Department of Ceramic Engineering

Curriculum of M. Tech. (Ceramic Engineering)

FIRST SEMESTER

Sl.No	Sub. Code	Subjects	L-T- P	Credits
1	CR 631	Structure & Properties of Engineering Ceramics	3-1-0	4
2	CR 611	Principles of Ceramic Processing & Fabrication	3-1-0	4
3		Professional Elective - I	3-1-0	4
4		Professional Elective - II	3-1-0	4
5		Professional Elective - III	3-1-0	4
6	CR 671	Instrumental Analysis Laboratory	0-0-3	2
7	CR 673	Characterization of Ceramic Products Laboratory	0-0-3	2
8	CR 685	Seminar & Technical Writing – I	0-0-3	2
	TOTAL		15-5-9	**26**

SECOND SEMESTER

Sl.No	Sub. Code	Subjects	L-T- P	Credits
1	CR 632	Advances in Phase Diagrams	3-1-0	4
2	CR 641	Nanomaterials	3-1-0	4
3		Professional Elective - IV	3-1-0	4
4		Professional Elective - V	3-1-0	4
5		Professional Elective - VI	3-1-0	4
6	CR 672	Electroceramics Laboratory	0-0-3	2
7	CR 674	Process Ceramics Laboratory	0-0-3	2
8	CR 686	Seminar & Technical Writing – II	0-0-3	2
	TOTAL		15-5-9	**26**

THIRD SEMESTER

Sl.No	Sub. Code	Subjects	L-T- P	Credits
1	CR 687	Seminar & Technical Writing – III	0-0-3	2
2	CR 691	Summer Research/ Industrial Project		4
3	CR 693	Research Project Work – I		8
4	CR 695	Research Project Review – I		8
	TOTAL			**22**

FOURTH SEMESTER

Sl.No	Sub. Code	Subjects	L-T- P	Credits
1	CR 688	Seminar & Technical Writing – IV		2
2	CR 692	Comprehensive Viva Voce		4
3	CR 694	Research Project Work - II		8
4	CR 696	Research Project Review - II		4
5	CR 699	Dissertation		8
	TOTAL			**26**

LIST OF PROFESSIONAL ELECTIVES

Sl.No	Sub. Code	Subject	L-T- P	Credits
1.	CR 610	Shaped and Unshaped Refractories	3-1-0	4
2.	CR 612	Refractories for Metallurgical & Allied Processes	3-1-0	4
3.	CR 614	Advanced Structural Ceramics	3-1-0	4
4.	CR 615	Non-Oxide Ceramics	3-1-0	4
5.	CR 617	Advances in Bio-ceramics	3-1-0	4
6.	CR 621	Energetics	3-1-0	4
7.	CR 622	Advanced Glass and Glass Ceramics	3-1-0	4
8.	CR 624	Advanced Composites	3-1-0	
9.	CR 625	Computer Aided Designing and Modeling of Ceramic Systems	3-1-0	4
10.	CR 627	Friction and Wear of Materials	3-1-0	4
11.	CR 633	Advanced Electroceramics	3-1-0	4
12.	CR 635	High Temperature Ceramic Processing	3-1-0	4
13.	CR 636	Science of Sol-Gel Processing	3-1-0	4
14.	CR 642	Magnetic Ceramics	3-1-0	4
15.	CR 643	Techniques of Materials Characterization	3-1-0	4
16.	CR 644	Ceramics in High Tech Applications	3-1-0	4
17.	CR 681	Special Topic in Ceramic Engineering - I		3/4
18.	CR 682	Special Topic in Ceramic Engineering - II		3/4
19.	CR 683	Special Laboratory in Ceramic Engineering - I	0-0-3	2
20.	CR 684	Special Laboratory in Ceramic Engineering - II	0-0-3	2

LIST OF PROFESSIONAL ELECTIVES OFFERED BY OTHER DEPARTMENTS

1.	BM 624	Bio Mems and Biosensors	3-1-0	4
2.	BM 626	Bio -Ceramics and Composite Materials	3-1-0	4
3.	MM 655	Transport Phenomena	3-1-0	4
4.	MM 606	X – Ray & Electron Microscopy	3-1-0	4
5.	MM 646	Composite Materials	3-1-0	4

SUMMARY OF COURSES

Sub Discipline: Nano & Bio-Ceramics

CR 610	Shaped & Unshaped Refractories	3-1-0	4
CR 611	Principles of Ceramic Processing & Fabrication	3-1-0	4
CR 612	Refractories for Metallurgical & Allied Processes	3-1-0	4
CR 614	Advanced Structural Ceramics	3-1-0	4
CR 615	Non-Oxide Ceramics	3-1-0	4
CR 617	Advances in Bio-Ceramics	3-1-0	4

Sub-Discipline: Glass & Composites

CR 621	Energetics	3-1-0	4
CR 622	Advanced Glass & Glass Ceramics	3-1-0	4
CR 624	Advanced Composites	3-1-0	4
CR 625	Computer Aided Designing & Modeling of Ceramic Systems	3-1-0	4
CR 627	Friction & Wear of Materials	3-1-0	4

Sub-Discipline: Functional Ceramics

CR 631	Structure & Properties of Engineering Ceramics	3-1-0	4
CR 632	Advances in Phase Diagrams	3-1-0	4
CR 633	Advanced Electroceramics	3-1-0	4
CR 635	High Temperature Ceramic Processing	3-1-0	4
CR 636	Science of Sol-Gel Processing	3-1-0	4

Sub-Discipline: Electrical & Magnetic Ceramics

CR 641	Nanomaterials	3-1-0	4
CR 642	Magnetic Ceramics	3-1-0	4
CR 643	Techniques of Materials Characterization	3-1-0	4
CR 644	Ceramics in High Tech Applications	3-1-0	4

Sub-discipline: Laboratory Courses

CR 671	Instrumental Analysis Laboratory	0-0-3	2
CR 672	Electroceramics Laboratory	0-0-3	2
CR 673	Characterization of Ceramic Products Laboratory	0-0-3	2
CR 674	Process Ceramics Laboratory	0-0-3	2

Sub-discipline: Project, Seminar and Special Courses

CR 681	Special Topic in Ceramic Engineering - I		03/04
CR 682	Special Topic in Ceramic Engineering - II		03/04
CR 683	Special Laboratory in Ceramic Engineering - I	0-0-3	2
CR 684	Special Laboratory in Ceramic Engineering - II	0-0-3	2
CR 685	Seminar & Technical Writing - I	0-0-3	2
CR 686	Seminar & Technical Writing - II	0-0-3	2
CR 687	Seminar & Technical Writing - III	0-0-3	2
CR 688	Seminar & Technical Writing - IV	0-0-3	2
CR 691	Summer Research/ Industrial Project		4
CR 692	Comprehensive Viva Voce		4
CR 693	Research Project – I		8
CR 694	Research Project – II		8
CR 695	Research Project Review-I		8
CR 696	Research Project Review-II		4
CR 699	Dissertation		8

DEPARTMENT OF CERAMIC ENGINEERING

DETAILED SYLLABI OF COURSES

CR 610	Shaped & Unshaped Refractories	3-1-0	4
CR 611	Principles of Ceramic Processing & Fabrication	3-1-0	4
CR 612	Refractories for Metallurgical & Allied Processes	3-1-0	4
CR 614	Advanced Structural Ceramics	3-1-0	4
CR 615	Non-Oxide Ceramics	3-1-0	4
CR 617	Advances in Bio-ceramics	3-1-0	4
CR 621	Energetics	3-1-0	4
CR 622	Advanced Glass & Glass Ceramics	3-1-0	4
CR 624	Advanced Composites	3-1-0	4
CR 625	Computer Aided Designing & Modeling of Ceramic Systems	3-1-0	4
CR 627	Friction & Wear of Materials	3-1-0	4
CR 631	Structure & Properties of Engineering Ceramics	3-1-0	4
CR 632	Advances in Phase Diagrams	3-1-0	4
CR 633	Advanced Electroceramics	3-1-0	4
CR 635	High Temperature Ceramic Processing	3-1-0	4
CR 636	Science of Sol-Gel Processing	3-1-0	4
CR 641	Nanomaterials	3-1-0	4
CR 642	Magnetic Ceramics	3-1-0	4
CR 643	Techniques of Materials Characterization	3-1-0	4
CR 644	Ceramics in High Tech Applications	3-1-0	4
CR 671	Instrumental Analysis Laboratory	0-0-3	2
CR 672	Electroceramics Laboratory	0-0-3	2
CR 673	Characterization of Ceramic Products Laboratory	0-0-3	2
CR 674	Process Ceramics Laboratory	0-0-3	2
CR 681	Special Topic in Ceramic Engineering - I		03/04
CR 682	Special Topic in Ceramic Engineering - II		03/04
CR 683	Special Laboratory in Ceramic Engineering - I	0-0-3	2
CR 684	Special Laboratory in Ceramic Engineering - II	0-0-3	2
CR 685	Seminar & Technical Writing - I	0-0-3	2
CR 686	Seminar & Technical Writing - II	0-0-3	2
CR 687	Seminar & Technical Writing - III	0-0-3	2
CR 688	Seminar & Technical Writing - IV	0-0-3	2
CR 691	Summer Research/ Industrial Project		4
CR 692	Comprehensive Viva Voce		4
CR 693	Research Project – I		8
CR 694	Research Project – II		8
CR 695	Research Project Review-I		8
CR 696	Research Project Review-II		4
CR 699	Dissertation		8

CR 610 SHAPED AND UNSHAPED REFRACTORIES 4 credits [3-1-0]

Refractories – General Classification, Properties and process flow diagram for fabrication of both shaped and unshaped refractories; Packing of solid particles – monosized particles, bimodal mixtures of spheres, bimodal mixture of non spherical particles, ternary and multiple mixtures, continuous particle size distribution, particle interaction during dry compaction; Shaped Refractories: Alumino-silicate, high alumina, magnesia, silica, doloma, carbon - raw materials, processing and forming. Study of relevant binary and ternary phase diagrams to understand the effect of impurities, minor additives, firing temperature and atmosphere and process control. Physical and thermomechanical properties of fired or heat treated refractories. Correlation of microstructure – properties of the above refractories; Composite refractories: alumina-carbon, magnesia-carbon, Spinel, alumina-silicon carbide- carbon, zirconia-carbon-processing, property optimization through microstructural control and quality optimization; Classification of unshaped refractories, versatility of unshaped refractories, discussion on different unshaped refractories- castables, gunning mass, ramming mixes, shotcreting mass, compositions, additives, manufacturing process, microstructure, properties and quality optimization; Some specific thermomechanical tests applicable to the refractories. Recent advances in this area.

Essential Reading:

1. J. H. Chesters, *Refractories- Production and Properties*, The Iron and Steel Institute, London, 1973.
1. C. A. Schacht, *Refractories Handbook*, CRC Press. , NY, 2004.
2. S. Banerjee, *Monolithic Refractories: A Comprehensive Handbook*, Wiley-American Ceramic Society, 1998.

Supplementary Reading:

1. P. P. Budnikov, *The Technology of Ceramics and Refractories*, Translated by Scripta Technica, Edward Arnold, The MIT Press, 4th Ed, 2003.
2. C. A. Schacht, *Refractory Linings: Thermo-mechanical Design and Applications*, CRC Press, 1995.
3. M. Rigaud and C. Allaire, *Advances in Refractories for the Metallurgical Industries IV*, Canadian Institute of Mining, Metallurgy and Petroleum, 2004

CR 611 PRINCIPLES OF CERAMIC PROCESSING AND FABRICATION 4 credits [3-1-0]

Powders synthesis method; mechanical methods, hydrothermal synthesis of ceramic oxide powders, servo thermal synthesis powders, chemical methods, synthesis of nano-scale ceramic powders, powder characterization, particle size, shape, surface area, chemical composition, crystal structure and phase composition. Science of colloidal processing, types of colloids, electrostatic, steric, elctrosteric stabilization, reheological properties, sol-gel processing, silicon alcoxides, hydrolysis and condensation, polymer growth, gelation, particulate gel, polymeric gel, mixing of particulate solids, packing of particles; Forming of ceramics – dry and semi dry pressing, slip, tape, gel casting. plastic forming, extrustion, injection moulding, hot iso-static pressing. Solid freeform fabrication; Thick films and thin films: screen printing, sputter coating, chemical vapour deposition of ceramics, electro vapour deposition, Sol-gel coating, ceramic membrane processing; Drying of granular ceramic green body, binder removal, green microstructures and their characterization. Recent advances in this area.

Essential Reading:

1. J. S. Reed, *Introduction to the Principles of Ceramic Processing*, 2nd Ed., John Wiley & Sons, 1995.
2. M. N. Rahaman, *Ceramic Processing*, CRC Press, 2007.

Supplementary Reading:

1. D. W. Richerson, *Modern Ceramic Engineering: Properties, Processing, and Use in Design*, 3rd ed, CRC Press, 2006.
2. D. A. Brosan and G. C. Robinson, *Introduction to Drying of Ceramics*, The American Ceramic Society, Ohio, USA, 2003.
3. H. Mehrer, *Diffusion in Solids: Fundamentals, Methods, Materials, Diffusion Controlled Processes*, Springer, 2007.

CR 612 REFRACTORIES FOR METALLURGICAL & ALLIED PROCESSES 4 credits [3-1-0]

Review of metallurgical processes; Iron and steel making principles. refractory linings for primary and secondary steel making operations, Refractories used in the coke oven, blast furnace, properties and problems. Refractories for hot metal handling. steel refining and secondary steel making. Continuous casting refractories: materials, production, properties and future trends. Hot repairing – Materials, Repairing techniques; Ladle refractories, Direct bonded mag-chrome aggregates, New generation slide gate refractories with improved performance; Principles of extraction of non-ferrous metals of commercial importance especially Cu, Zn and Al. Types of furnaces and refractories used. Factors affecting the performance of refractories; Refractories used in Glass production, Cement industries, Lime calcinations, regenerators, Pottery industries and allied industries. Standardization, testing – including non – destructive testing. Plant trial performance of non shaped and advanced refractories developed using surface chemistry, thermo-mechanical considerations for refractory linings, refractories for the refineries and circulating fluid beds, plasma processing of refractory aggregates, coating techniques for improving the oxidation resistance of graphite. Use of non-oxide ceramic materials in ferrous and non-ferrous industries. Future trends in utilization of refractories. Recent advances in this area.

Essential Reading:

1. J. H. Chesters, *Refractories- Production and Properties*, The Iron and Steel Institute, London.
2. R. Amavis (ed.), *Refractories for the Steel Industry*, Elsevier Applied Science, 1990.

Supplementary Reading:

1. S. C. Caniglia and G. L. Barna, *Handbook of Industrial Refractories Technology*, William Andrews Publishing, NY, 1992.
2. S. Banerjee, *The Changing Refractories Industry: New Technologies, Materials and Markets*, Business Communication Co, 1999.

Pre-requisite : CR 610

CR 614 ADVANCED STRUCTURAL CERAMICS 4 credits [3-1-0]

Griffith theory of fracture, toughness, statistical nature of strength, toughening mechanism, crack deflection, bridging, shielding, pullout; Alumina Ceramics: Crystal structure, phases, types of alumina, properties, microstructure; Zirconia Ceramics: Crystal structure and polymorphic

modifications, transformation toughening; effect of microstructure, different system in zirconia (PSZ, TZP, ZTA, ZTC), application; Composites: classification, importance, strengthening and toughening mechanisms, stress-strain curve, fabrication, densification. Composites of some oxides and non-oxides; Preparation, processing, properties and applications of silicon carbide, silicon nitride and SIALON, Tungsten Carbide, Boron Carbide, Boron Nitride, Carbon Nitride, Carbon and Graphite, SiC whiskers, reinforced Al_2O_3, silicon nitride whiskers, fiber reinforced ceramics; Abrasives: Natural and Synthetic; properties, applications and performances. Recent advances in this area.

Essential Reading:

1. J. B. Wachtman Jr., *Structural Ceramics, Treatise on Materials Science & Technology,* Vol - 29, Academic Press, New York, 1989.
2. S. Hampshire, *Non-Oxide Technical and Engineering Ceramics*, Elsevier Applied Science. Amsterdam, 1986.

Supplementary Reading:

1. W. E. Lee and W.M. Rainforth, *Ceramic Microstructures: Property Control by Processing*, First Edition, Chapman & Hall, London, 1994.

CR 615 NON-OXIDE CERAMICS 4 credits [3-1-0]

Silicon carbide: Different production routes and processing of ultra fine powders, abrication and sintering, polytypism and polytype distributions, Silicon carbide whiskers. Silicon-based non-oxide ceramics from rice husks; Silicon nitride: Powder preparation, Fabrication and sintering. Carbide bonded nitride and nitride bonded carbide, silicon oxy-nitride, silicon nitrides from plasma routes; Sialons: Related phase diagrams, Varieties of sialons and their properties, Preparations, Shaping and Applications; Preparation, properties and uses of boron nitride, boron carbide, tungsten carbide, titanium carbide, zirconium diboride and molybdenum disilicide; Carbon: Amorphous and crystalline, Types of carbon, Graphitization and Parameters of graphitization. Recent advances in this area.

Essential Reading:

1. S. Hampshire, *Non-Oxide Technical and Engineering Ceramics*, Elsevier Applied Science. Amsterdam, 1986.
2. W. E. Lee and W. M. Rainforth, *Ceramic Microstructures: Property Control by Processing*, First Edition, Chapman & Hall, London, 1994

Supplementary Reading:

1. S. Somiya (Editor), Y. Inomata (Editor), *Silicon Carbide Ceramics*, Springer; 1st edition 2007.
2. S. Somiya (Eds), *Silicon Nitride -I,* Elsevier Applied Sciences, 1987

CR 617 ADVANCES IN BIO-CERAMICS 4 credits [3-1-0]

Bio-compatible ceramic materials, Bioceramics as implant in human body: Cortical bone versus Trabecular bone structure, Physics of bone and structure of tooth. Properties of bones. Body environment and bio-compatibility; Hydroxyapatite based bio-ceramics - porous hydroxyapatite and coated Hydroxyapatite. Characterization of bioceramics. Composite implant materials. Material selection, design, performance and degradation, Use of Alumina and zirconia in

surgical implants, Bioactive glasses and glass-ceramics, machineable and phosphate glass-ceramics, stability of calcium-phosphate ceramics and plasma sprayed coating, bioactive glass coatings, bioactive carbon coating, bioceramic composites, design of bioactive ceramic-polymer composite, radiotherapy glasses; Testing of biomaterials and Implants: *In vitro* testing; Mechanical testing: tensile strength, compression strength, wear behavior, fatigue, corrosion studies and fracture toughness. *In-vivo* testing (animals): biological performance of implants. *Ex-vivo* testing: *in vitro* testing simulating the *in vivo* conditions. Tissue -ceramics interactions. Standards of implant materials, regulation of medical devices, ethical issues. Recent advances in this area.

Essential Reading:

1. L. L. Hench and J. R. Jones, *Biomaterials, Artificial Organs and Tissue Engineering,* Taylor & Francis, 2007
2. B. D. Ratner, A. S. Hoffman, F. J. Schoen and J. E. Lemons, *Biomaterials Science, Second Edition: An Introduction to Materials in Medicine,* Elsevier Academic Press, London, 2004

Supplementary Reading:

1. A. Wereszczak, *Advances in Bioceramics and Biocomposites II,* John Wiley & Sons, 2007.
2. J. Park, *Bioceramics: Properties, Characterizations and Applications,* Springer; 1st edition, 2008

CR 621 ENERGETICS 4 credits [3-1-0]

Thermodynamic system and control volume, first law of thermodynamics, heat capacity, enthalpy, reversible and irreversible processes; Second law of thermodynamics, quantification of irreversibility, Entropy and disorder on an atomic scale, criterion for equilibrium, combined statement of first law and second law; Free energy-temperature diagram, Auxiliary functions, the Helmholtz free energy, the Gibbs free energy, the chemical potential, Maxwell's Equations, Gibbs – Helmholtz equation, Gibbs free energy as function of temperature and pressure; The dependence of entropy on temperature and Third law of thermodynamics Fugacity, activity, ideal solution, Duhem–Margules equation, Gibbs Duhem equation,Raoult's and Henry's law, Statistical Thermodynamics–Maxwell-Boltzman, Bose-Einstein and Fermi-Dirac statistics, Partition Function; The criteria for reaction equilibrium for system containing condense matter Surface energy, Gibbs adsorption equation; Heterogeneous equilibrium, Gibbs Phase Rule, Applications of thermodynamics in phase transformation and synthesis of ceramic materials. Recent advances in this area.

Essential Reading:

1. D. R. Gaskell, *Thermodynamics of Materials*, Third Edition, Taylor & Francis, PA, 2003.
2. J. M. Smith, H. C. V. Neiss, and M. Abbott, *Introduction to Chemical Engineering Thermodynamics*, 7th Ed, McGraw-Hill Professional, 2004.

Supplementary Reading:

1. A. Ghosh, *Textbook of Metallurgical and Materials Thermodynamics*, PHI Learning Pvt. Ltd, 2004

CR 622 ADVANCED GLASS AND GLASS CERAMICS 4 credits [3-1-0]

Glassy state, Structural models for different glasses; Structural and kinetic theory of glass formation, Homogeneous and heterogeneous nucleation nucleation and crystal growth, TTT diagram; Importance of viscosity, viscoelsticity, viscosity measurment, compositional and temperature dependence of viscosity; Immiscibility and phase separation on glasses, application of immiscibility diagram; Different glass compositions, batch calculation and mixing, mechanism of batch melting and refining of glass, glass melting furnaces; Industrial glass production processes: Feeders, Colburn process, PPG process, Float process Sol gel sysnthesis of glasses; Density and thermal expansion of glasses; Mechanical properties of glasses, Annealing of thermal stress, toughening of glasses; Optical properties of glasses, molar and ionic refractivities, dispersions; Optical fibre: MOCVD process, Preform making, Fibre drawing techniques and applications; Glass ceramics- fabrication, advantages of glass ceramic formation, properties and applications. Recent advances in this area.

Essential Reading:

1. F. V. Tooley, *Hand Book of Glass Manufacture – Vol. I & II*, Ogden Publishing Co., NY,1960.
2. A. Paul, *Chemistry of Glasses*, 2nd Ed., Chapman and Hall, London, 1990.
3. J. E. Shelby, *Introduction to Glass Science and Technology*, The Royal Society of Chemistry, 2005.

Supplementary Reading:

1. P. W. McMillan, *Glass Ceramics*, Academic Press, 2nd Ed., NY,1979.
2. A. K. Varshneya, *Fundamentals of Inorganic Glass*, Academic press, 1994.
3. H. Bachs and D. Krause, *Low Thermal Expansion Glass Ceramics*, Springer, 2005.

CR 624 ADVANCED COMPOSITES 4 credits [3-1-0]

Composites- Definition, Classification, matrices and their properties. Importance of glass, ceramic and carbon fibres, polyster, epoxies, thermosetting and thermoplastic materials. Fabrication, structure, properties and application; Common ceramic matrix composite material and their properties, interfaces in composites, interaction at the interface. Types of reinforcement: continuous fiber, short fiber, whisker, glass fiber, carbon/graphite fiber, natural fiber, boron carbide silicon carbide fiber; Ceramic Matrix composites: Fabrication, properties, and uses, interface reaction, toughness; Specific examples - Alumina silicon carbide, Mullite-Zirconia, polymer-PZT composites, Processing and application; Mechanics of properties of composites: Density, Mechanical properties, mechanism of load transfer from matrix to fiber, variation of lamina properties with orientation, tensile and compressive strength of unidirectional fiber composite, fracture in composites, debonding, fiber pull out, delamination fracture; Qualty and testing; material testing, mechanical testing, thermal and environmental testing, flamibility testing, non-destructive testing; Composite design; stress type, lamination theory, modeling and finite element analysis. Recent advances in this area.

Essential Reading:

1. G. F. Carter and D. F. Paul, *Materials Science and Engineering*, ASM International, 1991.
2. J. F. Shackelford and M. Meier, *Introduction to Materials Science for Engineers*, Prentice Hall PTR, 2005.

Supplementary Reading:

1. F. L. Matthews and R. D. Rawlings, *Composite Materials: Engineering and Science*, Chapman and Hall, 1994.
2. K. K. Chawla, *Composite Materials: Science and Engineering*, Springer- Verlag, 1987.
3. W. Krenkel (Editor) *Ceramic Matrix Composites: Fiber Reinforced Materials and their Applications,* Wiley-VCH, 2008.

CR 625 COMPUTER AIDED DESIGNING AND MODELING OF CERAMIC SYSTEMS 4 credits [3-1-0]

Principles of mathematical modeling, principles of design of experiments, testing for relationship among variables, sample models based on difference and differential equations, fitting model to data, fitting models to data, deterministic and probabilistic model, description of atomic interactions; Basics of the density functional theory, approximations in terms of pair potentials; embedded atom method and tight-binding. Material behaviour and computational model in nano-, micro-, meso- and macro-scales in the content of real materials-related problems mechanical and thermodynamic properties, Phase transformation, precipitation and precipitation hardening, spinodal decomposition, displasive transformation in ceramic systems, ordering and crystal structure of ceramics, microstructure evolution during processing; molecular statistics, molecular dynamics; Monte Carlo and lattice dynamics, Interpretation of modeling in terms of structures using radial distribution function, Thermo dynamic and statistical analyses; Application of computing and statistical fundamentals to solve Material Science and Engineering problems. Recent advances in this area.

Essential Reading:

1. D. Raabe, *Computational Materials Science:The Simulation of Materials Microstructure and Properties*, Wiley-VCH, 1998
2. J. D. Hill, L.Subramaiah and A.Maiti, *Molecular Modeling Techniques in Material Science*, Taylor and Francis, 2005

Supplementary Reading:

1. M. Meyer and V. Pontikis, *Computer Simulation in Materials Science: Inter-atomic Potentials, Simulation, Techniques and Applications*, Kluwer Academic, 1991
2. K. Ohno, K. Esfarjani and Y. Kawazoe, *Introduction to Computational Material Science: from ab initio to Monte Carlo methods*, Springer-Verlag, 1999

CR 627 FRICTION AND WEAR OF MATERIALS 4 credits [3-1-0]

Surface topography, physico-chemical aspects of solid surfaces, and surface interactions. analysis and measurement of surface roughness, Surface and subsurface stress distributions and Hertzian contact ; Contact between solid surfaces; Adhesion and cohesion properties of solid; Mechanics of solid elastic and elastoplastic contacts; The laws of friction, mechanisms of friction, friction space, stiction, stick slip, and surface temperature; Various modes of wear: adhesive, delamination, fretting, abrasive, erosive, corrosive, oxidational (mild and severe), melt, and the wear-mechanism maps; Types of lubrication: boundary, solid-film, hydrodynamic, and hydrostatic lubrication; Surface Engineering Methods to reduce wear, Electrolytic, Spraying, Hard-facing, Chemical Vapour Deposition (CVD), Plasma Vapour Deposition (PVD), Mechanical methods, Surface melting and Thermo chemical treatments; Applications of sliding

contacts, rolling contacts, electric contacts, and micromechanical systems; Micro and Nanoscale Wear, Friction, Adhesion and Scratching; Design of wear life, frictional performance and tribological surfaces; Solution of tribological problems. Recent advances in this area.

Essential Reading:

1. B. Bhushan, *Principles and Applications of Tribology*, Willey –IEEE, 1999.
2. I. M. Hutchings, *Tribology: Friction and Wear of Engineering Materials*, Edward Arnold, 1992.

Supplementary Reading:

1. K. C. Ludema, *Friction, Wear, Lubrication: A Textbook in Tribology*, CRC Press, 1996.
2. R. D. Arnell, P. Davies, J. Halling, and T. Whomes, *Tribology Principles and Design Applications,* MacMillan, 1991

CR 631 STRUCTURE & PROPERTIES OF ENGINEERING CERAMICS 4 credits [3-1-0]

Bonding, stability of ionic crystals, Pauling's rule, the Madelung constant, Ceramic crystal structure, rock salt, Fluorite, antifluorite, zincblend, wurtzite, corundum, illemenite, rutile, peroveskite, spinel, covalent ceramics, silicon nitride, carbide, oxynitride, crystalline silicates Glass structure; Elasticity, Strength and Griffith theory, ductile, brittle, fracture behaviour, fracture toughness, creep and fatigue, Weibull parameters; Thermal properties, thermal stresses and fracture. Ligand field and Crystal field theory; colours, optical shields and optical fiber communication; Electrical behaviour, electronic conductivity, ionic conductivity, electrical insulators, semi conductors, superconductivity, dielectric properties, polarization, dielectric constants, dielectric loss, dielectric strengths, piezoelectricity, pyroelectricity, ferroelectricity. Magnetic behaviour, Magnetism, magnetic exchange mechanisms, Soft and hard ferrite and Microwave ferrite. Optical behaviour , absorption and transparency, colour, phosphorescence, laser, index of refraction, electro optic behaviour. Recent advances in this area.

Essential Reading:

1. W. D. Kingery, H. K. Bowen and D. R. Uhlmann, *Introduction to Ceramics*, 2nd Ed. John Wiley & Sons, Singapore, 1991.
2. L.V. Azaroff, *Introduction to Solids*, Tata McGraw Hill Publishing Co. Ltd, 1977.
3. F. A. Hummel, *Introduction to Phase Equilibrium in Ceramic Systems*, First Edition, CRC Press, 1984.

Supplementary Reading:

1. C. Kittel, *Introduction to Solid State Physics*, 8th Ed. John Wiley & Sons Pvt. Ltd, 2004.
2. G. Smith, R. S. Roth, T. Negas and L. P. Cook, *Phase Diagrams for Ceramists*, American Ceramic Society, 1983

CR 632 ADVANCES IN PHASE DIAGRAMS 4 credits [3-1-0]

Phase equilibrium in single and two component systems, Lever rule. Free energy composition diagram and miscibility gap. Eutectic, eutectoid, peritectic diagrams and incongruent melting, peritectoid, intermediate compounds, complex and real systems, complete solid solution, limited solid solution, sub solidous phase equilibriums, variable valence system; Temperature-composition representation in ternary systems, Isothermal and Isoplethal analysis. Ternary systems with binary and ternary eutectic, peritectic, congruently and incongruently melting

compounds, boundary curves and temperature contours, ternary invariant points, compatibility triangles, miscibility gap, liquid-liquid immiscibility, reciprocal salt diagram, ternary lever rule, ternary eutectic reaction, ternary peritectic reaction, heating through a ternary eutectic/peritectic, equilibrium crystallization path, eutectoid solidification, crystallization with partial resorption, non equilibrium crystallization, Real systems and applications. Common examples of sub-solidus behavior; some important three component systems- $CaO–Al_2O_3$ – SiO_2, $MgO\text{-}Al_2O_3\text{-}SiO_2$, $SiO_2\text{-}FeO\text{-}Fe_2O_3$, $MgO\text{-}FeO\text{-}Fe_2O_3$, $MgO\text{-}Al_2O_3\text{-}Cr_2O_3$. Quaternary System- $MgO\text{-}CaO\text{-}SiO_2\text{-}Fe_2O_3$, $MgO\text{-}SiO_2\text{-}CaO\text{-}B_2O_3$; Recent advances in this area.

Essential Reading:

1. W. D. Kingery, H. K. Bowen and D. R. Uhlmann, *Introduction to Ceramics*, 2nd Ed. John Wiley & Sons, Singapore, 1991.
2. F. A. Hummel, *Introduction to Phase Equilibrium in Ceramic Systems*, First Edition, CRC Press, 1984.

Supplementary Reading:

1. G. Smith, R. S. Roth, T. Negas, L. P. Cook, *Phase Diagrams for Ceramists*, American Ceramic Society, 1983

CR 633 ADVANCED ELECTROCERAMICS 4 credits [3-1-0]

Electrical and electronic conduction in ceramics, defect chemistry, ionic conductivity, ceramic electrolytes and fast ion conductors, ceramic insulators; Ceramic Capacitors, piezoelectric, ferroelectric and electro optic ceramics - material systems, processing and fabrication; Origin of magnetism in solids, classification of magnetic materials, soft ferrite, hard ferrite, spinel ferrite, hexagonal ferrite, garnet ferrite-processing, properties and applications; Ceramic Sensors and resistors- classification, materials systems, processing and applications. Positive temperature coefficient and negative temperature coefficient ceramics – thermistor, gas sensor, humidity sensor, pressure sensors, ZnO-varistors technology, varistor microstructure and fabrication, mechanism, equivalent circuit. Varistor application, ceramic thick film technology, materials and processing. Electro ceramic thin film technology, materials and deposition methods, application of thin films in microelectronics and micro systems; Multilayer ceramic technology – Sequential, laminated MLC processes, processing of multi layer ceramics, sintering of multilayer structure. Low temperature co-fired glass ceramics. Recent advances in this area.

Essential Reading:

1. R. C. Buchanan (Edt.), *Ceramic Materials for Electronics*, 3rd edition Marcel Dekker, NY, 2004.
2. L. M. Levinson, *Electronic Ceramics*, Marcel Dekker, NY, 1988.

Supplementary Reading:

1. A. J. Moulson and J. M. Herbert, *Electroceramics: Materials, Properties and Applications*, Wiley; 2nd edition, 2003.
2. B. Jaffe, W. R. Cook, H. Jaffe and H. L. C. Jaffe, *Piezoelectric Ceramics*, R.A.N Publishers, 1990.

CR 635 HIGH TEMPERATURE CERAMIC PROCESSING 4 credits [3-1-0]

Fundamentals, defects and defect chemistry, intrinsic, extrinsic defects, defect reactions, diffusion and defects, mechanisms of diffusion, types of diffusion co-efficients, chemical potentials of different systems, diffusional flux equation, ambipolar diffusion, driving force for

sintering; Solid state and viscous sintering, theoretical analysis, Herrings-Scaling law; sintering models and sintering diagrams, intial, intermediate, final stage sintering models. Sintering with an externally applied pressure – Hot Pressing and Hot Isostatic Pressing, stress in densifiction factor and sintering stress; Grain growth and Ostwald ripening. Normal and exaggerated grain growth, grain growth in dense and porous solid, grain growth kinetics, pore-grain boundary interactions, densification and coarsening, simultaneous densification and grain growth; Liquid phase sintering, mechanism, stages and microstructure of liquid phase sintering. Pressure assisted liquid phase sintering, activated sintering, vitrification Advanced techniques: Microwave sintering and spark plasma sintering Problems of sintering: Constrained sintering; Sintering of thin films; Sintering with a chemical reaction. Recent advances in this area.

Essential Reading:

1. J. Reed, *Introduction to the Principles of Ceramic Processing*, 2nd Ed., John Wiley & Sons. 1995.
2. M. N. Rahaman, *Sintering of Ceramics*, CRC Press, 2008.
3. C. Kittel, *Introduction to Solid State Physics*, 8th Ed. John Wiley & Sons Pvt. Ltd, 2004.

Supplementary Reading:

1. D.W. Richerson, *Modern Ceramic Engineering: Properties, Processing, and Use in Design,* 3rd Ed, CRC Press, 2006.
2. P. G. Shewmon, *Diffusion in Solids,* McGraw Hill, NY, 2nd edition, February 1998.
3. S. Somiya and Y. Moriyoshi Eds., *Sintering Key Papers,* Elsevier Applied Science, London, 1990.

Pre-requisite : CR 611

CR 636 SCIENCE OF SOL-GEL PROCESSING 4 credits [3-1-0]

Thermodynamics of surface. Adsorption Isotherm. Physical aspects of interfaces, Grain boundary, Contact angle, Dihedral angle and Grain shape prediction, Concept of wetting. Structure of surface and interface; Colloids, Sols and gels. Introduction to sol-gel processing. Hydrolysis and condensation of metals, borates, aluminates, aqueous silicates. Particulate sols and gels, mono-disperse particles from solution and other methods of particle processing Classical and percolation theory of gel formation, kinetic models. Aging of gels and mechanical properties. Drying of gels, driving forces, shrinkage, liquid transport, drying stress. Structural evolution during gel consolidation and heating-aerogel and xerogel. Sintering of gel-viscous sintering. Comparison between gel derived and conventional ceramics. Sol-gel technology and thin film

Essential Reading:

1. C. Jeffrey Brinker, George W. Scherer, *Sol-Gel Science: The Physics and Chemistry of Sol-Gel Processing,* Academic Press, 1990
2. L. L. Hench, *Sol-gel Silica: Properties, Processing & Technology,* Noyes Publications, 1998

Supplementary Reading:

1. M. N. Rahaman, *Ceramic Processing*, CRC Press, 2007.
2. M. N. Rahaman, *Sintering of Ceramics*, CRC Press, 2008.

CR 641 NANOMATERIALS 4 credits [3-1-0]

Synthesis of Nanomaterials- top down and bottom up approach. From vapor phase' Sputtering, Thermal Evaporation and Laser methods. Synthesis by Chemical Routes; Nucleation and Growth from solutions, Stabilization against agglomeration. Nanostructure by mechanical attrition; Processing of Nanomaterials: Nanostructured sol-gel materials, Consolidation of nanocrystalline materials by compaction and sintering. Characterization of nanostructured materials; By scattering techniques. Proximal microscopy (AFM and STM), Properties of Nanostructured materials - particle size, porosity, specific surface, chemical and supramolecular structures of Nanomaterials, Improvement of mechanical properties, super-plasticity of nano-structured materials, Structural, Magnetic and Electron transport properties of nanoparticles. Optical Characterization and applications of semiconductor quantum dots; Special Nanomaterials: Ultra-pure and biocompatible nanomaterials; Fullerenes, carbon nanotubes, Nanofabrication; Lithography, Pattern transfer. Layer-by-layer Self-Assembly, Nanocontact Printing and Writing. Nanoelectronics; nano gas sensors, Transparent coatings, Diamond-like coatings. Recent advances in this area.

Essential Reading:

1. G. Cao, *Nanostructures and Nanomaterials: Synthesis, Properties and Applications*, Imperial College Press, 2004.
2. M. Winterer, *Nano-crystalline Ceramics: Synthesis and Structure*, Springer, 2002

Supplementary Reading:

1. M Wilson, K Kannangara, G Smith and M Simmons, *Nanotechnology: Basic Science and Emerging Technologies*, Chapman and Hall, 2002
2. M A. Ratner, D Ratner, M Ratner, *Nanotechnology: A Gentle Introduction to the Next Big Idea*, Prentice Hall PTR, 2002.
3. K. E Drexler, *Nanosystems: Molecular Machinery, Manufacturing, and Computation*, John Wiley & Sons, 1992

CR 642 MAGNETIC CERAMICS 4 credits [3-1-0]

Crystal Structure of Magnetic Ceramics: Crystal structures, Cation distribution, Spinel and spinel solid-solutions, Rare Earth Garnet and its solid-solutions, Hexagonal Ferrites. Chemical Aspect and Microstructure of ferrites; Preparation of Magnetic Ceramics: Powder Preparation by; Coprecipitation, Precursor method, Sol-gel method, Spray-drying, Freeze-drying, Combustion synthesis and other methods. Nanocrystalline ferrites, Green Body forming, Sintering, Preparation of ferrite thin film, Preparation of ferrite single crystals; Magnetic Properties of Ferrites: Origin of magnetic moments, Magnetic Order, Domains and domain walls, Magnetization process and hysteresis, Initial permeability, Magneto-crystalline Anisotropy, Magneto-striction, Soft ferrites, Hard ferrites, AC Properties of Ferrites, Eddy Losses, Core Loss, Dis-accommodation, Microwave properties, Electrical and Magneto-optical properties; Applications of Ferrite: Permanent Magnet devices, Inductor and Transformer for Low and High Power applications, Ferrite for EMI Suppression, Ferrite for Entertainment Applications-Radio and TV, Magnetic recording, Microwave components and other applications. Recent advances in this area.

Essential Reading:

1. R. C. Buchanan (Ed), *Ceramic Materials for Electronics*, 3rd edition Marcel Dekker, NY, 2004.
2. R. Valenzuela, *Magnetic Ceramics*, Cambridge University Press, 2005.

3. A. Goldman, *Modern Ferrite Technology*, 2nd Ed., Springer, 2005.

Supplementary Reading:

1. L. L. Hench, J. K. West , *Principles of Electronic Ceramics*, Wiley-Interscience 1990.
2. L. M. Levinson, *Electronic Ceramics*, Marcel Dekker, NY, 1988.
3. B.D. Cullity, *Introduction to Magnetic Material*, Addison-Wesley Publishing Co.1972.
4. J. Smit and H. P. Wijn, *Ferrites*, John Wiley, 1959.

CR 643 TECHNIQUES OF MATERIALS CHARACTERIZATION 4 credits [3-1-0]

Thermal analysis methods- principles, instrumentation, data analysis and applications in ceramics; X-ray diffraction and Bragg Law, Diffraction under ideal and non-ideal condition, X-ray scattering and structure factor, X-ray diffractometer, X-ray data file analysis, Chemical analysis by x-ray fluorescence, Auger Electron Spectroscopy, X-ray Photoelectron Spectroscopy, Electron loss energy spectroscopy; Scanning Electron Microscopy – basic principle, instrumentation, electron specimen interaction, topographical and atomic number contrast. Transmission Electron Microscopy; practical aspect of microscopy, amplitude and phase contrast imaging, kinematical theory of image contrast, electron diffraction. Atomic Force Microscopy- basic principles, Atomic Force Microscopy modes, phase imaging, face curve, application of Atomic Force Microscopy; Infrared, Raman and Nuclear magnetic resonance spectroscopy: field ion microscopy, Basic principles, Instrumentation, Infra red and Raman active bonds, data analysis, applications, surface analysis and chromatography techniques for material characterization.

Essential Reading:

1. R. F. Speyer, *Thermal Analysis of Materials*, Marcel Dekker Inc., 1994.
2. B. D. Cullity, *Elements of X-ray Diffraction*, Addison Wesley Publishing Company; 2nd edition,1978.
3. P.J. Goodhew, J. Humphreys and R. Beanland, *Electron Microscopy and Analysis*, Third Edition, Taylor & Francis, 2001.

Supplementary Reading:

1. H. P. Klug and L. E. Alexander, *X-ray Diffraction procedures for Polycrystalline and Amorphous Materials*, 2nd Edition, John Wiley, 1974.
2. D. A. Skoog, F. J. Holler and T. A. Nieman, *Principles of Instrumental Analysis*, 5th Ed., Hartcourt College Publishers, 1998.

CR 644 CERAMICS IN HIGH TECH APPLICATIONS 4 credits [3-1-0]

Functional Ceramics: Scope, Present status and Future trend, Classification according to their different functions. Smart functional roles of the materials in devices which depends on their electrical, optical and thermal properties, e.g. active semi conducting devices and associated passive electrical components, smart transducers, optical fibers, optical coatings, liquid crystal displays, optical storage devices, ruby laser, solar cell, ceramic insulators, Peltier cooler. Ceramic thick and thin film technology, material systems and applications, understanding of functional materials and devices at the microscopic level (atomic and-or molecular level); Ceramic Sensors: Classification, Operating principles of different sensors, Preparation and applications; Optical fiber communication: scope, working principle, fabrication and applications; Ceramics in tribological application: scope, material requirements, fabrication and applications; Ceramic membranes: classifications, material requirements, preparation and applications;

Special glass and glass ceramics for defence application; Ceramics in biological application: classifications, material requirements, and applications. Recent advances in this area.

Essential Reading:

1. Z. Lin Wang, W. Z-Lin-Wang, Z C Kang, *Functional and Smart Material*, Springer 1998.
2. T. G. Nenov, S. P. Yordanov and N. Nenov, *Ceramic Sensors: Technology and Applications*, CRC Press, 1996.
3. J. B. Park, *Biomaterials: Principles and Applications*, CRC Press, 2002.
4. E. Rabinowicz, *Friction and Wear of Materials*, 2nd Ed, John Wiley & Sons, 1995.

Supplementary Reading:

1. N. Setter, *Electro-ceramic-based MEMS: Fabrication Technology and Applications*, Springer, 2005.
2. S. V Bhat, *Biomaterials* , Springer, 2002.
3. I. M. Hutchings and E. Arnold, *Tribology: Friction and Wear of Engineering Materials*, London, 1992.
4. H. Bachs and D. Krause, *Low Thermal Expansion Glass Ceramics*, Springer, 2005

CR 671 INSTRUMENTAL ANALYSIS LABORATORY 2 credits [0-0-3]

1. Study of phase transformation behaviour of ceramic materials by Differential Thermal Analysis (DTA).
2. Study of thermal decomposition of ceramic materials by Thermo-gravimetric Analysis (TGA).
3. Chemical analysis of ceramic materials by UV –Visible spectrophotometer.
4. Study of X-Ray Machine and Diffractometer.
5. Determination of lattice parameter of Cubic system and indexing of planes.
6. Determination of crystallite size from x-ray line broadening.
7. Indexing of XRD pattern using Structure factor.
8. Study of thermal expansion behaviour of ceramic materials by dilatometer.
9. Study of phase transition behaviour of ceramic materials by dilatometer.
10. Sintering study – constant rate sintering and isothermal sintering.
11. Study of sintering kinetics by Thermo Mechanical Analyzer (TMA)

CR 672 ELECTROCERAMICS LABORATORY 2 credits [0-0-3]

1. Determination of Curie temperature for ferro-electric and ferro-magnetic materials.
2. Study of Conductivity in ionic conductors and insulators.
3. Determination of dielectric constant and loss factor for capacitor materials.
4. Study of the I – V characteristics of varistors.
5. Study of the PTCR behaviour measurement of $BaTiO_3$.
6. Determination of Tefel plot for anodic and cathodic polarization of ceramic materials.
7. Study of Temperature dependent dielectric and electrical behavior of ceramics.
8. Study of Partial pressure dependent dielectric and electrical behavior of ceramics.
9. Determination of grain and grain boundary contributions in dielectric materials from Cole – Cole plot.
10. Study of magnetization behaviour of a soft ferrite material.
11. Determination of d_{33} co-efficient of a piezoelectric material.

CR 673 CHARACTERIZATION OF CERAMIC PRODUCTS 2 credits [0-0-3]

LABORATORY

1. Quantitative chemical analysis of alumino-silicate materials.
2. Chemical analysis of ordinary soda-lime-silicate glass.
3. Ceramographic sample preparation for optical microscope, study of micro-structural features by Image Analyzer.
4. Determination of Particle size and zeta potential of ceramic powder.
5. Study of porosity and pore size distribution of a ceramic material.
6. Determination of surface area of ceramic powder by BET adsorption.
7. Determination of fracture toughness of ceramic materials.
8. Determination of fracture strength of ceramic materials.
9. Measurement of Vickers Hardness of ceramic materials.
10. Study of wear behaviour and determination of COF of ceramic materials.
11. Familiarization with Scanning Electron Microscopy (SEM).

CR 674 PROCESS CERAMICS LABORATORY 2 credits [0-0-3]

1. Determination of particle size and particle size distribution by Andreasen Pipette and Centrifuge.
2. Effect of milling time on the surface area and phase transformation of ceramic powder.
3. Effect of additives on the rheological properties of oxide ceramic slurries.
4. Slip casting of oxide ceramics and study of casting process.
5. Effect of processing parameter on the properties of slip cast bodies.
6. Effect of binder type and amount on the green strength of dry-pressed article.
7. Effect of relative humidity on the green density of dry pressed bodies.
8. Study of compaction behaviour of ceramic powder.
9. Effect of powder and pressing properties on the generation of various defects in dry pressed articles.
10. Effect of different drying conditions on the properties of dried articles prepared by slip casting.

CR 681	**Special Topic in Ceramic Engineering - I**		**03/04**
CR 682	**Special Topic in Ceramic Engineering - II**		**03/04**
CR 683	**Special Laboratory in Ceramic Engineering - I**	**0-0-3**	**2**
CR 684	**Special Laboratory in Ceramic Engineering - II**	**0-0-3**	**2**
CR 685	**Seminar & Technical Writing - I**	**0-0-3**	**2**
CR 686	**Seminar & Technical Writing - II**	**0-0-3**	**2**
CR 687	**Seminar & Technical Writing - III**	**0-0-3**	**2**
CR 688	**Seminar & Technical Writing - IV**	**0-0-3**	**2**
CR 691	**Summer Research/ Industrial Project**		**4**
CR 692	**Comprehensive Viva Voce**		**4**
CR 693	**Research Project – I**		**8**
CR 694	**Research Project – II**		**8**
CR 695	**Research Project Review-I**		**8**
CR 696	**Research Project Review-II**		**4**
CR 699	**Dissertation**		**8**