{1.90}$	274
Fig. 8.10	DTA plots of all the composite samples (a) CM6S4/20LNCO (b) CM6S4/30LNCO and (c) CM6S4/35LNCO	279
Fig. 8.11	Powder X-ray diffraction patterns of all the compositions (a) CM6S4 (b) CM6S4/20 LNCO (c) CM6S4/30LNCO and (d) CM6S4/35LNCO	280
Fig. 8.12	Thermal expansion curves for CM6S4/LNCO composites	281
Fig. 8.13	SEM micrograph of all the sintered fractured samples (a) CM6S4 (b) CM6S4/20 LNCO (c) CM6S4/30 LNCO and (d) CM6S4/35 LNCO	282
Fig. 8.14	EDS spectrum of the composition CM6S4/35LNCO at two different points	283
Fig. 8.15	Complex plane impedance plots of the composition CM6S4/20LNCO at different temperatures	285
Fig. 8.16	Complex plane impedance plots of the composition CM6S4/30LNCO at different temperatures	288
Fig. 8.17	Complex plane impedance plots of the composition CM6S4/35LNCO at different temperatures	291
Fig. 8.18	Arrhenius plots of total conductivity for all the compositions	294
Fig. 8.19	Arhie plot for composites in the system CM6S4/LNCO	296

LIST OF TABLES

TABLE

		Page No.
Chapter III	Experimental Work	46-62
Table. 3.1	List of chemicals used	46
Table. 3.2	Calcination temperature and time of all the compositions	48
Chapter IV	La and Sr Co-Doped Ceria, $Ce_{1-x-y}La_xSr_yO_{2-\delta}$ (Fixed Oxygen Vacancies) and its Nanocomposites	63-115
Table. 4.1	Crystallite size (calcined powders), lattice parameter and % theoretical density (TD) of all the compositions in the system $Ce_{1-x-y}La_xSr_yO_{2-\delta}$	67
Table. 4.2	Total conductivity (at 500 °C and 600 °C), activation energy of grains (E_g), grainboundaries (E_{gb}) and total (E_t) conductivity of various compositions of the system $Ce_{1-x-y}La_xSr_yO_{2-\{x/2+y\}}$	89
Table. 4.3	Coefficient of thermal expansion of all the composites	97
Table. 4.4	Total conductivity at 500 °C and activation energy for all the samples	114
Chapter V	La and Sr Co-Doped Ceria, $Ce_{0.85}La_{0.15-x}Sr_xO_{2-\delta}$ and its Nanocomposites	116-159
Table. 5.1	Crystallite size (calcined powders), lattice parameter and % theoretical density of compositions of the system $Ce_{0.85}La_{0.15-x}Sr_xO_{\{2-(0.075+x/2)\}}$	119
Table. 5.2	Total conductivity (σ_t) at 600 °C, and configurational entropy (S) of various compositions in the system $Ce_{0.85}La_{0.15-x}Sr_xO_{\{2-(0.075+x/2)\}}$	138
Table. 5.3	Activation energy of grains (E_g), grain boundaries (E_{gb}) and total (E_t) conductivity and blocking factor (α_{gb}) of various compositions in the system $Ce_{0.85}La_{0.15-x}Sr_xO_{\{2-(0.075+x/2)\}}$	139
Table. 5.4	Coefficient of thermal expansion (CTE) of all the composites	143
Table. 5.5	Total conductivity at 500 °C, activation energy and pre-exponential factor (σ_0) for all the compositions	157

Chapter VI	Sm and Sr Co-Doped Ceria and its Nanocomposites	160-205
Table. 6.1	Crystallite size (calcined powders), lattice parameter and % theoretical density of all the compositions in the system $Ce_{1-x-y}Sm_xSr_yO_{1.90}$	164
Table. 6.2	Activation energy of grains (E_g), grain boundaries (E_{gb}) and total (E_t) conductivity of all the compositions in the system $Ce_{1-x-y}Sm_xSr_yO_{1.90}$	181
Table. 6.3	Grain boundary blocking factor, α_{gb} at 400 °C, configurational entropy (S) and total ionic conductivity (σ_t) at 600 °C of all the compositions in the system $Ce_{1-x-y}Sm_xSr_yO_{1.90}$	183
Table. 6.4	Values of CTE for all the composite samples	191
Table. 6.5	Total conductivity at 500 °C, pre-exponential factor (σ_0) and activation energy at temperature >400 °C for all the compositions	203
Chapter VII	Ca and Sr co-doped ceria and its nanocomposites	206-248
Table. 7.1	Crystallite size, lattice parameter and % theoretical density of compositions in the system $Ce_{0.95-x}Ca_{0.05}Sr_xO_{1.95-x}$	209
Table. 7.2	Activation energy for conductivity of grains (E_g), grain boundaries (E_{gb}), total (E_t) and pre-exponential factor	227
Table. 7.3	Total conductivity (σ_t) and configurational entropy (S) of all the compositions	227
Table. 7.4	Coefficient of thermal expansion of all the composites	235
Table. 7.5	Total conductivity at 500 °C, activation energy and pre-exponential factor for all the compositions	246
Chapter VIII	Mg and Sr co-doped ceria and its nanocomposites	249-297
Table. 8.1	Crystallite size, lattice parameter and % theoretical density of compositions of the system $Ce_{0.90}Mg_{0.10-x}Sr_xO_{1.90}$	252
Table. 8.2	Activation energy for conduction of grains, grain boundaries and total conductivity of various compositions in the system $Ce_{0.90}Mg_{0.10-x}Sr_xO_{1.90}$	275
Table. 8.3	Total conductivity at 500 and 700 °C and configurational entropy of various compositions in the system $Ce_{0.90}Mg_{0.10-x}Sr_xO_{1.90}$	276
Table. 8.4	Coefficient of thermal expansion of all the composites	282
Table. 8.5	Total conductivity at 500 °C, activation energy and pre-exponential factor for all the compositions	295