

Advancing Light Emission: A Comprehensive Review of Recent Electroluminescence Material Developments

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Abstract

This paper explores the remarkable strides made in the field of electroluminescence and their profound impact on luminescence research. The emission of light because of excitation is known as luminescence. Electroluminescence, a specific form of luminescence triggered by an electric field, has emerged as a promising area of investigation. The underlying principles of luminescence and the intricate mechanisms driving electroluminescence have been examined. Furthermore, recent breakthroughs in electroluminescent materials, device architectures, and fabrication techniques are investigated, highlighting advancements that have yielded superior light emission efficiency, color purity, and device performance. The dynamic interplay of scientific principles and technological advancements unfold, underscoring the continuous evolution of electroluminescence as a pivotal area of research within the broader field of luminescence. The pursuit of excellence in light-emitting characteristics and device functionalities propels this exploration, revealing a trajectory of innovation that holds great promise for future advancements in both scientific understanding and practical applications. In the light of these advancements, the quest for optimized electroluminescent materials becomes increasingly intricate, demanding a nuanced approach to fabricate devices with superior attributes. The interdisciplinarity of this research is evident as it converges principles from material science, physics, and engineering. Novel device architectures, such as organic light emitting diodes and quantum dot LED's, have emerged as frontrunners in enhancing color purity and efficiency. Advanced fabrication techniques, including vacuum deposition and solution processing, contribute significantly to achieving precise control over material deposition and layer thickness. As research delves deeper, the intricate tapestry of electroluminescence continues to unfold, promising a future where this phenomenon plays an integral role in cutting-edge technologies and scientific exploration.

Keywords: Emission, Electroluminescence, QLEDs, Quantum Dots, Perovskite Materials

INTRODUCTION

In this research paper, we will be investigating the field of electroluminescence and its recent advancements. Electroluminescence refers to the process of converting electrical energy into light. Luminescence is the term used to describe the excitation-induced light emission [1-5]. Moving forward, we will focus on the emergence of electroluminescence in the 20th century, our main objective is to highlight the latest advancements in electroluminescence. This includes the discovery and optimization of new electroluminescent materials, improvements in device architectures and fabrication techniques, and the enhancement of device efficiency and performance. Furthermore, we will explore the diverse applications of electroluminescence in areas such as lighting,

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displays, wearable electronics, and smart cities. By presenting a comprehensive analysis of recent advances, we hope to contribute to the existing knowledge and inspire further research in the field of electroluminescence. Through continuous exploration and refinement, we anticipate a promising future for this technology [6-11].

LUMINESCENCE – AKA LOW TEMPERATURE LIGHT

It is the “spontaneous emission of radiation from an electronically excited species” not in thermal equilibrium with its environment”, according to IUPAC definition.

A luminescent object is emitting ‘cold light’, in contrast to ‘Incandescence’, where an object only emits light after heating [1, 13-16].

HISTORY

The word luminescence was first used by a German physicist ‘Eilhard Wiedemann’ in 1888. In Latin The word ‘Lumen’ means ‘Light’ and The material exhibiting this phenomena are called ‘Luminescent materials’ or ‘Phosphors’ which means ‘Light bearer’ in Greek language.

Examples of naturally occurring luminescence are the light from the aurora borealis, glow worms, luminescent wood, rotting fish and meat.[2], [12].

TYPES OF LUMINESCENCE

- Radioluminescence – Due to bombardment by ionizing radiation
- Electroluminescence – happens when electric current is passed through any substance
- Cathodoluminescence – a result of luminescent material being struck by electrons.
- Chemiluminescence – light is emitted as a result of chemical reactions..
- Bioluminescence – a result of biochemical reaction in living organisms.
- Electrochemiluminescence – caused by an electrochemical reaction.
- Lyoluminescence- describes the light that is released when a solid dissolves in a liquid solution.
- Candoluminescence- Certain transition-metal and rare-earth oxide ceramic materials, like zinc oxide, cerium (IV) oxide, and thorium dioxide, exhibit this behavior to a substantial degree.
- Mechanoluminescence- is the light released when a solid is subjected to any kind of mechanical action. It can be created using ultrasonic technology or another method.
- Triboluminescence- is supposedly brought on by rubbing, however it can also happen as a result of fractoluminescence. It frequently serves as a synonym.
- Fractoluminescence- is brought on by stress, which causes fractures to form and release light.
- Piezoluminescence- is brought on by pressure, which causes the piezoelectric action to produce significant polarization and elastic deformation.
- Thermoluminescence-light emission from a substance that has been subjected to ionizing radiation and has been moderately heated.
- Cryoluminescence – emission of light when an object is cooled (eg. Wulfenite)
- Photoluminescence [3]. is the release of light from matter in any form following photon absorption (electromagnetic radiation)

ELECTROLUMINESCENCE

In essence, electroluminescence is the electrical and optical phenomenon that occurs when a material is exposed to a high electric field or when an electric field is applied. This has grabbed the attention of people for many years.

WHO WAS CAPTAIN HENRY JOSEPH ROUND

Captain Henry Joseph Round [as shown in Fig.1]] was the first person to report about Electroluminescence phenomena in Silicon Carbide in the year 1888. He said that a yellow light was produced on passing current through a Silicon Carbide detector.

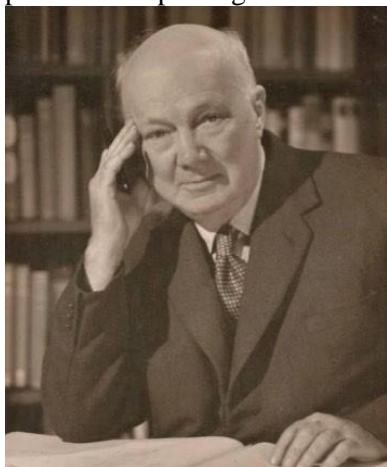


Figure 1. Captain Henry Joseph Round.

He was an employee in the Marconi company and was also the personal assistant of Guglielmo Marconi. Captain Round was also an inventor. He owns 117 patents under his name [4, 17-19].

WHAT ELSE DO WE KNOW ABOUT THE HISTORY OF ELECTROLUMINESCENCE

The following observation was made during World War II. According to accounts, there were several stories about research being done in this field in the 1920s and 1930s.

Once again in the year 1936, George Destriau, worked in the laboratories of Madame Curie in Paris, reported that he noticed that Electroluminescence can be produced from Zinc Sulphide powder when electric current is applied for producing light. People believed that Destriau, was the first person to coin the word 'Electroluminescence'.

To make EL lights, GTE Sylvania shot several coatings, such as EL Phosphors, onto thick steel plates in the 1950s. During this time, the majority of researchers concentrated on powder EL Phosphors in order to create bright lamps with low power requirements and maybe longer lifespans.. But when people discovered that the lifetime of product was too short the research fundings were cut back.(product had lifetime of approx 500hrs).

When Vlasenko and Popkov created the first film EL structure in the late 1950s, they noticed that using a thick layer of zinc sulfide doped with manganese (ZnS:Mn) significantly increased luminosity in EL devices.

BUT WHAT WAS THE PROBLEM IN MASS PRODUCTION

The biggest problem which needed to be solved before production of EKD's in mass was production of ELD's could begin with increasing the reliability of EL thin film stack.

As the devices was to be operated at a very high field levels, i.e. about 1.5MV/em, the probability of break down was high, especially when there was insufficient uniformity in the stack.

- Sharp, Tektronix, and Lohja Corporation in Finland were able to tackle this issue by employing rather different strategies.
- In 1985, when LCDs lacked the brightness or contrast necessary to be employed in commercial products, Sharp and Planar, respectively, introduced the Grid and Data General Laptops with EL displays to the market, contributing to the establishment of the fledgling laptop computer industry.

The phosphor utilized by both sharp and planar monochrome ELDs was derived from zinc sulfide doped with manganese (ZnS: Mn). These exhibits have a brilliant, aesthetically pleasant amber (orange yellow) color [5, 20–22].

APPLICATION OF ELECTROLUMINESCENCE

Electroluminescent devices find widespread applications in various fields. In the consumer electronics industry, they are utilized in the production of thin, flexible displays for smartphones, tablets, and televisions. These devices offer advantages such as low power consumption, wide viewing angles, and high brightness uniformity. Electroluminescent panels are also employed in automotive lighting, providing energy-efficient and aesthetically pleasing solutions for dashboard displays, instrument clusters, and interior lighting.

There are numbers of application of Electroluminescence, like - LEDs

- Backlights
- Liquid crystal displays
- Night lamps Electroluminescent lighting

WORKING PRINCIPLE OF ELECTROLUMINESCENT DEVICES

Electroluminescent devices typically consist of a phosphor layer sandwiched between two electrodes, which are connected to a power source. When an alternating current is applied, electrons and holes are injected into the phosphor material, resulting in the recombination of charge carriers and the emission of light. By choosing particular phosphor materials, we are able to regulate the hue of the light that emits.

ELECTROLUMINESCENT MATERIALS-

Electroluminescent materials are a crucial component of electroluminescent devices, as they are responsible for the emission of light when an electric current is applied. The phenomenon known as electroluminescence is exhibited by materials that transform electrical energy into visible light. Typical categories of electroluminescent materials include:

1. **Inorganic Electroluminescent Materials:** Inorganic materials such as zinc sulfide (ZnS) doped with copper (Cu) or silver (Ag) are widely used as phosphors in electroluminescent devices. These materials emit light in the visible spectrum when excited by an electric field.
2. **Organic Electroluminescent Materials:** Organic electroluminescent materials are based on organic compounds that emit light when subjected to an electric current. This category includes small organic molecules (Small Molecule OLEDs) and polymers (Polymer OLEDs or PLEDs). Examples of organic materials used in electroluminescence include fluorescent dyes and phosphorescent compounds like iridium complexes.
3. **Quantum Dots:** Quantum dots are nanocrystals made of semiconductor materials. These materials have unique optical properties, and their size can be tuned to emit light of specific colors. Quantum dots are increasingly being used in electroluminescent devices to achieve high color purity and efficiency.
4. **Perovskite Materials:** Due to their remarkable optoelectronic qualities, perovskite materials—such as hybrid organic-inorganic lead halide perovskites—have attracted a lot of attention recently. Perovskite-based electroluminescent materials have shown promise in achieving high-efficiency and low-cost light emission.

The selection of electroluminescent materials depends on factors such as desired emission wavelength, efficiency, stability, and manufacturing compatibility. Researchers are continuously exploring new materials and improving existing ones to enhance the performance and versatility of electroluminescent devices [6].

RECENT ADVANCES IN ELECTROLUMINESCENCE **Quantum Dot Light Emitting Diode (QLED'S)**

One kind of display technology that makes use of quantum dots to produce light is called a quantum dot light-emitting diode, or QLED. It is an emerging technology that has the potential to offer several advantages over traditional display technologies like liquid crystal displays (LCD) and organic light-emitting diodes (OLED).

Here's a brief overview of how a quantum dot light-emitting diode works:

1. **Quantum Dots:** these are tiny semiconductor particles, made from substances like cadmium selenide (CdSe) or indium phosphide (InP). When these nanoparticles are stimulated by an external energy source, their special quantum mechanical characteristics enable them to emit various colors of light.
2. **Excitation:** In a QLED, the quantum dots are excited by an electric current or by a blue LED backlight. When the quantum dots absorb the energy from the excitation source, their electrons get promoted to higher energy levels.
3. **Color Conversion:** The excited electrons in the quantum dots quickly return to their lower energy states, emitting light in the process. Quantum dots size determines the wavelength of light they emit, allowing precise control over the color output. A vast spectrum of colors can be produced by utilizing quantum dots of various sizes.
4. **Color Filters:** In QLED displays, the emitted light from the quantum dots passes through color filters to create the desired colors. A wide color spectrum can be produced using these filters, leading to accurate and rich color reproduction.

Compared to traditional LCDs, QLED displays have the potential to offer several advantages, including:

1. **Color Accuracy:** Quantum dots can produce highly saturated and pure colors, offering a wider color gamut than LCDs. This can result in more lifelike and accurate color representation.
2. **Efficiency:** QLED displays can be more energy-efficient compared to LCDs, as they can convert a higher percentage of the backlight energy into visible light.
3. **Contrast Ratio:** QLED displays can achieve higher contrast ratios, allowing for deeper blacks and brighter whites. This is because they can selectively emit light, whereas LCDs rely on a backlight that can cause light leakage.
4. **Lifespan:** Quantum dots used in QLED displays are generally more durable and resistant to degradation over time, leading to a longer display lifespan.

It's worth noting that QLED technology is still evolving, and commercial products using this technology have started to appear on the market. However, QLED screens were less common than LCDs or OLEDs as of the September 2021 cutoff. For the most recent information on QLED technology, it is advised to consult industry developments and manufacturer's websites [11].

Organic Inorganic Hybrid Electroluminescent Materials-

Organic-inorganic hybrid electroluminescent materials are a class of materials that combine organic and inorganic components to exhibit electroluminescent properties. These materials are designed in such a way that they emit light on passing an electric current through them, which makes them suitable for applications like light-emitting diodes (LEDs), displays, and optoelectronic devices.

The organic component of these hybrid materials typically consists of conjugated polymers or small organic molecules. These organic materials possess delocalized π -electron systems, which enable them to efficiently transport charges and emit light when stimulated by an electric field. The inorganic component can vary and may include metal complexes, quantum dots, or nanocrystals. The inorganic component enhances the electrical and optical properties of the material, such as charge injection, charge transport, and emission efficiency.

There are several advantages of the combination of organic and inorganic components in these hybrid materials. Organic materials provide flexibility, low-cost fabrication, and compatibility with large-area

processing techniques like printing and roll-to-roll manufacturing. Inorganic components, on the other hand, contribute to improved charge transport, stability, and color tunability.

The performance of organic-inorganic hybrid electroluminescent materials depends on various factors, including the choice of organic and inorganic components, their molecular structures, energy levels, and the interfaces between the organic and inorganic phases. These parameters are crucial for achieving high device efficiency, brightness, and long-term stability.

Researchers continue to explore and develop new organic-inorganic hybrid electroluminescent materials to overcome the limitations of purely organic or inorganic systems. These materials hold promise for the next generation of efficient and versatile optoelectronic devices with applications in lighting, displays, sensors, and energy harvesting [12].

2D (Two-Dimensional) Material Based Electroluminescence

Two-dimensional materials have gained a significant amount of interest and attention in recent years for their unique electrical, optical, and mechanical properties. Electroluminescence, the phenomenon of light emission from a material under an applied electric field, has also been explored in two-dimensional materials.

One of the most researched two-dimensional materials is graphene, which has been shown to have electroluminescent qualities. The electroluminescence in graphene is typically achieved by applying a high electric field or using a local electric field enhancement mechanism. When a high electric field is applied to graphene, it can undergo impact excitation, where electrons are accelerated to high energies and can emit light upon relaxation.

Another class of two-dimensional materials that have shown electroluminescent behavior is transition metal dichalcogenides (TMDs). TMDs with significant photoluminescence characteristics and a layered structure include molybdenum disulfide (MoS₂) and tungsten diselenide (WSe₂). Because of the recombination of electrons and holes in the material, electroluminescence can be induced by applying an electric field across TMD devices.

Two-dimensional materials' electroluminescent qualities can be used for a variety of purposes, including optoelectronic devices like screens and light-emitting diodes (LEDs). The ability to integrate these materials into thin, flexible, and transparent devices makes them particularly promising for next-generation electronics.

It's worth noting that research in the field of two-dimensional material-based electroluminescence is still ongoing, and new discoveries and advancements continue to emerge [12].

LIGHT EXTRACTION AND PHOTON MANAGEMENT

Light extraction and photon management techniques play a significant role in improving the efficiency and performance of electroluminescent devices. In electroluminescence, light is generated through the recombination of electrons and holes under an applied electric field. However, not all generated light is efficiently extracted and utilized. Here are some approaches used in electroluminescent devices:

1. *Transparent Electrodes*: Transparent conductive electrodes, for example indium tin oxide (ITO) or graphene, can be used to allow light to pass through while providing electrical conductivity. These electrodes facilitate efficient light extraction by minimizing light absorption and reflection losses at the electrode interface.
2. *Light Extraction Layers*: Specialized materials, such as phosphors or scattering layers, can be incorporated into the device structure to enhance light extraction. Phosphor materials can down convert the emitted light to longer wavelengths, allowing for better extraction due to reduced

total internal reflection. Scattering layers can scatter and redirect light, increasing the chances of escaping the device.

3. *Surface Texturing*: Surface roughening or micro structuring of device layers can improve light extraction by reducing the chances of total internal reflection and increasing the escape cone of emitted light. Techniques such as nanoimprinting, laser ablation, or etching can be employed to create controlled surface textures.
4. *Distributed Bragg Reflectors*: Distributed Bragg reflectors (DBRs) are periodic multilayer structures that can control the reflection and transmission of light. By engineering the DBR's layer thickness and refractive indices, it is possible to enhance light extraction by preferentially reflecting the emitted light back into the active region or increasing the escape cone.
5. *Photonic Crystal Structures*: Photonic crystals with carefully designed periodicities can manipulate the propagation of light within the device. These structures can provide enhanced light extraction by suppressing certain modes and controlling the emission direction.
6. *Optical Coupling*: Proper optical coupling between the electroluminescent layer and external media, such as lenses or waveguides, can optimize light extraction. These optical elements can efficiently collect and redirect emitted light, improving its extraction efficiency.

By employing these light extraction and photon management techniques, the overall efficiency and brightness of electroluminescent devices can be significantly improved. These approaches are actively researched and optimized to enhance the performance of applications like organic light-emitting diodes (OLEDs), inorganic LEDs, and other electroluminescent systems [12].

Flexible and Transparent Electroluminescent Devices

Flexible and transparent electroluminescent devices have gained significant interest due to their potential for applications in wearable electronics, flexible displays, and transparent lighting [22]. Here are some crucial factors and methods for creating such devices:

1. *Transparent Electrodes*: Transparent conductive materials are essential for achieving transparency in electroluminescent devices. Although transparent electrodes made of indium tin oxide (ITO) are frequently utilized, researchers are also looking into graphene, silver nanowires, and conductive polymers as alternatives. These materials can be deposited as thin films onto flexible substrates to enable transparency while maintaining electrical conductivity.[15]
2. *Flexible Substrates*: Flexible and transparent substrates are crucial to realize the flexibility of electroluminescent devices. Materials like polyethylene terephthalate (PET), polyethylene naphthalate (PEN), and flexible glass can serve as suitable substrates. These substrates offer mechanical flexibility while providing transparency for efficient light extraction.
3. *Organic Light-Emitting Diodes (OLEDs)*: OLEDs are particularly well-suited for flexible and transparent electroluminescent devices. They are made of layers of organic semiconductors that, when electrons and holes recombine, release light. By depositing these organic layers on flexible substrates, OLEDs can be made flexible and transparent. Various strategies, such as solution processing or vacuum deposition techniques, can be employed to fabricate flexible OLEDs.
4. *Stretchable Materials and Encapsulation*: In addition to flexibility, stretchability is a desirable feature for some applications. Elastic or stretchable materials, such as elastomers or hybrid materials, can be integrated into the device structure to allow for stretching and bending without compromising device performance. Furthermore, appropriate encapsulation techniques are crucial to protect the device from environmental factors while maintaining flexibility and transparency.
5. *Transparent Conductive Layers*: In transparent electroluminescent devices, the emission of light should not be obstructed by opaque layers. Therefore, it is important to ensure that all layers, including charge transport layers and light-emitting layers, are transparent or have minimal light

absorption. Careful selection and optimization of materials are necessary to achieve both transparency and efficient charge injection and transport.

6. *Thin-Film Encapsulation*: Transparent and flexible barrier layers are required to protect the device from moisture and oxygen ingress, which can degrade the performance and lifetime of electroluminescent devices. Thin-film encapsulation techniques, such as atomic layer deposition or plasma-enhanced chemical vapor deposition, can be employed to provide a protective barrier while maintaining device transparency and flexibility.

The development of flexible and transparent electroluminescent devices involves a multidisciplinary approach combining materials science, device fabrication techniques, and optimization of device structures. Ongoing research aims to improve the efficiency, lifetime, and manufacturability of these devices for various applications in the field of flexible electronics [12, 13-20].

CONCLUSION

In summary, the remarkable progress in electroluminescence has brought about transformative changes across diverse industries. The continuous refinement of materials and methodologies has not only enhanced the luminosity of light emission but has also extended the lifespan of electroluminescent technologies. This evolution is propelling a paradigm shift towards brighter, more enduring, and energy-efficient illumination. Moreover, the pervasive integration of electroluminescent technologies in displays, lighting systems, and optoelectronic devices underscores their growing significance in modern applications. As these advancements gain traction, it becomes imperative to delve into the broader implications and potential future directions of electroluminescence. The discussion surrounding the future of electroluminescence prompts considerations such as the environmental impact, scalability, and ongoing research avenues. Assessing the environmental sustainability of materials used in electroluminescent devices is crucial in ensuring a responsible technological transition. Additionally, exploring avenues for scalability and cost-effectiveness can further accelerate the widespread adoption of these technologies. In conclusion, while celebrating the achievements in electroluminescence, it is essential to foster discussions that address the broader implications and steer the trajectory of future developments in a direction that aligns with sustainability and accessibility. The journey of electroluminescence continues, promising even more exciting possibilities on the horizon.

REFERENCES

1. Valeur B, Berberan-Santos MN. A brief history of fluorescence and phosphorescence before the emergence of quantum theory. *Journal of Chemical Education*. 2011 Jun 1;88(6):731-8.
2. Fischer H. E. Newton Harvey, A History of Luminescence From the Earliest Times Until 1900 (Memoirs of the American Philosophical Society held at Philadelphia for Promoting Useful Knowledge). XXIII+ 692 Seiten, 50 Abbildungen. The American Philosophical Society, Independence Square, Philadelphia 1957. \$6.00. *Gesnerus*. 1958 Oct 24;15(3-4):179-81.
3. Wang L, Xiao L, Gu H, Sun H. Advances in alternating current electroluminescent devices. *Advanced Optical Materials*. 2019 Apr;7(7):1801154.
4. A History of Electroluminescent Displays - Written by: Jeffrey A. Hart, Stefanie Ann Lenway & Thomas Murtha - University of Minnesota (1999).
5. Kamtekar KT, Monkman AP, Bryce MR. Recent advances in white organic light-emitting materials and devices (WOLEDs). *Advanced Materials*. 2010 Feb 2;22(5):572-82.
6. Current and Future OLED Applications by Craig DrFreundenrich, Dr. Craig Freundenrich.
7. Researchers develop perovskite leds external quantum efficiency exceeding 30 by Roni Peleg ,posted 04/06/23 , Advance materials.
8. B. S. Mashford, M. Stevenson, Z. Popovic, C. Hamilton, Z. Zhou, C. Breen, J. Steckel, V. Bulovic, M. Bawendi, S. Coe-Sullivan, P. T. Kazlas, *Nat. Photonics* 2013, 7, 407.
9. Armășelu A. Recent developments in applications of quantum-dot based light-emitting diodes. *Quantum-dot Based Light-emitting Diodes*. 2017 Oct 25.

10. Jeon, N. J., Noh, J. H., Yang, W. S., Kim, Y. C., Ryu, S., Seo, J., & Seok, S. I. (2015). Compositional engineering of perovskite materials for high-performance solar cells. *Nature*, 517(7535), 476-480.
11. Shirasaki, Y., Supran, G. J., & Bawendi, M. G. (2013). Emergence of colloidal quantum-dot light-emitting technologies. *Nature Photonics*, 7(1), 13-23.
12. Kim, J. S., & Park, S. Y. (2014). Organic-inorganic hybrid materials as semiconducting channels in thin-film field-effect transistors. *Chemistry of Materials*, 26(1), 59-71.
13. U. Shukla and S. Gupta, "Mechanisms and Applications of Lyoluminescence," *J. Nucl. Eng. Technol.*, vol. 12, no. 1, pp. 1–6, Jun. 2022.
14. "Electroluminescence | Shukla | Trends in Opto-Electro and Optical Communications." [Online]. Available: <https://engineeringjournals.stmjournals.in/index.php/TOEOC/article/view/5683>. [Accessed: 01-Apr-2022].
15. U. Shukla and G. Srivastava, "Influence of the Temperature on the Photoluminescence Intensity of the CdS:Cu Nanophosphors," *Int. J. Multidiscip. Consort.*, vol. 1, no. 1, pp. 1–4, 2014.
16. Shukla U and Priyadarshi K, "Study on the Electroluminescence of Y 2 O 3 Material Doped with Rare Earth Elements," *RRJPAP*, vol. 9, 2021.
17. U. Shukla, "Mechanisms and Applications of Bioluminescence," *J. Pure Appl. Ind. Physics An Int. Res. Journal*, vol. 8(1), no. 4, pp. 1–6, 2018.
18. U. Shukla and S. Bari, "Study on the Photoluminescence," *Online) J. Pure Appl. Ind. Phys.*, vol. 8, no. 5, pp. 25–31, 2018.
19. U. Shukla, "Effect of temperature on the thin film Electroluminescence of ZnS:Tb Phosphors," "Proceeding of ISAFBM-2019, ISBN: 978-93-5351-824-0, page no.100-103
20. U. Shukla and Mohd. Taib, "THERMOLUMINESCENCE," *Research direction*, ISSN No. 2321-5488, 2019.
21. Shukla, U. (2022). Bioluminescence: Biologically Living Organism. *International Journal of Optical Sciences*, 8(2), 9–19.
22. Shukla, U. (2023). Recent Advances in Mechaniluminescence. *Mukt Shabd Journal* 12(5),5 9–71.