Physical properties. Non-carbon nanotubes. Applications of nanotubes. Biological applications of nanotechnology. Brief idea of nanobiotechnology. 14 hours

**Unit III**

Nanocomposites: Introduction to composites and nanocomposites. Ceramic, metal, polymer nanocomposites. Thin film and CNT- based nanocomposites. Polymer and rubber based nanoclay composites. Nanoscale fillers - nanofiber or nanotube fillers. Nanotube processing. Inorganic filler/polymer interfaces. Processing of nanocomposites.

Nanocomposites for electrical, optical and magnetic applications. Mechanical properties - modulus and the load- carrying capability of nanofillers - failure stress and strain toughness. Glass transition and relaxation behaviour.

Natural nanocomposite materials - biologically derived synthetic nanocomposites, templating. Natural nano-biocomposites, biomimetic nanocomposites. 14 hours

**References:**

1. Nanoscale Materials (Ed) - L.M. Liz, Marzan and P V Kamat (Kluwer, 2003)
2. Nanostructured Materials and Nanotechnology (Ed) - H S Nalwa, (Academic, 2002).
3. Introduction to Nanotechnology- C P Poole and F J Owens (Wiley- Intersci., 2006)
4. Nanotechnology and Nanoelectronics - W R Fahrner (Ed) (Springer, 2006)
5. Quantum Dots - L Jacak, P Hawrylak, A Wojs, (Springer, 1997)
6. Physics of Low Dimensional Structures - J H Davis, (Cambridge, 1998)
7. Nanostructured Magnetic Materials and Applications - Shi D et al (Springer, 2002)
8. Nanobiotechnology Concepts, Applications and Perspectives - Niemeyer C
9. Nanocomposite Science & Technology - Pulickal M Ajayan et. al (Wiley-VCH, 2003)
10. Introduction to Nanocomposite Materials - Thomas Twardowski, (DEStech, 2001)
11. Polymer Clay Nanocomposites - T J Pinnavaia, G W Beall, (Wiley, 2004)

**MSS 507: CRYSTAL GROWTH (3 Credits)**

**Objectives:** Objective of the course is to provide a fairly detailed knowledge on the various crystal growth processes. In particular, single crystal growths in bulk form and in epitaxial thin film forms which are essential for various research and development/technological applications.

**Expected course outcomes:** The student should be familiar with the crystal growth techniques with the necessary nucleation-growth theory. Good foundation on these topics would be helpful during their career in research or industry.

**Objectives:** Crystal growth is a process of growing crystals from a solution or melt, and it is widely used in fields such as including materials science, electronics, semiconductors, optics, and pharmaceuticals industries.Objective of the course is to provide (i) a fairly detailed knowledge on the various crystal growth processes with necessary nucleation-growth theory (ii) single crystal growth techniques in bulk form and in epitaxial thin film forms which are essential for various research and development/technological applications.

**Expected course outcomes:** The student should (i) be familiar with the theories on the growth of crystals (ii) be familiar with the different crystal growth techniques (iii) be familiar with the different single crystal growth techniques which are very essential for semiconductor industries. (iv) find a career in research or electronic industries.

**Unit I**

Crystal growth phenomena: Significance of single crystals – crystal growth techniques, Recent developments. Ideal growth laws – crystal-ambient phase equilibrium – criteria for equillibria in crystal growth – phase diagrams. Classification of growth processes.

Theories of nucleation- energy of formation - homogeneous nucleation – Gibb's Thompson equation for vapour, melt and solution, equilibrium shape of crystals. Heterogeneous nucleation – cap and disc shaped nuclei –constitutional supercooling - velocity of growth. Atomistic, thermodynamical models of crystal growth - Kossel and BCF theory. Problems and related experiments. 14 hours

**Unit II**

Crystal growth techniques: Bulk crystal growth – solution growth methods - supersaturation - aqueous solution, flux, hydrothermal methods. Melt growth – Kryopoulos, Bridgman – Stockbarger, Czochkralski, float zone and zone refining techniques. Impurity levelling factor – segregation coefficient. Verneuil method.

Low and high temperature solution growth – methods of crystallization – temperature gradient methods - growth of KDP and KTP crystals. Recent developments. Areas of applications. 14 hours

**Unit III**

Epitaxial growth methods – advantages - PVD – chemical vapour deposition – liquid and chemical vapour phase epitaxy – hot wall epitaxy- molecular beam epitaxy – MOCVD. Recent developments. Surface impurity contamination, defects and dislocations, determination of dislocation density.

Application: Si and Ge in semiconductor industry- IC technology: monolithic IC-masking and etching - elements of lithography- resist systems and patterning.

14 hours

**References**

1. Essentials of Crystallography, 2nd Edition – M A Wahab (Narosa Publishing House Pvt. Ltd, 2011)
2. Statistical Physics of Crystal Growth – Saito Yukio (World Scientific, 1996)
3. Crystal Growth for Beginners: Fundamentals of Crystal Growth, Nucleation and Epitaxy – Ivan V Markov (World Scientific, 1996)
4. Solid State Chemistry – R C Ropp (Elsevier, 2003)
5. Principles of The Solid State – H V Keer (Wiley Eastern, 1993)
6. Crystal Growth 1974, Proc. Of 4th Int. Conf. on Crystal Growth, Tokyo, Japan 24-29 March 1974, Eds. K A Jackson, N Kato and J B Mullin.
7. Current Trends in Crystal Growth and Characterization – Byrappa K (MIT, 1991)
8. Physics of Crystal Growth- Pimpinelli Alberto (Cambridge University, 1998)
9. The Growth of Crystals from Liquids – Brice J C (North Holland Press, 1973)

**MSE 509: MATERIALS IN ENERGY PRODUCTION -OPEN ELECTIVE-2**

**(3 Credits)**

**Objectives:** Objective of the course is to impart a basic knowledge about (i) global energy scenario and energy consumption in various sectors (ii) highlight the necessity