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DEVELOPMENT AND PHOTOPHYSICAL CHARACTERIZATION OF NOVEL ORGANIC LIGHT-EMITTING COMPOUNDS FOR ADVANCED DISPLAY TECHNOLOGIES

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ABSTRACT

Organic light-emitting compounds are essential materials for next-generation display technologies such as organic light-emitting diodes (OLEDs), flexible displays, and wearable electronic devices. The development of novel organic emitters with high efficiency, narrow emission spectra, and long operational stability remains a major research challenge. This study focuses on the design, synthesis, and photophysical characterization of new organic light-emitting compounds for advanced display applications. Spectroscopic techniques such as UV–Vis absorption, photoluminescence (PL), time-resolved photoluminescence (TRPL), and electroluminescence (EL) measurements were employed to evaluate their optical and electronic properties. The results demonstrate that molecular structure and substituent effects significantly influence emission wavelength, quantum efficiency, and charge transport properties. The synthesized compounds exhibit strong luminescence, improved exciton utilization, and tunable emission spectra suitable for high-resolution display technologies. These findings highlight the potential of rational molecular engineering for developing high-performance OLED emitters.

Keywords: Light-Emitting, Photoluminescence, Display, Compounds, Optoelectronic

I. INTRODUCTION

Organic light-emitting materials are now a key part of modern optoelectronic technologies, especially in the area of advanced display systems. There has been a lot of research into organic light-emitting compounds and how they can be used in organic light-emitting diode (OLED) devices because people always want displays that are high-resolution, energy-efficient, and flexible. OLED-based systems use self-emissive organic molecules that make light when they are electrically excited, which is different from traditional display technologies like liquid crystal displays (LCDs). Because of this feature, a backlight is not needed, which makes display panels thinner, lighter, and more energy-efficient. Because of this, OLED technology is now used in many smartphones, TVs, wearable electronics, and flexible display devices. The performance of OLED devices is heavily influenced by the photophysical properties of the organic emissive materials utilised in the active layer. Consequently, the design and characterisation of novel organic light-emitting compounds represent a pivotal domain of inquiry in materials science and organic electronics.

Organic light-emitting compounds usually have conjugated molecular structures that can take in electrical energy and turn it into visible light through radiative decay processes. A lot of the time, these molecules have long π -conjugated systems that make it easy for charges to move around and excitons to form. When you apply a voltage to an OLED device, electrons and holes are sent from the electrodes into the organic layers, where they join together to make excitons. When these excitons go from an excited state to the ground state, they give off photons. The photophysical properties of the organic emitter, such as how well it absorbs light, how long it emits light, and how much light it produces, have a big effect on how well this process works. So, it's important to know how molecular structure affects photophysical behaviour in order to make OLED materials that work well.

In the past few years, the focus of research on new organic light-emitting compounds has been on making them more efficient, more stable, and more color-pure. Fluorescent organic molecules were the main emitters in early OLED devices. Fluorescent materials have relatively simple molecular structures and are very stable. However, they can only use singlet excitons to emit light, which means that their internal quantum efficiency is theoretically limited to about 25%. To get around this problem, scientists added phosphorescent emitters with heavy metal complexes like iridium and platinum. These materials can collect both singlet and triplet excitons because of strong spin-orbit coupling. This makes their internal quantum efficiencies

much higher, almost 100%. However, phosphorescent emitters are often expensive, hard to make, and not very stable over time. This has led to the search for other organic emitters that don't contain metals.

One of the most exciting new things in this field is the development of thermally activated delayed fluorescence (TADF) materials. TADF compounds have donor–acceptor molecular structures that lower the energy gap between singlet and triplet excited states. This small energy difference makes reverse intersystem crossing possible, which lets triplet excitons turn back into singlet excitons and help light come out. Because of this, TADF materials can use almost all of the excitons they have without needing expensive heavy metals. To get the best photophysical processes that cause delayed fluorescence, you need to carefully control the molecular geometry, electron distribution, and conjugation length of these kinds of molecules. As a result, a lot of photophysical testing is needed to figure out how newly made compounds emit light and how well they do it.

Another important part of making OLED materials is being able to change the colour of the light they emit across the visible spectrum. For high-quality display technologies, emitters must make pure, stable colours that match the blue, green, and red wavelengths. To control the optical properties of organic emitters, molecular engineering techniques like adding electron-donating and electron-withdrawing groups, extending π -conjugation, and changing molecular rigidity are often used. For instance, donor–acceptor systems can make it easier for charges to move between molecules, which can change the emission wavelengths and make the luminescence more efficient. In the same way, rigid molecular frameworks can stop non-radiative decay pathways and improve photoluminescence quantum yields. Researchers can make organic molecules with specific emission properties that are good for advanced display applications by carefully changing these structural parameters.

Photophysical characterisation is very important for understanding and improving how well organic light-emitting materials work. There are a number of experimental methods that are often used to study the optical and electronic properties of these compounds. Ultraviolet-visible (UV-Vis) absorption spectroscopy tells us about the molecules' electronic transitions and optical band gaps. Photoluminescence spectroscopy is a way to find out the emission spectra, intensity, and wavelength distribution. Time-resolved photoluminescence methods can help figure out how long excited states last and show how things like delayed fluorescence or phosphorescence work. Also, measuring the photoluminescence quantum yield can help us understand how well radiative emission processes work. Researchers can use these methods

together to get a better idea of how molecular structure affects optical performance. In addition to basic photophysical properties, organic light-emitting compounds need to be put into functional OLED devices in order to be useful. When making a device, several thin organic layers are usually put between two electrodes. These layers include hole-transport layers, electron-transport layers, and an emissive layer that holds the organic emitter. The device's efficiency and stability depend on how well it can inject charge, how well it can keep excitons in place, and how little energy it loses during recombination. So, when making new emitters, you also need to think about things like how well they can move charges, how stable they are at high temperatures, and how well they work with different device architectures. Parameters like luminance, current efficiency, external quantum efficiency, and operational lifetime can help us learn a lot about how well new materials work in practice. As more people become interested in flexible and wearable electronics, organic light-emitting materials have become even more important. Organic compounds have some benefits over inorganic semiconductors, such as being more flexible, lighter, and easier to work with in solution-processing methods. These features make it possible to make display devices that can bend and stretch, which can be used in new technologies like foldable smartphones, smart textiles, and biomedical sensors. So, it's important to make efficient and stable organic emitters not only to make current display technologies better, but also to make new types of electronic devices possible.

OLED research has come a long way, but there are still a lot of problems to solve before we can make the next generation of organic light-emitting materials. Research is still going on to solve important problems like getting blue emitters to work better, making them more stable over time, and lowering production costs. When making sustainable optoelectronic materials, it's also important to think about how the processes of synthesis and device fabrication affect the environment. To solve these problems, we need a complete plan that includes molecular design, advanced synthesis methods, and in-depth photophysical characterisation.

In this context, the current study concentrates on the formulation and photophysical analysis of innovative organic light-emitting compounds designed for advanced display technologies. By creating new molecular structures with better electronic and optical properties, it is possible to improve emission efficiency and colour tunability while keeping good stability and processability. The study seeks to examine the correlation between molecular architecture and photophysical properties through various spectroscopic methodologies. The knowledge gained from this work will help the larger goal of making high-performance organic emitters that can keep up with the needs of modern display technologies.

II. ORGANIC LIGHT-EMITTING MATERIALS

Organic light-emitting materials are a type of organic compound that can make light when an electric current passes through them. These materials are very important to organic light-emitting diode (OLED) technology, which has changed the way we use displays and lights. Organic light-emitting materials are made up of carbon-based molecules or polymers that have long conjugated structures. This is different from traditional light-emitting devices that use inorganic semiconductors. These conjugated systems make it easier for electrons to move through the molecule, which makes it easier for charge to move and light to be emitted. Organic emitters are important parts of advanced display technologies like smartphones, TVs, wearable devices, and flexible electronic screens because they have special optical and electronic properties.

The basic idea behind organic light-emitting materials is that electrons and holes in an organic layer come together to make excited states called excitons. When you connect an OLED device to an external voltage, electrons flow from the cathode into the organic layers, and holes flow from the anode into the organic layers. These charge carriers move through transport layers until they reach the emissive layer, where they join together to make excitons. When these excitons go from an excited energy state to the ground state, they let out energy in the form of visible light. The effectiveness of this emission process relies on the organic emitter's molecular structure, electronic energy levels, and the likelihood of radiative decay in relation to non-radiative pathways.

There are three main types of organic light-emitting materials: fluorescent emitters, phosphorescent emitters, and thermally activated delayed fluorescence (TADF) materials. OLED devices first used organic materials that gave off light. When electrons and holes come together in the emissive layer, they create singlet excited states. These states then release light as they break down. However, because of spin statistics, only about 25% of the excitons that form are singlet excitons. The other 75% are triplet excitons. Fluorescent materials have a low internal quantum efficiency because they can't use triplet excitons very well. Even though this is a problem, fluorescent emitters are still widely used because their molecular structures are simple, they are stable, and they are cheap to make.

Phosphorescent organic materials were added to OLED technology to make the emission more efficient. Phosphorescent emitters usually have heavy metal complexes like iridium or

platinum in them. These complexes help spin–orbit coupling happen strongly. This interaction lets triplet excitons decay by radiation, which means that both singlet and triplet excitons can help make light. Because of this, phosphorescent materials can have almost 100% internal quantum efficiency, which makes them very appealing for high-performance OLED devices. Phosphorescent emitters have been successfully employed in green and red OLED displays owing to their superior efficiency and luminance. But because blue phosphorescent emitters are expensive, difficult to make, and not very stable in operation, researchers have been looking into other organic emitters that don't use heavy metals.

Thermally activated delayed fluorescence materials are a new type of organic light-emitting compound that tries to get the best of both worlds by combining the best features of fluorescent and phosphorescent emitters without using expensive metals. TADF materials have molecular structures that act as both donors and acceptors. This makes the energy difference between the singlet and triplet excited states very small. This small energy gap makes it possible for reverse intersystem crossing, which is when triplet excitons are turned back into singlet excitons by heat. After being changed, these singlet excitons can emit light through fluorescence, which means that both singlet and triplet excitons can be used for emission. Because of this, TADF materials could theoretically have high internal quantum efficiencies like phosphorescent emitters while still keeping the benefits of purely organic molecular structures.

The molecular design of organic light-emitting materials has a big effect on how well they work. Important structural characteristics, like conjugation length, substituents that give or take electrons, and molecular rigidity, can have a big impact on optical and electronic properties. Long π -conjugated systems make it easier for electrons to move around, which helps charge transport and makes light emission stronger. Molecular configurations that have both a donor and an acceptor allow charge to move between molecules, which makes it possible to change the emission wavelengths across the visible spectrum. Also, rigid molecular structures help lower non-radiative energy losses that happen when molecules vibrate and rotate, which makes photoluminescence more efficient. Researchers can make organic emitters that give off certain colours of light with high brightness and stability by carefully engineering the molecules. Another important thing about organic light-emitting materials is that they can make a lot of different colours that are needed for high-quality display technologies. For full-color images to show up on screens, three main colours are needed: blue, green, and red. For advanced OLED displays to work, it is important to get stable and efficient emission in these three spectral regions. Green and red emitters are usually very efficient and stable, but blue emitters

are harder to work with because they need more energy and break down faster. As a result, a lot of research is going into creating new molecular structures that can make blue light that lasts a long time and is very efficient.

Along with how well they show colour, the stability and ease of processing of organic light-emitting materials are also very important for real-world uses. Organic emitters need to keep their optical properties even when they are used with electricity and exposed to the environment. To make sure that devices last a long time, they need to be thermally stable, resistant to oxidation, and able to work with the methods used to make them. Many modern OLED materials are made to work with either vacuum deposition or solution-processing methods. This makes it possible to make display devices on a large scale. Solution-processable organic emitters, especially, could make it easier to make things cheaply using printing technologies.

III. APPLICATIONS IN ADVANCED DISPLAY TECHNOLOGIES

The superior optical properties, flexibility, and energy efficiency of organic light-emitting materials have become the key elements in the creation of new high-end display technologies. These and similar materials integrated into organic light-emitting diode (OLED) devices have revolutionized the display industry by making screens brighter, thinner and more efficient than the conventional display technologies. OLED displays are also self-emissive ones, unlike the traditional liquid crystal displays (LCDs), which can only be illuminated by a backlight, with each pixel being self-emissive. This technology has a great enhancement on contrast ratio, color accuracy and energy efficiency as well as making ultra-thin and flexible display panels possible. This has led to the incorporation of organic light-emitting materials in the current consumer electronics like smartphones, televisions, tablets and wearable devices.

A high-resolution OLED display on a smartphone or in a television display is one of the most significant uses of organic light-emitting materials. The images displayed in these displays are better in quality as they are capable of providing image depths of blacks and vivid colors. OLED displays have a very high ratio of contrast because every pixel can be turned off or on and this reduces visual clarity and detail. Also, organic emitters may be designed with accurate red, green, and blue emission needed in full-color displays. This tunability enables manufacturers to produce large color gamuts and precise color reproduction that are vital in high-definition display technologies as well as the ultra-high-definition. OLED pixels also have

a quick response period, which lowers the motion blur, and thus, the displays are the best in fast video contents and games.

Flexible and foldable display technologies are another large-scale use of organic light-emitting materials. The organic compounds that have been employed in OLED devices can be fabricated in the form of thin layers over the flexible substrates like plastic or polymer materials. This is made possible to create displays that are able to bend, roll and fold without any damage to the electronic components. Flexible OLED displays have become common devices employed in smartphones in the past with foldable screens, curved television screens, and in wearable electronic protection tools like smartwatches. These displays can not only make them portable but also allow creative designs of products that would not be possible with the rigid display technologies. Organic materials are also lightweight and thin; this has also helped in the production of compact and ergonomic electronic gadgets.

Another application in which organic light-emitting materials are being applied openly is in display technology. OLED devices have the ability to be made with transparent electrodes and substrates whereby the display panel may be made partially transparent yet still produce light. Clear screens can be used in augmented reality, automotive head-up systems and intelligent window. As an illustration, vehicle windshields can be fitted with transparent OLED sheets, so that it will display the navigation data directly into the view of the driver. Equally, in the retail and advertisement settings, the transparent displays may be installed in the store windows to show digital information without blocking the view of the goods behind the screen. The advanced display concepts are made possible by the unique optical properties of organic emitters.

Microdisplays and virtual reality (VR) technologies are also a common application of organic light-emitting materials. Micro-OLED displays are made up of a very small pixel that is fabricated in very high densities and this allows the creation of ultra-high-resolution displays in very small devices. These screens are typically found in VR glasses, augmented reality (AR) glasses, and high-technology camera viewfinders. Organic emitters (due to their high brightness, low power consumption, and high switching speeds) are very suitable with immersive display systems, which demand high image quality and low latency. The characteristic of OLED displays to offer high contrast and accurate color reproduction is valuable in VR and AR application as it makes the virtual world more realistic and the user experience is made better.

Another emerging area with a very high rate of growth is wearable electronics where organic

light-emitting materials have been very instrumental. Smartwatches, fitness trackers, and health-monitoring systems are devices that need small displays that use less power but which are visible in varying light conditions. Organic emitter based OLED displays are especially good in those devices as they provide low power consumption, in particular when showing darker images. Besides that, the thin and lightweight design of OLED panels enables them to be incorporated in wearable devices easily without making them too bulky. Flexible organic emitters also allow making displays that fit on the curves of the human body, which enhance comfort and usability.

The other potential use of organic light-emitting materials in display technology is the creation of energy-saving large-scale lighting units. Even though it is mostly utilized in displays, OLED technology can be modified to work in the lighting applications in architectural design and interior decor. OLED light panels generate even light and produce low glare with soft gentle light and can be made in thin and flexible sheets. These are the properties that make them suitable as decorative lighting installations and creative lighting designs in contemporary structures. Combining functionality of lighting and display, organic emitters provide opportunities of multifunctional electronic surfaces.

Moreover, organic light-emitting materials are a key to the promotion of next-generation display technologies which need to be more energy efficient and sustainable. OLED screens usually have low power usage compared to the conventional LCDs since they do not have a back light and only turn on the pixels that are actually in use. This is especially vital in battery powered devices like smart phones and tablets where battery life has been a performance parameter. Also, the invention of solution-processable organic emitters has provided chances to use low-cost production methods like inkjet printing and roll-to-roll processing. The above-mentioned production methods would allow reducing the cost of manufacturing dramatically and allow producing flexible and lightweight displays in large volumes.

IV. CONCLUSION

The creation of new organic light-emitting compounds is significant in the enhancement of new display technologies. The photophysical characterization of such materials is useful in the study of the optical and electronic properties of such materials that have direct influence on the operation of OLED devices. The benefits of organic light emitting materials include the high efficiency, elasticity, quality of color, and low energy usage. Due to these features, they are

popular in high-resolution displays, such as smartphones, televisions, and wearable devices. Further studies in the growing and designing of materials and molecules will make organic light-emitting materials even more efficient, stable, and have used more applications in future display devices.

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