CHAPTER 15

ELECTRONIC SCIENCE

Doctoral Theses

01. AJAY KUMAR
Synthesis and Characterizations of Pure and Mn-/y-doped 0.49bifeo3-0.20pb(mg1/3nb2/3) o3-0.31pbtio3 (bf-pmn-pt) Perovskite Ceramic for Di-/piezo-/Ferro-Electric Propertiesm.
Supervisors: Prof. Udaipir Singh and Dr. N. Santakrus Singh
Th 27466

Abstract

Perovskite ceramics have been studied extensively due to their unique and versatile properties, which make them highly valuable in various technological applications including energy and electronic devices. This thesis explores a comprehensive study on synthesis and characterizations of pure and Mn-/Y-doped 0.49BiFeO3-0.20Pb(Mg1/3Nb2/3)O3-0.31PbTiO3 (BF-PMN-PT) ternary ceramics aimed at enhancing their dielectric, piezoelectric and ferroelectric properties for possible applications in various devices. The synthesis process was optimized to achieve pure phase of perovskite structure and various characterizations including X-ray diffraction (XRD), field emission scanning electron microscope (FESEM), P-E loop tracer etc. were employed to analyse the structural, morphological and electrical properties of the synthesized ceramics. The dielectric properties were studied to understand the materials potential for capacitive applications. Piezoelectric measurements were conducted to evaluate material's suitability for actuators. Ferroelectric hysteresis loops were recorded to assess the remnant polarization and coercive field, which are key indicators of ferroelectric behaviour. The magnetization vs. magnetic field (M-H) loop was also recorded to study the magnetic property of the material. A theoretical study of the pure 0.49BF-0.20PMN-0.31PT ceramic using modified Debye model reveals its distributive dielectric nature. The results revealed that the optimization led to a dense phase-pure perovskite structure with excellent dielectric, piezoelectric and ferroelectric properties, making BF-PMN-PT a strong candidate for advanced multifunctional devices. This study contributes to the growing field of perovskite ceramics and provides insights into their potential applications in the modern electronic and electromechanical systems.

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02. GOYAL (Priyanshi)
Modeling and Simulation of Novel Ga2O3 Devices for High Power and High Frequency Applications.
Supervisor: Prof. Harsupreet Kaur
Th 27884

Abstract

Gallium Oxide (Ga_2O_3) is a promising material for high-power and RF applications due to its ultra-wide bandgap (4.8 eV) and high-voltage withstanding capability. The wide bandgap allows Ga_2O_3 devices to operate at higher voltages and temperatures, making it ideal for power applications. Further, Ga_2O_3 also offers cost-effective production process and high-quality substrate availability, making it as a viable semiconductor alternative. Despite these advantages, Ga_2O_3 devices have not yet reached theoretical limits in terms of breakdown voltage and key figure of merits. The thesis addresses these gaps by exploring new device designs to enhance high-power and RF performance. The study additionally focuses on improvement in device efficiency and performance by employing simulations with Technology Computer-Aided Design (TCAD) and developing analytical models. The thesis also demonstrates Ga_2O_3-based circuits including compact switch and maximum-gain microwave amplifier, showing significant advancement in breakdown voltages and key figure of metrics. This work not only advances the understanding of Ga_2O_3 devices but provides crucial design guidelines., thus, paving the way for future research and applications in power and RF Electronics.

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03. KHURANA (Manisha)
Modeling and Simulation of Photo Absorber Gated Field Effect Phototransistor Under Optical.
Supervisor: Prof. Mridula Gupta
Th 27467

Abstract

In this work, phototransistor based on field effect transistor has been studied for infrared (IR) and ultraviolet (UV) radiation detection. The applications of detector include imaging, remote control, high temperature flame detection, military application, biomedical applications, optical communication, and environmental monitoring. The study has been done using the physics based analytical modeling and the SILVACO TCAD simulations of the proposed phototransistors. The photoabsorber gated Tunnel Field Effect Transistor (TFET) has been presented as the advanced phototransistor architecture with advantages over the conventional architectures. The different semiconductors (like Germanium, Gallium oxide (Ga2O3)) has been used as the photoabsorber layer with an interfacial gate oxide layer to absorb the radiations that further controls the channel conduction separately. This separates the photoabsorber layer and the conduction layer of the phototransitor that further improves the elimination of the unwanted detection of radiations. The Germanium has been used as the photoabsorber layer for the detection of the infrared radiations and the study is specifically focused for the optical window of 1550 nm wavelength (i.e. for optical interconnects application). However, the Ga2O3 has been used as the photoabsorber layer for detecting solar blind UV radiations in the range 200 nm to 280 nm for high temperature flame detection and missile warning sytems applications. The TFET has been explored and presented as phototransistor due to its numerous advantages over conventional MOSFET in terms

of leakage current. A novel face tunnel field effect phototransitor has also been presented in this thesis as best optimized architecture with better optical figure of merits. Comparative study has also been presented with the MOSFET and Junctionless FET to verify the better performance of TFET based architectures. The parameters that are evaluated for analysing the optical behaviour of the devices includes sensitivity, responsitivity, detectivity and response time of the optical switch

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1. Introduction 2. Modeling and simulation of germanium absorber based tunnel field effect phototransistor. 3. Investigation of gallium oxide based tunnel field effect phototransistor for solar blind UV Detection. 4. Highly sensitive Ga2-O3_FACE tunnel field effect phototransistor for deep UV detection. 5.TCAD based investigation to junction less phototransistor for UVC radiation detection.6. Conclusion and Future Scope.

04. MANOJ KUMAR
Study of Resonances in Optical Waveguides and its Application.
Supervisor: Prof. Manoj Kumar Khanna
Th 27469

Abstract

Light transmission through optical waveguides has long been a popular phenomenon. Since ancient times, light has been used as a medium of communication. In recent decades, there has been extensive study on multilayer waveguide structures having semiconductor and metal clad to design various applications like polarizers, modulators, and sensors. These multilayer waveguides can be tailored to design highly efficient optical devices using distinctive techniques such as Surface plasmon resonance (SPR) and Lossy mode resonance (LMR) to select a specific polarization of light. SPR is the technique that mainly requires metal-clad waveguide structure to design optical devices such as sensors, polarizers, etc. The resonance state occurs when the frequency of light photons matches the natural frequency of surface electrons. On the other hand, LMR is supported by absorbing thin layers of various semiconductors and transparent conducting oxides. LMR occurs when lossy modes supported by a thin layer of semiconducting clad material attempt to phase match with guided modes supported by the guiding layer. Among the various optical waveguide techniques, the most recently developed one is the lossy mode resonance, which is used to design the polarizer and sensor in this work. In the first work, theoretical study of a PbSe semiconductor clad optical waveguide in visible range to design a TE/TM pass polarizer using high index buffer layer is presented. Transfer matrix method is used to derive and numerically solve the eigenvalue equations for the proposed structures. In the second work, high extinction ratio TE pass polarizer using Ge semiconducting clad is investigated along with the effect of the superstrate layer. Environmental stability of the polarizer was also discussed. In the third work, the role of PbSe film was extended to design a LMR based refractive index sensor. The obtained characteristics are utilized to generate the sensing results to measure sucrose concentration.

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1. Introduction 2. Lossy mode resonance. 3.Design of visible range polarizer using PbSe clad waveguide. 4. Design of high extinction ratio polarizer using Ge clad wave guide 5. Design of lost mode resonance based sensor using PbSe thin film. 6. Conclusion and future scope of present work.

05. NEHA
Investigation of Field- Plate HEMT Devices for High Voltage Applications: Design Optimization and Reliability.
Supervisors: Prof. Manoj Saxena
Th 27470

Abstract

Traditional AlGaN/GaN HEMT configurations encounter challenges such as high off-state current, resulting in diminished performance in terms of inefficient power utilization. Additionally, they raise reliability concerns related to hot electron effects and self-heating caused by trapped electrons which can be mitigated by introducing the Field Plates (FP) into the conventional HEMT designs. This dissertation explores the reliability concern of AlGaN/GaN HEMTs employing FP using TCAD simulations. Optimizing of Gate Field Plate (GFP) and Dual Field Plate (DFP) designs has been performed for high-voltage, extreme radiation environments. The goal of this work is to enhance the breakdown voltage (BV) and reliability issues of the AlGaN/GaN HEMT for efficient high-power devices. To address this, the GFP concept was first realized using the Slant FP approach using TCAD device software. The work provided in this chapter demonstrates that breakdown voltage decreases with increasing barrier thickness and decreasing gate-drain spacing length with the marginal influence of the number of field plate steps. The addition of a multi-recessed buffer further enhances the BV of GFP HEMT by reducing the drain-side electric field, thereby increasing the device`s voltage handling capacity. Thereafter, the analysis include the impact of DFP HEMTs on high-power applications through parameter optimization. The chapter discusses trade-off studies involving BV and cut-off frequency, comparing different FP architectures. Later, the impact of proton radiation on the properties of DFP HEMT has been demonstrated to provide comprehensive insights using extensive TCAD simulation that includes the analysis of threshold voltage, drain current and cut-off frequency. The performance degradation due to the heavy ions during the OFF and ON states has also been summarized using different substrate materials. The results emerging from this thesis indicate that the DFP HEMT exhibits greater resilience to radiation in comparison to both conventional and GFP HEMT technologies with high power density.

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06. PAWAN KUMAR
Study of Carbon Quantum Dots for Organic Photovoltaics.
Supervisors: Prof. Geeta Bhatt
Th 27885

Abstract

Carbon Quantum Dots (CQDs) emerged as an alternative to the Semiconductor Quantum Dots (SQDs) as a new frontier in the field of fluorescent nanomaterials, and they exhibit fascinating properties such as biocompatibility, low toxicity, eco-friendliness, good water solubility and photo-stability. In the present thesis, we have synthesised the CQDs from Citric acid monohydrate (carbon source), Urea (nitrogen source) and distilled water (solvent) by microwave method and optimize their synthesis time at which they exhibit excellent optical properties. Microwave method is facile, rapid, cost effective, efficient, provides uniform heat energy distribution, and precise control over heat duration. The obtained CQDs were amorphous, spherical with size ~13nm having various functional groups like COOH, OH, C=O, etc. To further enhance the optical characteristics of CQDs, surface passivation and sodium (Na) doping was done through Ethylenediaminetetraacetic acid disodium salt dehydrate (EDTA). It was found that the inter-planar spacing of EDTA-CQDs increased from ~0.34nm to ~0.36nm with increase in EDTA concentration due to the intercalation of sodium ions into the lattice. The thermal stability of the EDTA-CQDs decreased drastically from 208oC to below 70oC due to increase in the concentration of sodium ions and oxygen with increase in EDTA concentration. Consequently, CQDs@300sec (without EDTA) exhibiting excellent optical properties was chosen for organic photovoltaics. The absorbance and electrical conductivity of Hole Transport Layer (HTL) was found to enhanced with incorporation of CQDs. However, at 10% CQDs concentration charge carrier kinetics was excellent in contrast to other; at this 69% of charge carriers found participating in transfer process at very fast pace (0.32ps), 16% undergoing trapping in reasonably small time (31.4ps) and only 5% undergoing the recombination in large time span (>6ns). Bulk heterojunction organic solar cell (ITO: PEDOT: PSS: 10% CQDs: P3HT: PCBM: Al)* was fabricated in ambient conditions and the efficiency was enhanced by ~10%.

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1. Introduction 2. Sample preparation and characterization techniques 3. Synthesis and optimisation of CQDs 4. Effect of sodium (Na) doping and surface passivation on CQDs 5. Enhancing the performance of P3HT: PCBM solar cells through CQDs 6. Conclusion and future scope.

07. SENGAL (Puneet)

Design and Analysis of Split-Ring Resonator Antennas for WLAN/WiMAX/Wi-Fi 6.

Supervisor: Dr. Kamlesh Patel

Th 27471

Abstract

In this thesis work, the split ring resonator (SRR) based antennas are designed and developed for the WLAN, WiMAX, and WiFi6 applications. First, a circular SRR antenna with metallic loading on a low-cost FR4 substrate is designed, which has a wider impedance bandwidth and higher gain than the rectangular SRR (R-SRR) antenna. An impedance modeling is proposed and equations are derived to obtain the equivalent lumped element parameters of a circular SRR antenna. To further improve impedance matching and gain, a hexagonal SRR (H-SRR) antenna is designed in the same WLAN/WiMAX bands. The fabricated C-SRR and H-SRR antennas have achieved impedance bandwidths of 36.85%/83.75% and 50%/76.53% at 2.4GHz/5.2GHz bands, respectively. Their applications in the single-in-multiple-out (SIMO) and multiple-in-single-out (MISO) systems are investigated. The channel capacity in both transmitter (3□1) and receiver (1□3) diversities are found to be in the same range of 2.70 – 4.50 Mbps for 2.4/5.2 GHz bands. A 4□4 multiple-in-multiple-out (MIMO) antenna is simulated on the same FR4 substrate and the effect of multiport excitations for WLAN/WiMAX bands is discussed in terms of the radiation patterns. On placing the Z-structure between the H-SRR element antennas, the measured S-parameters have confirmed the impedance matching bandwidth improvement by approximately 15% and the increase in isolation by about 30%. It is noted that exciting three or four ports results in very low gain values, even negative gain, while exciting one or two ports produces positive gain up to a maximum of approximately 6 dB in the 2.4/5.2 GHz bands. Lastly, two new, cost-effective triband H-SRR antenna designs: a single port antenna and a dual port antenna are proposed to cover the WiFi6 band also. The dual port triband H-SRR antenna has shown a reasonable gain, enhanced impedance bandwidths, and acceptable MIMO parameters at 2.4/5.2/6.0 GHz frequencies with Wi-Fi 6 connectivity

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1. Introduction 2. Literature review and equipment/tools used. 3.Performance analysis and impedance modelling of rectangular and circular split ring resonator antennas in 2.4/5.2 GHz Bands. 4, Dual band hexagonal SRR antennas and their applications in WLAN/ WiMAX systems. 5.Dual-band 4x4 hexagonal SRR MIMO

antenna with port excitation-controlled gain and directivity for WLAN/WiMAX applications. 6. Performance and analysis of triband dual port hexagonal SRR MIMO antenna for WLAN/WiMAX/WiFi6 applications. 7. Conclusion and scope for future work.

08. SINGH (Ajit)
Solar Photovoltaic Cell and Characterisation of Related Materials.
Supervisors: Prof. Neeraj Tyagi and Dr. Sanjai Kumar
Th 27473

Abstract

This thesis focuses on crystalline-based silicon solar cells and modules and is divided into three parts. In the first part, the study examines the effect of grain size on the performance of polycrystalline silicon solar cells. The grain size significantly influences the efficiency of poly-Si solar cells, with smaller grains leading to increased boundaries that can impede charge flow, while larger grains enhance electrical properties. Therefore, optimizing grain size is crucial to maximize efficiency in solar cells. Two significantly different impedance spectra are obtained: one for the bulk of the grain and another for the grain boundaries. The effect of varying silicon material resistivity (1.0–3.5 Ωcm) and temperature (300-420 K) on grain size was also analyzed using impedance spectra. The second part of the thesis involves a comparative analysis of different electrical and physical properties of commercial crystalline solar cells such as Mono, Multi, and PERC. The solar cells underwent testing for spectral response (SR), quantum efficiency (QE), and current-voltage (I-V) characteristics. Measurements of SR, internal quantum efficiency (IQE), and external quantum efficiency (EQE) were used to analyze internal parameters such as diffusion length (L) and dead layer (dl) thickness values in all types of solar cells utilizing Medium Wavelength Spectral Response (MWSR) and Short Wavelength Spectral Response (SWSR) methods. The impact of surface passivation on diffusion length was also investigated for mono, multi, and PERC crystalline solar cells. The final section of this thesis aims to manufacture flexible/bendable solar mini-modules made of crystalline silicon without using glass as a front material. Various commercially available polymer materials like Polyethylene Terephthalate (PET), Tedlar Polyethylene Terephthalate (TPT), Ethylene Chloro Tri Fluoro Ethylene (ECTFE), Poly Vinylidene Fluoride (PVDF), Fluorinated Ethylene Propylene (FEP), and Ethylene Tetra Fluoro Ethylene (ETFE) are analyzed for their optical, mechanical, and thermal properties

Contents

1. Introduction 2. Basic Physics, Fabrication, and Characterization of Solar Cell and Module. 3. Study Grain Boundary Properties of Polycrystalline Cells using Impedance Spectroscopy. 4. Comparative Study of the Physical and Electrical Parameters of different Commercial Crystalline Solar Cells and Modules. 5. Development of Flexible Crystalline Modules using Different Polymer Materials 6. Conclusions and Scope of Future Work.

09. SINGH (Manohar)
Study of Absorption Enhancement in Zno-MWCNT based Nanocomposites for Sustainable Environment.
Supervisors: Prof. Amit Jain and Dr. Santakrus Singh
Th 27474

Abstract

Nanotechnology has transformed the development of new materials with specific properties for modern technological applications. Semiconductor nanocomposites have gained significant attention due to their unique electronic and optical properties, making them essential in fields like bandgap tailoring, photocatalysis, solar cells, sensors, and optoelectronics. The evolution of bandgap engineering in semiconductor oxides began post-World War II with an initial focus on elemental semiconductors such as silicon and germanium. The field advanced significantly in the 1980s with the advent of bandgap engineering, enabling researchers to modify atomic structures to create materials with desired properties. Nanotechnology further propelled this field by introducing nanostructures such as nanowires and nanodots, which allowed for adjustable bandgaps and enhanced light absorption. Recent developments in strain engineering, co-doping, and perovskite oxides have broadened applications, driven by both computer simulations and experimental research. This thesis examines the synthesis and bandgap customization of Ag/Fe/N-doped ZnO-MWCNT (Multi-Walled Carbon Nanotube) nanocomposites to improve their absorption properties and effectiveness in photocatalysis. It investigates how different concentrations of metal and non-metal doping influence the electronic and optical properties of these nanocomposites. This research explores the structural, morphological, and compositional changes caused by the doping process in the nanocomposites using X-ray diffraction, electron microscopy and spectroscopic method. The result of this research can be extended to address current environmental challenges. Customizing the bandgap of semiconductor nanocomposites opens new possibilities for developing efficient, cost-effective, and environmentally friendly technologies in photocatalysis and energy conversion. This thesis enhances our scientific understanding of nanocomposite materials and paves the way for their practical application in addressing some of today's most pressing technological challenges.

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