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LED Technology Advancements

Light-emitting diodes (LED) are devices that convert electric energy directly into light of a single color. It produces light via a diode, hence its namesake, mounted in a reflector cup to maximize brightness. This diode is a simple semiconductor. It utilizes the basic qualities of a semiconductor: the ability to selectively move electrons. When the LED is powered and electrons flow, they move to a lower energy state which releases photons at a given frequency proportional to an electron's drop in energy. This drop can be fine-tuned to design LEDs that emit light in any given color along the visible spectrum [2]. This release of energy is very efficient as there is very little energy lost to heat. Combining this with needing very low power to operate means LEDs are well-suited for applications in mobile devices.

Due to architectural limitations, an LED can only emit one color from the visible spectrum at a time. It either requires multiple LEDs to create white light, or for an LED to be covered in a phosphor coating. White LEDs commonly serve as backlights to many devices (TVs, computer monitors, mobiles, etc.) In white LED applications, Organic LEDs (OLEDs) have advantages compared to inorganic LEDs in that they can create flexible, large area light-emitting panels with cost efficient fabrication techniques. However, OLEDs have shorter lifespans than traditional inorganic LEDs. Li, Rizzo et al. demonstrated the first efficient hybrid LED from stable nanocrystal composites within an organic matrix [3]. This hybrid LED combines the advantages of organic LED technology (cost and flexibility) with those of inorganic materials (long-term stability and life.) It shows that a flexible, low-cost, and long-lasting white LED can be produced for devices.

Other state-of-the-art advancements include making LEDs more efficient at emitting light. LEDs are fundamentally limited by the design of a semiconductor and its high refractive index. This prevents most of the light emitted by electrons from ever leaving the device. Researchers at the University of California at Santa Barbara discovered a method of improving optical output power on blue LEDs up to 3.3 times higher than conventional LED chips. This was possible through direct wafer bonding of an n-type Zinc Oxide (ZnO) substrate to a III-nitrate LED wafer. The O-plane ZnO was selectively etched to form an electrode with the necessary hexagonal pyramid shape to maximize optical output power. It was this wafer bonded LED that was evaluated with respect to optical output power and was measured to have on average a 2.2 times higher optical output than a conventional LED-type chip using a 20 mA current [4].

For OLEDs, improvements in light emitting efficiency have been realized in two-dimensional low-index spin-on-glass (SOG)-assisted, planarized photonic crystal OLEDs (SOG PC OLEDs, type II) when compared to traditional operating conditions of first generation PC OLEDs (type I) [1]. The enhancements in type II PC OLEDs yield a 63% increase in light extraction efficiency [1]. The improvement is due to the liberation of photons trapped in the high-index guiding layer and a reduction in surface plasmon contribution. In type-I OLEDs, internal efficiencies are very high, but light extraction is low as much of the light energy never escapes the diode. Kim, Cho, and Song showed that introducing 2-D SiO_2/SiN_x PC layers into OLEDs is effective at resolving much of the light-trapping problem.

OLEDs that employ thermally activated delayed fluorescence (TADF) have been shown to be cheaper alternatives to other phosphorescent OLEDs with noble-metal-based dopants. Blue TADF OLEDs are still limited by low efficiency at high luminance which hinders full-color display [6]. Zhang, Li, et al. report a blue OLD with a 9,10-dihydroacridine/diphenylsulphone derivative with comparable performance to the best phosphorescent OLEDs in the market. Their device offers an external quantum efficiency of 19.5% and boasts a reduced efficiency decline with increase luminance. These gains in efficiency come from the formation of a small energy gap between two electron orbitals (^{1}CT and ^{3}CT) and the higher energy of the ^{3}LE state than the ^{3}CT orbital [6]. Their findings show that TADF materials can be used to fabricate low-cost high-performance blue OLEDs that may be used to bright white OLED applications.

LEDs are advanced lighting solutions with many advantages over traditional incandescent/fluorescent technologies, but they are limited due to cost and total light output. Many advancements in LED technology are centered around increasing the efficiency of light output at high luminance while maintain a pure white color which is difficult due to the technology being unable to naturally produce pure white light.

References

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