CHAPTER 21

ELECTRONIC SCIENCE

Doctoral Theses

01. AJAY KUMAR
Scalable Synthesis of Graphene and MoS2 2D Films for Application in Optoelectronics and Flexible Electronics Devices
Supervisors: Prof. Amit Jain and Dr. L. Radhapiyari Devi
Th 29015

Abstract

This thesis addresses the critical need for scalable and high-performance two-dimensional (2D) films, particularly Graphene and Molybdenum disulfide (MoS2), for next-generation optoelectronic and flexible electronic applications. As conventional silicon-based technologies approach their physical and operational limits, 2D materials have emerged as compelling alternatives owing to their atomic thickness, high carrier mobility, tunable bandgaps, and mechanical flexibility, enabling seamless integration with transparent and flexible substrates. To advance these emerging technologies, this research establishes a unified and reproducible framework for the chemical vapor deposition (CVD) based synthesis, transfer, and device integration of high-quality 2D films. Optimized growth protocols for monolayer Graphene and MoS2 2D films are developed, alongside CMOS-compatible fabrication methodologies that facilitate cost-effective and large-area device realization. Key objectives of this work is the fabrication of Back-Gate Field-Effect Transistors (FETs) incorporating suspended graphene channels, which exhibit a 47% enhancement in carrier mobility (from 1900 to 2800 $cm^2\ V^{-1}\ s^{-1}$), attributed to the suppression of substrate-induced scattering. The research further explores, a plasmonically enhanced MoS2 interdigitated electrode (IDE) photodetector that demonstrates a 12.4 times increase in responsivity (from 2.13 mA/W to 26.4 mA/W) through localized surface plasmon resonance (LSPR) induced by gold nanoparticles under 780 nm illumination. In addition, a flexible electrochemical biosensor fabricated based on Graphene/MoS2 heterostructures that achieves an ultra-low detection limit (LOD) of 0.0036 pg/mL for Bovine Serum Albumin (BSA), while maintaining mechanical stability under repeated bending cycles. Comprehensive structural, optical, and electrical characterizations including Raman spectroscopy, photoluminescence, XPS, electron microscopy, and electrochemical analyses were performed to validate the material quality and device performance. Altogether, this thesis provides a systematic route for the scalable synthesis and integration of 2D films into high-performance architectures, establishing a foundation for next-generation optoelectronic and flexible electronic systems with potential applications spanning healthcare, defence, and high-frequency communications.

Contents

1. Introduction and Literature Review 2. Experimental Methodology: Synthesis, Characterization and Fabrication 3. Growth of Graphene via CVD Technique and Fabrication of Suspended Back-gate FETs 4. Scalable CVD Synthesis of MoS for Plasmonically Enhanced IDE Photodetector 5. Graphene/MoS2 Heterostructure

based Flexible Electrochemical Biosensor 6. Conclusion and Future Prospects for 2D Films Technologies.

02. ANSARI (Mohd. Rehan)
Synthesis and Characterization of Nano-spinel Ferrite Electrode Materials for Supercapacitor Applications
Supervisor: Dr P. Koteswara Rao
Th 29016

Abstract

The demand for energy on globally growing day by day. The exhaustion of natural fossil fuels has intensified the necessity of efficient and sustainable energy storage devices. Nano-spinel ferrites have attracted significant attention as electrode materials for energy storage applications due to their non-toxicity, high specific capacitance, thermal stability and abundance of electroactive sites. In this study, spinel ferrites including ZnFe2O4 (ZFO), cobalt doped ZnFe2O4 (CoxZn1-xFe2O4), SrFe2O4 (SFO), and BaFe2O4 (BFO) were green synthesized via eco-friendly approach. The thermal, structural, morphological and electrochemical properties of ferrites characterized using TGA, HR-XRD, FESEM, FTIR, XPS, BET, CV and GCD analysis. At the optimized annealing temperature, the green-synthesized ZFO nanoparticles exhibited small crystallite size and a high surface-to-volume ratio, resulting in an increased specific surface area that provided more electroactive sites for charge storage. Electrochemical measurements revealed that ZFO exhibited a specific capacitance of 435.45 F/g at 1 A/g, which further improved to 453.63 F/g upon cobalt doping, along with excellent cycling stability of 87.18% after 1000 cycles. The corresponding symmetric supercapacitor device achieved 111.25 F/g, demonstrating efficient charge–discharge behavior. The enhancement in electrochemical activity was attributed to Co2+ substitution (with smaller ionic radius than Zn2+), which introduced additional redox-active sites and improved electron transport. To further improve capacitance retention, SrFe2O4 nanoparticles were synthesized, where the larger Sr2+ ions stabilized the spinel framework, enhancing chemical and thermal stability. SFO displayed a specific capacitance of 106.18 F/g, with its symmetric device reaching 161.66 F/g and 92.59% retention for 1000 GCD cycles. Moreover, BaFe2O4 nanoparticles with larger Ba2+ ions formed 2D hexagonal flakes, increasing surface area and electroactive sites, yielding a remarkable capacitance of 1098 F/g and 80.27% retention after 3000 cycles. These findings justified that, spinel ferrite nanostructures have great potential for supercapacitor applications.

Contents

1. Introduction 2. Synthesis and Characterization 3. Synthesis and Process of ZnFe2O4 Nano-Spinel Ferrite 4. Cobalt Doping into ZnFe2O4 Nano-Spinel Ferrite: Energy Storage Properties 5 Energy Storage Properties of Green Synthesized SrFe2O4 6. Effect of Annealing Temperature on Structural and Energy Storage Properties of BaFe2O4 7. Conclusion and Future Scope of Work.

03. CHANCHAL
Experimental Study of GaN HEMT Device Technology for RF Performance Improvement.
Supervisors: Prof. Manoj Saxena and Dr. Dipendra S. Rawal
Th29339

Abstract

Wide bandgap (WBG) semiconductors such as Silicon Carbide (SiC) and Gallium Nitride (GaN) have emerged as promising materials for next-generation high-power and high-frequency electronic devices due to their superior material properties, including wide bandgap, high breakdown field, and high thermal conductivity. This thesis presents a comprehensive experimental and analytical study on the realization, characterization, and reliability evaluation of ohmic contacts in SiC and AlGaN/GaN High Electron Mobility Transistors (HEMTs), and Schottky contacts on HEMTS, along with electric field (E-field) management for enhanced device performance using Field Plate (FP) technology. Using TCAD, we first optimized the Gate FP, Source FP, Dual FP, and Sunken Source Connected (SSC) FP architectures and then fabricated these structures. SSC FP architecture gives us a balance in the breakdown voltage and cutoff frequency. Overall, the findings of this work contribute to a deeper understanding of contact engineering, short-channel behavior, E-field management, and reliability optimization in wide bandgap semiconductor devices, paving the way for their deployment in advanced power and RF electronics.

Contents

1. Insight into the Wideband Gap Semiconductors 2. Basic Fabrication and Measurement Steps: Process, Tools, and Technique 3 Ohmic Contact Engineering on SiC and GaN HEMTs: Role of Metal Schemes and Annealing Temperature 4 Exploring Schottky Contact Behavior in AlGaN/GaN HEMTs: A Study of Ni/Au and Pt/Au Metallization 5. Field Plate Engineering in AlGaN/GaN HEMTs: Enhancing Breakdown and Power Handling Capacity at High Frequency 6. Summary and Future Prospective.

04. CHATURVEDI (Ragini)
Engineering MoS_2-Based Hybrid Materials as Advanced Electrodes for Supercapacitor Application.
Supervisors: Prof. Amit Garg
Th29380

Abstract

Molybdenum disulfide (MoS_2) has received considerable attention as an electrode material for supercapacitor applications due to its layered structure, high theoretical capacitance, and tuneable electrochemical properties. However, its practical application is limited by poor electrical conductivity, restacking of nanosheets, and slow ion transport. This thesis focuses on developing high-performance MoS_2-based electrodes by optimizing material composition, binder-free electrode fabrication, electrolyte selection, and device performance. First, an environment friendly synthesis method was used for reduced graphene oxide (rGO)-MoS2 composites, enabling sustainable composite production without compromising electrochemical activity. Subsequently, a MoS_2/g-C_3N_4 heterostructure was prepared and directly assembled onto screen-printed carbon electrodes (SPCEs) without using a binder. The synergistic interaction between MoS_2 and g-C_3N_4 enhanced capacitive performance and cycling stability by improving electrical conductivity, increasing the electrochemically active surface area, and facilitating efficient charge transfer. To further improve electrochemical performance, cobalt-doped MoS_2 (CMS) was synthesized and systematically investigated in different aqueous electrolytes with and without redox additives. Comprehensive electrochemical techniques, including cyclic voltammetry (CV), galvanostatic charge–discharge,

electrochemical impedance spectroscopy, chronoamperometry, and kinetic analysis, were employed to understand charge-storage mechanisms and electrolyte-dependent behaviour. Optimization of the electrolyte composition improved ion transport, charge-storage capability, and long-term cycling stability, highlighting the importance of electrolyte engineering. Finally, the optimized CMS electrode was used to fabricate a symmetric solid-state supercapacitor with Ni foam as the current collector. The device exhibited desirable energy-storage performance, high-rate capability, and excellent cycling stability. Overall, the findings provide insights into the structure–property–performance relationships of MoS_2-based materials and support the development of efficient, scalable, and environment friendly energy-storage materials for portable, wearable, and next-generation electronic devices.

Contents

1. Supercapacitors: Classification, Charge storage Mechanisms, Electrochemical Performance Evaluations and State-of- Art Review 2. Synthesis Methods and Characterization Techniques 3. Environment-friendly approach to rGO–TMD composite synthesis for use as a supercapacitor. 4. Electrochemical Analysis of MoS2–rGO Composites using Screen-Printed Carbon Electrode for Supercapacitor Application 5. Synergic energy storage performance of MoS2/g-C3N4 composite on screen-printed carbon electrode 6. Engineering Electrolyte Chemistry for Enhanced Charge Storage in Binder-Free Co-Doped MoS_2 on Screen-Printed Carbon Electrodes.7. Optimizing KOH Electrolyte Concentration for High Performance Co-Doped MoS_2-Based Symmetric Solid-State Supercapacitors 8. Conclusion and Future Wotk

05. DINESH KUMAR
Synthesis and Characterization of Polymer Nanocomposites Thin Film and its Application.
Supervisor: Prof. Udaibir Singh
Th 29017

Abstract

This research investigates the synthesis, fabrication, and characterization of PVDF-based polymer nanocomposite thin films incorporating nanoparticles such as ZnO, TiO_2, Ag, and ZnSe. The objective is to enhance the structural, optical, electrical, dielectric, and piezoelectric properties of PVDF for advanced technological applications. The study begins with an overview of polymer nanocomposites and thin film technology, highlighting their importance in electronics, sensors, and optoelectronic devices. A comprehensive literature survey emphasizes the role of nanoparticle type, size, and concentration in determining nanocomposite performance. Nanoparticles were synthesized using eco-friendly green methods, and nanocomposite thin films were fabricated using the sol–gel assisted spin-coating technique. Various characterization techniques, including XRD, SEM, HRTEM, UV–Vis spectroscopy, FTIR, and electrical measurements, were employed to analyze structural, morphological, optical, and electrical properties. The incorporation of ZnO and TiO_2 nanoparticles significantly enhanced the piezoelectric properties of PVDF by promoting β-phase formation and improving interfacial interactions. Ag-doped PVDF nanocomposites exhibited improved optical and plasmonic properties, along with enhanced crystallinity. ZnSe-doped films showed increased electrical conductivity, dielectric constant, and tunable optical band gap due to quantum confinement effects. Overall, all nanocomposite films demonstrated

superior performance compared to pure PVDF, with improved multifunctional characteristics. The results confirm that nanoparticle doping effectively enhances material properties through synergistic interactions within the polymer matrix. This work highlights the potential of PVDF-based nanocomposite thin films for applications in nanogenerators, sensors, flexible electronics, optoelectronic devices, and energy storage systems. The use of eco-friendly synthesis methods and scalable fabrication techniques further supports their practical applicability and future development.

Contents

1. Introduction and Literature Survey 2. Synthesis, Fabrication and Characterisation Techniques 3. Piezoelectric properties of PVDF and green synthesized metal oxide nanocomposite thin films 4 Fabrication and Characterization of Doped Silver Nanoparticle-Poly (vinylidene fluoride) Nanocomposite Thin Films via Sol-Gel Spin-Coating Method 5. Effect of ZnSe Doping Level on the Physical and Electrical Properties of PVDF-Based Nanocomposite Thin Films for Optoelectronic Applications 6. Conclusions and Future Scope.

06. GUPTA (Shweta)
Investigation of Junctionless FinFET for Biosensing and Radiation Hardening Applications.
Supervisor: Prof. Mridula Gupta
Th29340

Abstract

As life-threatening diseases are looming worldwide, for example, the recent global pandemic that inundated millions of lives by engulfing the world, there is an urgent need to meet the requirements of biosensors and the diagnosis of diseases at an early stage. This has raised the need to study the utility of semiconductor devices as an electronic biosensor. An electronic biosensor is an analytical device that detects a biological element or analyte, which is a substance of interest required to be detected in a given sample, by converting the response of a biological reaction into an electrical signal that can be measured. The biosensor has brought an exemplary revolution in sensing technology. Biosensors encompass extensive applications such as the monitoring of diseases, the detection of pollutants, drug discovery, food quality analysis, agriculture, etc. Owing to its several advantages of the Junctionless Fin Field Effect Transistor (JLFinFET), the research work reported in this thesis is primarily based on the study of its utility in biosensing applications. In this work, Junctionless FinFET (JLFinFET) has been employed for the detection of varied breast cancer (Hs578T, MDA-MB-231, MCF-7 and T47D) and non-tumorigenic (MCF-10A) cell lines. Moreover, the sensing potential of Junctionless FinFET in split gate topology consisting of dual oxides and dual gate metals has been investigated for the detection of both the charged and neutral biomolecules and the influence of the Steric Hindrance Issue has also been studied. Furthermore, the radiation-hardening attribute of the Junctionless FinFET has also been investigated.

Contents

Introduction and Literature Survey 2. Investigation of Junctionless FinFET Biosensor for Neutral and Charged Biomolecules Detection and Steric Hindrance Issue Analysis 3. Breast Cancer Detection Using Dual Nanocavities Junctionless Fin

FET Biosensor 4. Investigation of GaN Junctionless FinFET for Radiation Hardening Applications 5. Conclusion and Future Scope

07. SHARMA (Shakti)
Engineered Metal Oxide and Metamaterial Architectures for Emerging Sensing Applications.
Supervisor: Prof. Manoj Kumar Khanna and Dr. Shankar Dutta
Th 29341

Abstract

Engineered materials are materials that are specially designed and made to have certain features and functions which are not easily available in natural materials. Metal oxide based sensors (MOX sensors) are the most common sensors. They possess great sensitivity, low cost, and compatibility with microelectronics. Titanium dioxide (TiO2) is a high dielectric constant material and is extensively explored. However, the dielectric properties of other TiOx systems, have not been studied as much. In this work, the effect of thermal annealing on temperature-dependent dielectric characteristics of ultrathin TiOx-SiOx nanocomposite films is explored for futuristic sensor applications. Tungsten trioxide (WO_3) is also an important transition d-block metal oxide semiconductor. In the previously published papers, the dielectric properties using electrical characteristics of the WO3 films are not adequately explored. In this work, the dielectric properties of the WO3 films are also investigated to explore their possible use in futuristic sensors. Metamaterials are structures that have been artificially designed to have electromagnetic properties that normal materials don`t have. Metamaterial sensors have a number of benefits, such as high sensitivity, quick response, the ability to work at room temperature, and change their selectivity. We have explored and designed some metamaterial perfect absorbers. We have proposed a safe, compact, non-contact explosive detection methods using copper-silicon-based THz metamaterial perfect absorbers. These absorbers have potential applications in precise RDX detection, thereby shielding the environment from hazardous elements and saving invaluable human life. Another metamaterial absorber proposed by us is an ultra-wideband (UWB) terahertz perfect absorber based on the phase change feature of vanadium dioxide (VO2) offers an excellent bandwidth of 4.26 THz (2.2 - 6.8 THz). Conclusively, this research aims to investigate the properties of transition metal oxides (such as titanium oxide, vanadium oxide, tungsten oxide) and metamaterials for their futuristic sensor applications.

Contents

1. Introduction 2. Materials and Methods 3. THz Metamaterial Explosive- rdx Detector 4. Design of Vanadium Dioxide Based Ultra Wideband Tunable metamaterial absorber 5. Development of Titanium Oxide Thin Films and Examination of Various Characteristics Relevant to Sensing Applications 6. Development of Tungsten Oxide Thin Films and Examination of Various Characteristics Relevant to Sensing Applications 7. Conclusion and Future Perspective.