**DEPARTMENT OF PHYSICS**

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Author : **ASHISH KUMAR**

Title of the thesis : **Compatibilization and Characterization of Bio-Based and Bio-Degradable Poly (Lactic Acid) Blends and Composites**

Guide : **Dr. T. VENKATAPPA RAO**

Degree : **Ph. D.**

Student ID No. : **716053**

**ABSTRACT**

The bio-based and biodegradable poly (lactic acid) (PLA) is a commercially available synthetic biopolymer. It is being exploited to develop green plastic which can replace the currently existing petrochemical based non-degradable plastic in the near future. The major drawbacks of PLA such as poor toughness, brittleness, low heat resistance and high cost hamper its growth in the development of commercial green plastic. Hence, the prime objective of the thesis is to circumvent these drawbacks of PLA. The polymers and fillers such as poly (ethylene-co-glycidyl methacrylate (PEGM), lignin (LG) and hexagonal boron nitride (HBN) particles, bamboo powder (BP) respectively are employed to develop PLA based blends and composites. The compatibility between the PLA matrix and dispersed phase or filler is a key parameter to tailor the mechanical and thermal properties of the PLA in the resulting blends and composites. The melt blending method is opted to prepare all reported PLA blends and composites. Further, to improve the compatibility between the PLA matrix and dispersed phases the various compatibilizers have been used. In some cases, the fillers are physically modified with an electron beam (E-beam) prior to blending with PLA to enhance their compatibility. The effect of blending of reinforcement on the hydrolytic degradation of PLA is also studied and reported in the thesis. The blending of PLA with PEGM at weight ratio 80:20 (PLA:PEGM) significantly improves the elongation at break from 5.76 % to 157.40%, tensile toughness from 2.70 MJ/m3 to 36.82 MJ/m3 and notched impact strength from 2.65 kJ/m2 to 5.91 kJ/m2. The PLA/PEGM blend is compatibilized with in-situ formed PLA-g-PEGM graft copolymers explained with possible reaction mechanism. These properties are further enhanced with the incorporation of HBN particles at low concentrations i.e. 1 phr (part per hundred) such that elongation at break 166.50 %, tensile toughness 37.73 MJ/m3 and notched impact strength 8.89 kJ/m2. Further, heat deflection temperature (HDT) is also improved from 52.60 °C to 54.50 °C. The blending of PEGM with PLA and further incorporation of HBN particles restrict the hydrolytic degradation of PLA. So, to achieve the good impact strength and fast hydrolytic degradation the samples of prepared blend-composites were irradiated to E-beam. Moreover, in the view of cost reduction of PLA and complete biodegradation, the fully bio-based PLA/lignin blends and PLA/bamboo powder composites are prepared. The commercial lignin and bamboo powder are second most inexhaustible and low-cost fillers which are used as an additive to reduce the cost of PLA. The PLA/lignin blends and PLA/bamboo powder composites are compatibilized with the simple green physical approach in which the fillers were physically modified with E-beam irradiation prior to melt blending. The modification of the bio-fillers with E-beam irradiation at low radiation doses is an inexpensive technique and can be done at a large scale.

The PLA/LG-5% 30 kGy and PLA/LG-20% 30 kGy blends having 5 wt% and 20 wt% E-beam irradiated lignin respectively and TAIC is compatibilized with PLA-TAIC-Lignin cross linked structures formed during melt blending. The formation of PLA-TAIC-Lignin cross linked structures during melt blending is explained with proposed possible reaction mechanism. The PLA/LG blends having E-beam irradiated lignin show better mechanical and thermal properties as compared to PLA/LG blends having unirradiated lignin. The PLA/LG-5% 30 kGy blend exhibits slightly more notched impact strength, elongation at break, HDT and less hydrolytic degradation than virgin PLA. Furthermore, the unirradiated and E-beam irradiated bamboo powder is melt blended with PLA to prepare PLA/bamboo powder (PLA/BP) composited. The epoxy silane is used to improve the compatibility between the PLA matrix and filler. Among all PLA/BP composites, PLA/EBP5/ES 5phr with 5 wt% E-beam irradiated bamboo powder and 5 phr epoxy silane exhibits good tensile properties and highest notched impact strength which is 12% more than pure PLA.

**DEPARTMENT OF PHYSICS**

Author : **C. Hari Krishna**

Title of the thesis : **VECTOR VORTEX MODES IN FEW MODE OPTICAL FIBERS: GENERATION AND CHARACTERIZATION**

Guide : **Dr. Sourabh Roy**

Degree : **Ph. D.**

Student ID No. : **701441**

**ABSTRACT**

Phase, polarization and intensity are the most important features of an electromagnetic beam field, which helps us in understanding the field distribution across the beam, its interactions with other fields and also with matter. Recently, optical beams with complex or inhomogeneous phase and polarization topology are gaining much importance over beams with homogeneous phase and polarization states, leading to a new branch of optics known as *singular optics*. It deals with complex light beams that are either phase or polarization singular, which are referred to as scalar and vector vortex modes respectively. The advent of laser technology paved the path for generation of such complex light beams by modifying the cavity so as to generate modes of desired phase and polarization. Later, many methods are reported on the generation and study of the characteristics of such complex fields thereby hinting at possible applications. In early 90’s, it was reported that beams with helical phase structure are associated with orbital angular momentum of light which are in recent days finding applications in optical tweezing and advanced optical communication via orbital angular momentum mode multiplexing. Additionally, beams with inhomogeneous polarization states are found to be useful in microscopy, data encoding, lithography and laser machining. There are numerous active and passive methods proposed to generate phase and polarization structured beams in order to address the stability and controllability of such fields as well as aiming at various applications. Most of the methods use bulk optical setups, which include complex micro-structured devices to generate complex optical beams that increase the cost of experiments. One of the most convenient and cost-effective methods of generating such fields is optical fibers.

Optical fiber is an inhomogeneous, dielectric, cylindrical optical waveguide whose eigen modes have spatially inhomogeneous polarization and are known as cylindrical vector beams or zeroth order vector modes. These modes includes radial, azimuthal and hybridly polarized vector modes. In this thesis, we are devoted to generate and characterize such complex vector fields using a few mode optical fiber by controlling the coupling conditions of fiber with input Gaussian beam. Our method fully relies on precise control over coupling conditions and the input state of polarization which has the potential to switch between various vector fields. We begin the thesis with a brief introduction to phase and polarization structured beams with their generation schemes and possible applications. Further, we analyze the wave propagation mechanism in optical fibers with the help of Maxwell’s equations to understand the origin of polarization inhomogeneity of the modes. Various vector modes in optical fiber are generated and characterized using standard Stokes polarimetry.

An attempt has been made to represent linearly polarized modes of optical fiber and their combinational vector modes onto standard and higher order Poincare sphere respectively. We have also generated polarization singular beams that are a combination of Gaussian and vortex modes of orthogonal polarizations within the fiber by selective excitation of modes. Complex polarization topologies such as lemon, star and monstar are generated and also the formation of dipoles is studied. The behaviour of polarization singular beams under the action of half wave plate and cylindrical lens are studied.

**DEPARTMENT OF PHYSICS**

Author : **N. SHARA SOWMYA**

Title of the thesis : **Synthesis and characterization of magneto electric properties in multiferroic[ (0.5) BCT - (0.5) BZT] NIFe2O4 composite**

Guide : **Dr. K. Venu Gopal Reddy**

Degree : **Ph. D.**

Student ID No. : **714162**

**ABSTRACT**

In multiferroic materials, the coupling between the magnetization and polarization orders allows the realization of four-state logic in a single device. The magneto-electric coupling in multiferroics provides an opportunity to use as magnetic field sensors, electrically controlled microwave devices and energy harvesting devices. Another important focus in modern materials science and engineering is utilization of lead-free piezoelectrics. In most of the device applications, lead-zirconate-titanate (PZT) materials are used for electromechanical devices such as sensors, actuators and transducers.

Magneto-electric composite with [(0.5) BCT- (0.5) BZT] (BCZT) as piezoelectric phase and NiFe2O4 (NFO) as magnetostrictive phase can effectively replace the existing PZT based composites. Moreover, there is no systematic study on the effect of composition on magnetoelectric coupling. In addition, no attempts have been made especially to explain the magnetoelectric properties in low-frequencies and electromechanical resonance (EMR) frequencies. In this study, the effect of composition on ferroelectric, magnetostrictive and magnetoelectric properties in both particulate and laminate configurations are studied. Lead free piezoelectric ‘Barium calcium zirconium titanate’ (Ba0.85 Ca0.15)(Zr0.1 Ti0.9)O3 was prepared by sol-gel synthesis method. Calcination of the as-synthesized precursor powders at 700°C resulted in the formation of perovskite single phase BCZT ceramics.

A maximum sintered density of ~95% of theoretical density and an average grain size of about 10 μm was achieved for the samples sintered at 1550°C for 2 h. The morphotropic phase boundary (MPB) composition of BCZT showed a high remnant polarization (Pr) of ~ 10.62 μC/cm2 and a low coercive field (Ec) of ~ 1.84 kV/cm. The optimized poling conditions for BCZT ceramics resulted in high piezoelectric charge coefficient d33 ~ 627 pC/N, large electromechanical coupling coefficient kp ~ 57%. The simultaneous existence of more than one crystallographic phase at the MPB composition resulted in excellent piezoelectric and ferroelectric properties, which are further enhanced by optimized poling of these ceramics. Nickel-ferrite (NiFe2O4) was synthesized by citrate gel technique. XRD analysis of calcined NFO powders and sintered pellets confirmed the single phase cubic inverse spinel structure. Maximum magnetization (MS) and coercivity (HC) of ~ 30 emu/g and ~ 20 Oe was observed for NiFe2O4. Magnetostriction (λsat) of ~ 21 ppm and ~ 8 ppm was observed for parallel (λ11) and perpendicular (λ12) directions respectively. Stain sensitivity (q = dλ/dH) achieved at the lower magnetic field was around ~ 180 Oe which is due to the exchange interaction between the two sublattices.

The effect of composition on ferroelectric, piezoelectric, ferromagnetic and magnetoelectric properties of (x) BCZT – (100-x) NFO [x= 90, 80, 70, 60, 50 wt%] ceramic particulate composites are discussed. Magnetoelectric composites were synthesized by mixing of the calcined individual ferroic phases with required weight fractions. X-ray diffraction (XRD) studies indicated the coexistence of BCZT and NFO phases in the composites sintered at 1370°C for 2 hrs. The average grain size of the BCZT phase was found to be in the range of 4 - 6 μm which is larger than that of NFO phase (2 - 4 μm) in all the composites. The coercive field (EC) increased from 4.7 kV/cm for sample with x = 10 wt% to 11.5 kV/cm for x = 20 wt% NFO. The P-E loops become lossy for samples with x= 30, 40, 50 wt% NFO and Pr values of the composites have increased from 5.2 to 17 μC/cm2 with increase in NFO content. A maximum d33 around 84 pC/N was obtained for x = 90 wt % and decreased to 27 pC/N for x = 50 wt % composite. The saturation magnetization (emu/g) was found to increased from 2 emu/g for x = 10 wt % to 14.5 emu/g for x= 50 wt% NFO. The highest ME voltage coefficient (αE,31) value of 17.42 mV/cmoe has been observed in x= 60 wt% BCZT. For further enhancement of ME voltage coefficient, laminate composites have beenprepared by sandwiching piezoelectric BCZT between two NFO pellets by epoxy bonding. The piezoelectric material BCZT has been prepared by sol-gel method and sintered at 1550°C and the magnetostrictive material NFO by citrate gel method. The laminates are poled and subjected to magnetoelectric measurements. The magnetoelectric output was measured in both longitudinal and transverse modes for all the compositions. A large magnetoelectric coefficient (α), 480 mV/cm.Oe (L-T), was obtained for the configuration consisting of trilayer NFO/BCZT/NFO. The coefficient, obtained for tri-layer composites is higher than that of corresponding particulate ME composites. The effect of magnetic field annealing on the magneto-elastic and magneto-electric properties is discussed. For magnetic field annealing, the sintered pellets of NFO (1200⁰C – 2 h) are subjected to annealing at 500⁰C under a magnetic field of 0.3 T for 1 h. The magnetic field during annealing was applied along the parallel (in-plane) direction of the sintered pellet. A maximum value of saturation magnetization, Ms (41 emu/g) at relatively a lower field of ~ 2 kOe was observed in the parallel direction due to induced uniaxial magneto-crystalline anisotropy with the easy axis, lies along the field-annealing direction. A maximum value of *λs* = ~ 40 ppm and ~ 34 ppm was obtained at the saturation field of 2 and 3 kOe along the parallel and perpendicular directions, respectively. Field annealed samples exhibited a higher strain sensitivity ‘q’ (- 3.3 ppm/Oe at 5 Oe) when compared to that of sintered samples (- 0.05 ppm/Oe at 180 Oe). Further, magneto-electric bi- and tri-layer laminates are prepared by using magnetically annealed NFO samples. A large transverse ME (αE,31) coefficient of ~ 1.1 V/cm.Oe and ~ 0.98 V/cm.Oe was estimated for the NFO/BCZT/NFO and NFO/BCZT laminates and the results are discussed.