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A review Report on Material Science & Applied Physics

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***Abstract*--The review is an important experimental concept in modern material science. The experiment includes discussion of theoretical principles governing the technique. These concepts include energy band theory, reaction kinetics, optical absorptions, electron transitions, and thermal affects in solid materials. By linking theoretical understanding with experimental observation, the training helped develop analytical skills necessary for scientific research.**

The procedure generally involves preparation of the sample, calibration of instruments, execution of the measurement process, and analysis of the collected data. Observations are recorded in tables and later converted into graphical representations using scientific software tools. Such graphical analysis provides valuable insight into the behaviour of materials under different conditions.

Repeated trials, careful observation, and verification of results are essential components of the scientific method. The internship session emphasized how experimental uncertainty, measurement limitations, and material purity can influence final results. Therefore, proper experimental design and systematic analysis are required for reliable conclusions. The knowledge gained from this session is directly applicable in research laboratories working in nanotechnology, semiconductor devices, spectroscopy, astrophysics, and advanced materials engineering.

I. INTRODUCTION

Scientific internship is an important experimental concept in modern material science and applied Physics laboratory. Understanding the theory, instrumentation, and data analysis involved in this method allows researchers to study the physical, optical, electrical, and thermal properties of materials. During the internship session students were introduced to the fundamental background, the working principal of the equipment used, and the step-by -step experimental methodology. Particular emphasis was placed on laboratory safety, correct handling of chemical reagents and accurate recordings of experimental data.

Modern material science and nanotechnology rely heavily on advanced characterization techniques to understand the structural, optical, and electrical properties of materials, among these, UV–Visible spectroscopy, infrared (IR) spectroscopy, photoluminescence (PL) analysis, current–voltage (I–V) characterization, and thermoluminescence (TL) studies play a vital role in both research and industrial applications. UV–Visible spectroscopy is a fundamental analytical technique used to study the interaction of ultraviolet and visible light with matter, providing valuable information about electronic transitions, band gap energy, and optical absorption behaviour of materials, especially semiconductors and nanomaterials; it enables researchers to determine how materials absorb light across different wavelengths, which is crucial for applications in optoelectronics, photovoltaics, and sensor development. Complementary to this, infrared spectroscopy focuses on the vibrational transitions of molecules and is widely used to identify chemical bonds, functional groups, and molecular structures by analysing how materials absorb infrared radiation, this technique is particularly useful in confirming the composition and purity of synthesized compounds and thin films. Photoluminescence theory and analysis further extend the understanding of optical properties by examining the emission of light from a material after it absorbs photons; this process reveals detailed information about recombination mechanisms, defect states, impurities, and energy levels within a material, making it an essential tool for studying semiconductors, quantum dots, and phosphor materials. In addition to optical characterization, electrical properties are equally important, and I–V characterization provides insight into the conduction behaviour of materials by analysing the relationship between current and applied voltage; this technique helps in determining key parameters such as resistivity, conductivity, barrier height, and diode characteristics, thereby playing a critical role in evaluating electronic devices like diodes, transistors, and solar cells. Furthermore, thermoluminescence study and analysis offer a unique approach to investigating trap states and defect levels in materials by measuring the light emitted when a previously irradiated material is heated, the glow curve obtained from TL analysis provides information about trap depth, charge carrier dynamics, and energy storage mechanisms, which are significant in radiation dosimetry, archaeological dating, and phosphor research. Together, these techniques form a comprehensive framework for analysing materials from multiple perspectives—optical, structural, and electrical—allowing researchers to correlate properties and optimize material performance for advanced technological applications. The integration of these characterization methods not only enhances the understanding of fundamental material behaviour but also supports the development of innovative devices in fields such as renewable energy, electronics, photonics and biomedical engineering, making them indispensable tools in modern scientific investigation and engineering practice.

II. UV-VISIBLE & INFRARED SPECTROSCOPY

UV–Visible spectroscopy is an important analytical technique used to study the optical properties of materials, especially nanoparticles. It helps in understanding how a substance interacts with light in the ultraviolet (UV), visible, and near-infrared (NIR) regions of the electromagnetic spectrum. In this method, the wavelength range of approximately 200 nm to 1500 nm is passed through a sample, and the absorption or transmission of light is measured.

In the given experiment, NIR spectroscopy covering the range 1500–200 nm is used to analyze the sample. This wide range allows the study of both electronic transitions in the UV-visible region and vibrational transitions in the near-infrared region. By analyzing the absorption spectrum, we can determine various optical and structural properties of nanomaterials.

2.1 Types of Spectroscopies:

There are mainly two types of spectroscopies used in this context:

DRS (Diffuse Reflectance Spectroscopy):

This technique is used to determine the optical properties of both solid and liquid nanomaterials. It is especially useful for powdered or solid samples where transmission measurements are difficult. It measures the reflected light from the surface of the sample.

UV–Visible Spectroscopy:

This method is mainly used for analyzing liquid nanomaterials. It measures the amount of light absorbed by the sample when light passes through it. It is widely used for determining concentration and optical characteristics.

2.2 Experimental Procedure

Take a clean cuvette and fill it with distilled water. Place this cuvette in the spectrometer to perform baseline correction. This step ensures that any background absorption or interference is eliminated.

For solid samples, Barium sulphate ($BaSO_4$) is used instead of water for baseline correction because it acts as a standard reflecting material.

Baseline correction helps to remove the effect of unwanted particles or impurities present in the solvent or environment. After baseline correction, load the prepared sample into the spectrometer. The light of different wavelengths (from 1500 nm to 200 nm) through the sample. The instrument records how much light is absorbed or transmitted by the sample at each wavelength.

2.3 Factors Affecting the Results

The results of UV–Visible spectroscopy depend on several important factors:

Concentration of the sample:

Higher concentration leads to higher absorption. This principle is used to measure nanoparticle concentration.

Distance of the sample placement:

The position of the sample in the spectrometer can slightly affect the readings.

Thickness of the sample:

Thicker samples absorb more light, affecting the intensity of transmitted light.

2.4 Applications of UV–Visible Spectroscopy

- Determination of nanoparticle concentration
- Determination of Band gap of materials
- Used in sensor applications
- Quantitative chemical analysis
- Identification of compounds
- Various biological applications, including protein and DNA analysis.

2.5 Analysis and Observations

Using this technique, we can determine the specific wavelengths at which nanoparticles absorb and transmit light. The spectrometer generates a graph showing absorbance vs wavelength or transmittance vs wavelength. By varying parameters such as: **Concentration Thickness Distance of the sample.**

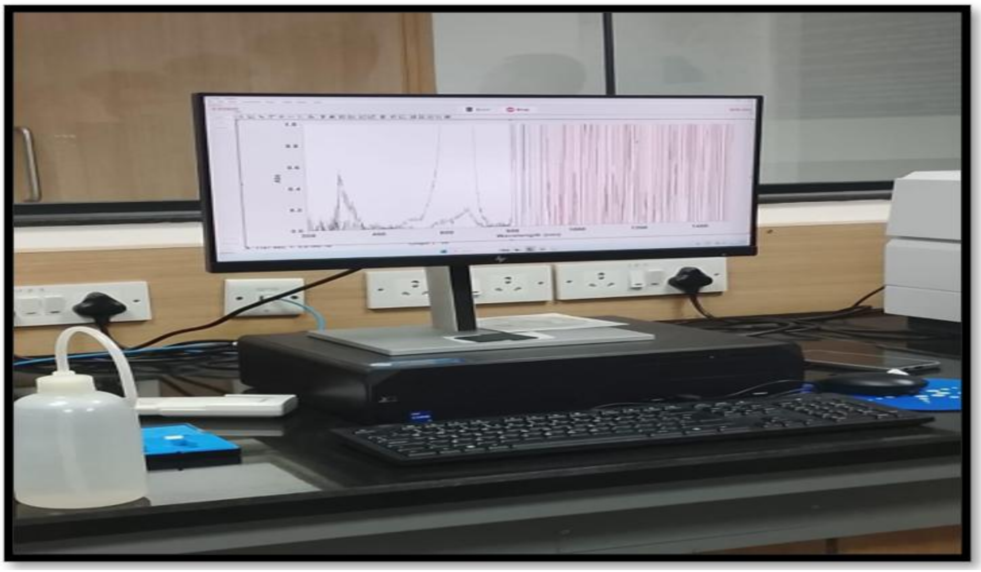
We can study how these factors influence the optical behavior of nanoparticles.At around 800 nm, there may be a noticeable change or pause in the signal, which indicates the transition from the infrared (IR) region to the visible region of the spectrum.

2.6 Band Gap Determination

The band gap of nanoparticles can be determined using Tauc's equation. This method involves plotting a graph and extrapolating the linear portion to find the energy gap of the material.

2.7 Reflectance Measurement

To analyze the reflectance properties of nanoparticles, the Kubelka–Munk (KM) equation (sometimes referred to as "Koblenker's equation") is used. This equation helps in converting diffuse reflectance data into absorption-related information, which is useful for solid samples.



III. Photoluminescence Theory And Analysis

Photoluminescence (PL) spectroscopy is an important optical characterization technique used to study the electronic and optical properties of materials, especially semiconductors and nanomaterials. It is based on the emission of light from a material after it absorbs photons. When a material is exposed to electromagnetic radiation (usually ultraviolet or visible light), electrons in the material absorb energy and get excited to higher energy states. As these excited electrons return to their ground state, they release the absorbed energy in the form of light, which is known as photoluminescence.

PL spectroscopy is widely used in materials science, physics, and chemistry to analyze band structure, defect states, impurity levels, and recombination mechanisms. It is a non-destructive technique, making it highly suitable for studying delicate thin films and nanostructures.

3.1 Theory of Photoluminescence

The fundamental principle of photoluminescence involves three main processes: excitation, relaxation, and emission.

Excitation:
When photons with sufficient energy strike a material, electrons in the valence band absorb this energy and jump to the conduction band, leaving behind holes in the valence band. This process creates electron-hole pairs.

Relaxation:
After excitation, the electrons may lose some of their energy through non-radiative processes such as phonon interactions (vibrations of the crystal lattice). This step brings the electrons to a lower excited energy state.

Emission (Recombination):
Finally, the electrons recombine with holes and release energy in the form of emitted photons. The energy of the emitted light is usually less than the absorbed energy due to energy losses during relaxation. This emitted light is analyzed in PL spectroscopy.

There are two main types of photoluminescence:

Fluorescence:
Occurs when the emission process is very fast (within nanoseconds). The emitted light stops almost immediately after the excitation source is removed.

Phosphorescence:
Involves a delayed emission (milliseconds to minutes) due to the presence of metastable states. The material continues to emit light even after the excitation source is turned off.

3.2 Energy Band Concept

In semiconductors, photoluminescence can be explained using the band theory. When electrons move from the conduction band to the valence band, they emit photons with energy approximately equal to the band gap of the material. The wavelength of the emitted light provides information about the band gap energy.

Defects and impurities in the material introduce additional energy levels within the band gap. Transitions involving these defect states result in additional peaks in the PL spectrum, which helps in identifying the quality and purity of the material.

3.3 Instrumentation of PL Spectroscopy

A typical photoluminescence setup consists of the following components:

Excitation Source: Usually, a laser or UV lamp to provide high-energy photons.

Sample Holder: Holds the material under study.

Monochromator: Separates the emitted light into different wavelengths.

Detector: Measures the intensity of emitted light (e.g., photomultiplier tube or CCD detector).

Data Acquisition System: Records and analyzes the PL spectrum.

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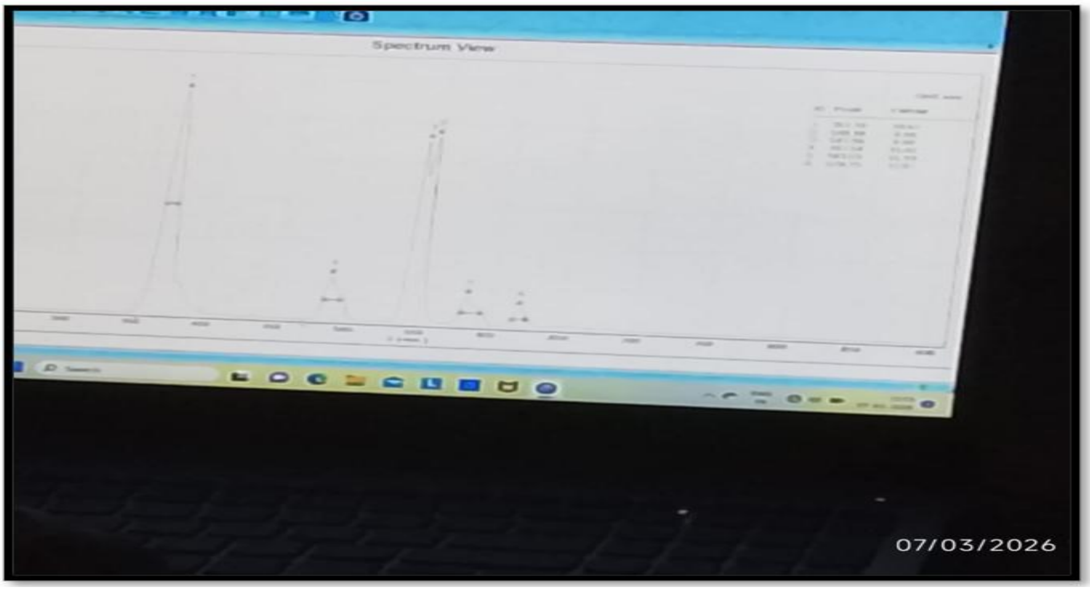

3.4 PL Spectrum and Analysis

The PL spectrum is a graph plotted between intensity (y-axis) and wavelength or photon energy (x-axis). It provides valuable information about the material's properties.

Key aspects of PL analysis include:

Peak Position: The position of the emission peak indicates the band gap energy of the material. A shift in peak position may indicate changes in composition, size (in nanomaterials), or strain.

Peak Intensity: The intensity of the PL peak reflects the efficiency of radiative recombination. Higher intensity usually indicates fewer defects and better material quality.

Peak Width (FWHM): The full width at half maximum (FWHM) indicates the distribution of energy states. A narrow peak suggests a uniform and high-quality material, while a broad peak indicates defects or disorder.

Defect-Related Emissions: Additional peaks at lower energies often correspond to defect states, impurities, or surface traps in the material.

Quantum Confinement Effect: In nanomaterials, the PL peak shifts toward shorter wavelengths (blue shift) as particle size decreases due to quantum confinement effects.

3.5 Applications of Photoluminescence

Photoluminescence spectroscopy has a wide range of applications:

Determination of band gap energy of semiconductors
Detection of impurities and defects
Study of recombination mechanisms
Characterization of nanomaterials and quantum dots
Evaluation of thin films and coatings
Analysis of optical devices such as LEDs and lasers

3.6 Advantages and Limitations

Advantages:

Non-destructive technique
High sensitivity
Simple and quick analysis
Suitable for a wide range of materials

Limitations:

Surface-sensitive technique
Requires proper sample preparation
Interpretation can be complex in defect-rich materials

IV. I- V Characteristics And Analysis

The current–voltage (I–V) characteristics represent the relationship between the electric current flowing through a device and the voltage applied across it. This analysis is one of the most fundamental methods used in electrical and electronic engineering to understand the behavior, performance, and efficiency of various materials, devices such as diodes, transistors, solar cells, and thin films.

The I–V characteristics are typically obtained by applying a variable voltage to a device and measuring the resulting current. The plotted graph between current (I) on the y-axis and voltage (V) on the x-axis provides valuable insight into the electrical properties of the material under study. Depending upon the nature of the material or device, the I–V curve may be linear or non-linear.

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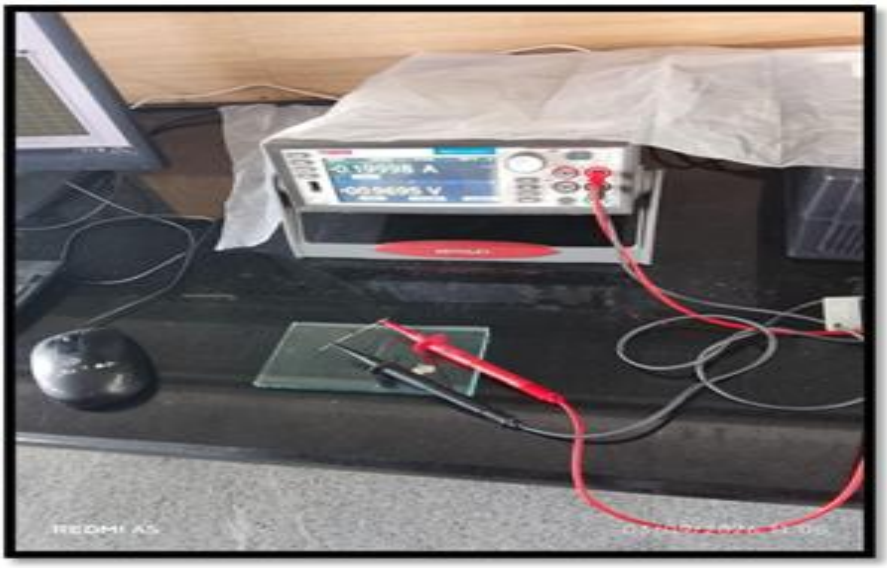


In such cases, the I–V graph is a straight line passing through the origin, and the slope of the graph gives the resistance of the material. Materials that exhibit this linear behavior are known as ohmic conductors, such as metals and some semiconductors under specific conditions.

In contrast, non-ohmic devices such as p–n junction diodes exhibit non-linear I–V characteristics. In a diode, current flows significantly only after a certain threshold voltage, known as the cut-in or knee voltage, is reached. Below this voltage, the current is negligible. Once the applied voltage exceeds this threshold, the current increases exponentially.

The behavior of a diode can be described by the Shockley diode equation:

$$I = I_s\left(e^{\frac{qV}{nkT}} - 1\right)$$

where $'I_s'$is the saturation current, $q$is the charge of an electron, $'V'$is the applied voltage, $'n'$ is the ideality factor, $'k$ 'is Boltzmann's constant, and '$T'$is the temperature in Kelvin. This equation explains the exponential rise of current with voltage in forward bias conditions.

In reverse bias, the current remains very small and nearly constant until breakdown occurs. The breakdown can be either Zener or avalanche type, depending on the doping level and material properties. This region is important for applications such as voltage regulation and protection circuits.

For semiconductor devices like solar cells, the I–V characteristics are crucial in determining their efficiency and performance. The curve typically lies in the fourth quadrant, where power is generated. Key parameters obtained from the I–V curve include:

- Short-circuit current (Isc): the current when voltage is zero
- Open-circuit voltage (Voc): the voltage when current is zero
- Maximum power point (MPP): the point at which the product of current and voltage is maximum
- Fill factor (FF): a measure of the quality of the solar cell

The fill factor is defined as:

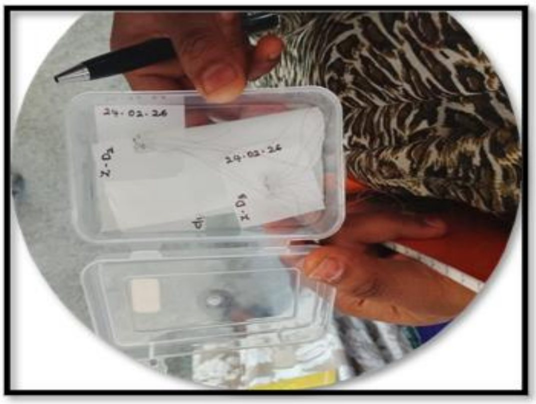
$$FF = \frac{V_{mp} I_{mp}}{V_{oc} I_{sc}}$$

where $V_{mp}$and I_{mp}correspond to the voltage and current at the maximum power point. A higher fill factor indicates better device performance.

In thin film materials and nanomaterials, I–V analysis helps in understanding charge transport mechanisms such as ohmic conduction, space-charge-limited conduction (SCLC), and tunneling effects. The deviation from linearity in the I–V curve can indicate defects, traps, or barriers within the material.

Experimental measurement of I–V characteristics is typically carried out using instruments such as a source meter, voltmeter, and ammeter. Advanced systems can automatically sweep voltage and record current with high precision. The measurements are often performed under controlled environmental conditions such as temperature and illumination, especially for optoelectronic devices.

Graphical analysis of I–V curves allow researchers to extract parameters such as resistance, conductivity, barrier height, and carrier mobility. By analyzing the slope and shape of the curve, one can determine whether the device exhibits ohmic or non-ohmic behavior and identify regions of operation.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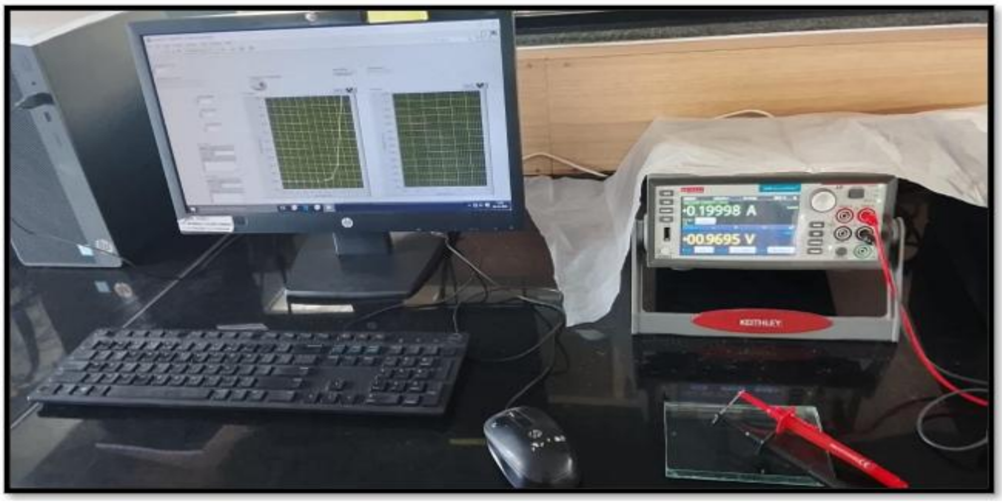
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V. Thermoluminescence Study And Analysis

Thermoluminescence (TL) is an important characterization technique used to study defects, impurities, and trapping states in insulating and semiconducting materials. It is based on the emission of light when a material that has previously absorbed energy from ionizing radiation is heated. This phenomenon provides valuable information about the electronic structure and defect levels present within a material.

5.1 Principle of Thermoluminescence

When a material is exposed to external radiation such as UV rays, X-rays, or gamma rays, electrons in the valence band absorb energy and get excited to the conduction band. Some of these excited electrons become trapped in metastable defect states (trapping centers) within the band gap. These traps are formed due to impurities, vacancies, or structural defects in the material.

Upon heating, the trapped electrons gain sufficient thermal energy to escape from these traps and recombine with holes in the luminescence centers. During recombination, energy is released in the form of light. The intensity of emitted light is measured as a function of temperature, resulting in a curve known as the glow curve.

5.2 Experimental Method

In a typical TL experiment, the sample is first irradiated using a suitable radiation source. After irradiation, the sample is placed in a thermoluminescence reader. The temperature is increased at a controlled heating rate, and the emitted light is detected using a photomultiplier tube or photodiode.

The intensity of emitted light is recorded as a function of temperature. Proper control of heating rate is essential because it affects the position and shape of the glow peaks. Faster heating rates shift peaks to higher temperatures, while slower rates provide better resolution of peaks.

5.3 Factors Affecting Thermoluminescence

Several factors influence the TL properties of a material:

Radiation Dose: Higher doses increase the number of trapped electrons, leading to higher TL intensity.

Heating Rate: Affects peak temperature and intensity.

Nature of Material: Defect concentration, crystal structure, and purity play a major role.

Annealing Conditions: Thermal treatment can modify trap distribution and stability.

Dopants: Addition of impurities can introduce new trap levels and enhance luminescence.

5.4 Applications of Thermoluminescence

Thermoluminescence has wide applications in science and technology:

Radiation Dosimetry: Used in personal and environmental radiation monitoring.

Archaeological Dating: Determines the age of pottery and minerals by measuring stored radiation energy.

Defect Analysis: Helps in studying defects in nanomaterials and semiconductors.

Medical Physics: Used for dose measurement in radiotherapy.

Geological Studies: Useful in dating rocks and sediments.

5.5 Advantages and Limitations

Advantages:

High sensitivity to low levels of radiation
Provides information about trap levels and defects
Non-destructive technique

Limitations:

Requires careful calibration
Glow curve interpretation can be complex
Signal may fade over time (fading effect)

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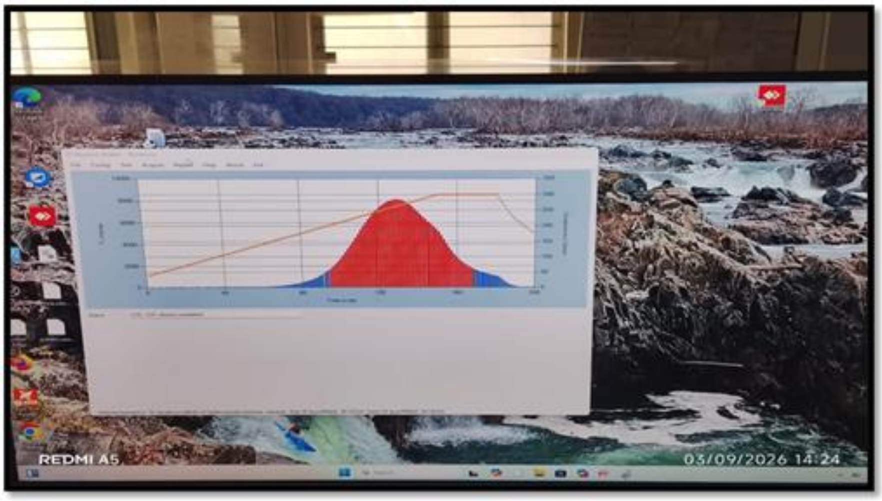

VI. CONCLUSION

In conclusion, the combined study of UV-Visible and Infrared spectroscopy, Photoluminescence (PL), I–V characteristics, and Thermoluminescence (TL) provides a comprehensive understanding of the optical, electrical, and thermal properties of materials. These techniques are essential in material science and nanotechnology as they help in analyzing the behavior, structure, and performance of materials from multiple perspectives.

UV-Visible spectroscopy is widely used to study the absorption of light in the ultraviolet and visible regions, which helps in determining important properties such as band gap energy and electronic transitions. This information is crucial for understanding how materials interact with light and is useful in applications like solar cells and optical devices. Infrared spectroscopy complements this by providing details about molecular vibrations and chemical bonding. It helps to identify functional groups and detect impurities, thereby giving insight into the structural composition of the material.

Photoluminescence spectroscopy further contributes by analyzing the emission of light from a material after excitation. It provides valuable information about energy levels, recombination processes, and defect states. The nature of the emission spectrum helps in assessing the quality and purity of the material. A strong and sharp emission peak generally indicates good crystallinity and fewer defects, while broader peaks suggest the presence of structural imperfections or impurities.

I–V characteristics play a key role in understanding the electrical properties of materials. By studying the relationship between current and applied voltage, important parameters such as resistance, conductivity, and charge transport mechanisms can be determined. This analysis is particularly useful in evaluating the performance of electronic devices.

The nature of the I–V curve also helps in identifying whether the material exhibits linear (ohmic) or nonlinear (non-ohmic) behavior, providing insight into device efficiency and potential limitations.

Thermoluminescence analysis focuses on the thermal and defect-related properties of materials. It involves the emission of light when a material is heated after being exposed to radiation. This technique helps in studying trap states and defect levels within the material. The glow curve obtained from TL measurements provides information about trap depth, activation energy, and stability of charge carriers. It is widely used in radiation dosimetry and material characterization.

Overall, these techniques complement each other by providing a complete picture of material properties. UV-Visible and Infrared spectroscopy offer insights into optical absorption and molecular structure, Photoluminescence reveals emission characteristics and defect-related behavior, I–V analysis explains electrical conduction, and Thermoluminescence highlights thermal stability and trapping mechanisms. This integrated approach is essential for accurate characterization and helps in improving material performance for advanced applications such as optoelectronics, sensors, and nanotechnology.

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