



The road to high efficiency organic light emitting devices

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Abstract

Advances leading to very high efficiency organic light emitting devices for use in flat panel displays and solid state illumination are described. The topics addressed in the Special Issue on High Efficiency Organic Light Emitting Devices are introduced.

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The world of “modern”, high efficiency organic light emitting devices (OLEDs) was born in 1987 with the publication by Tang and VanSlyke describing a device consisting of a junction between a thin layer of a vacuum deposited, small molecular weight hole transporting triarylamine, followed by an equally thin layer of the electron transporting green fluorescent emitting molecule, tris(8-hydroxyquinoline)aluminum [1]. While this seminal paper was not recognized immediately as the source of what was going to become a new and exciting scientific field with widespread application, it nevertheless provided a seed for exploration, particularly in Japan, into the application of OLEDs for flat panel displays. Some, even, began to believe that OLED displays might eventually replace liquid crystal displays (LCDs) in laptop computers and other mobile applications.

The work on small molecular weight OLEDs was soon augmented (in 1990) with a similar observation of efficient electroluminescence from the

polymer, poly(*para*-phenylene vinylene) by the Cambridge group led by Friend and co-workers [2]. Since that time, the research and commercial efforts into OLEDs as a practical vehicle leading to a range of display possibilities from head-mounted microdisplays, to high resolution laptop displays and televisions, to ultra-large signboards, has grown at an astonishing pace, and has been accompanied by large steps in their improvement into the most efficient emissive display technology yet developed.

Given the remarkable pace of our understanding of OLEDs and in their technological development, we can ask: what is it that separates OLEDs from other light emitters, and particularly those light emitters used in displays? Their primary advantage rests in the ability of organic thin films to be deposited on virtually any substrate, for example on glass, plastic or thin metal foils [3,4]. This allows for very lightweight, robust displays to be rolled up and stowed away in very small volumes—a possibility that does not exist for other high information content display media. In addition, OLEDs can result in full color flat panels that support full motion video, and many manufacturers

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are already demonstrating that large screen displays, extending to 20 inch diagonal and beyond, are within reach.

Most successful display applications today must support high definition, flat, lightweight and mobile platforms such as laptop computers, however, to be competitive in the largest and fastest growing sectors of the approximately \$20B flat panel display market. To be competitive in this sector, therefore, the display technology must offer the highest efficiency along with long operational lifetimes. Fortunately, OLEDs appear to have considerable advantages over incumbent technologies such as LCDs in regard to efficiency. With fluorescence combined with top emission [5], external quantum efficiencies of from 5% to 8% are achievable [6,7]. But the very highest efficiencies are accessible only through the use of electrophosphorescence, which allows for 100% of the injected electron-hole pairs to result in emissive triplet excitons [8,9]. OLEDs based on small molecular weight metallorganic iridium complexes have internal quantum efficiencies approaching 100%, resulting in 20–40% external efficiency, depending on whether substrate or top emission schemes are employed [10,11]. Although phosphorescence has not been fully exploited in poly-

mer based systems, significant progress in this direction has been made recently in demonstrating high efficiency red, green and blue triplet emission in modified forms of poly(vinylcarbazole) (see [15]). And most importantly, the operational lifetime of electrophosphorescent devices is as long as, or even exceeds that of fluorescent OLEDs, thereby meeting the needs of many current display platforms [12].

A comparison of the efficiencies of several different display and light sources is shown in Fig. 1. It is apparent that OLEDs provide the highest efficiency of any emissive display source. In particular, active matrix liquid crystal displays (AMLCDs) have efficiencies of ~ 2 lm/W, compared to ~ 10 lm/W for molecular organic phosphorescence (or PHOLED) based displays. Note that emissive display pixels are only turned on when needed, whereas LCD backlights must be fully on during use. Given that only $\sim 25\%$ of the pixels need to be illuminated when displaying a “typical” image, this alone provides for a significant power saving over LCDs. Then, given the very high efficiencies of PHOLEDs, even a greater advantage in power saving is realized.

Progress in LED efficiencies over the last three decades is summarized in Fig. 2. Extremely rapid

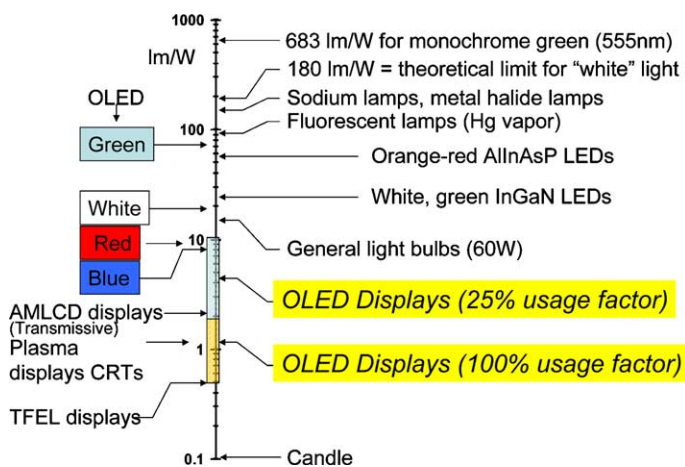


Fig. 1. Comparison of the luminous efficiencies of several different lighting and display sources. Here, a typical emissive display image is assumed to require that only 25% of the pixels be lit at one time, resulting in an electrophosphorescent display efficiency of 2–10 lm/W, as compared to an active matrix liquid crystal display (AMLCD) efficiency of only 2 lm/W. Also, thin film electroluminescent (TFEL), plasma display, and inorganic LED efficiencies are shown for comparison. The various OLED efficiencies noted are best results obtained for phosphorescent emitters in red, green, blue and white. Figure courtesy of C.W. Tang, Kodak, Inc. (This figure is available in color, see the on-line version.)

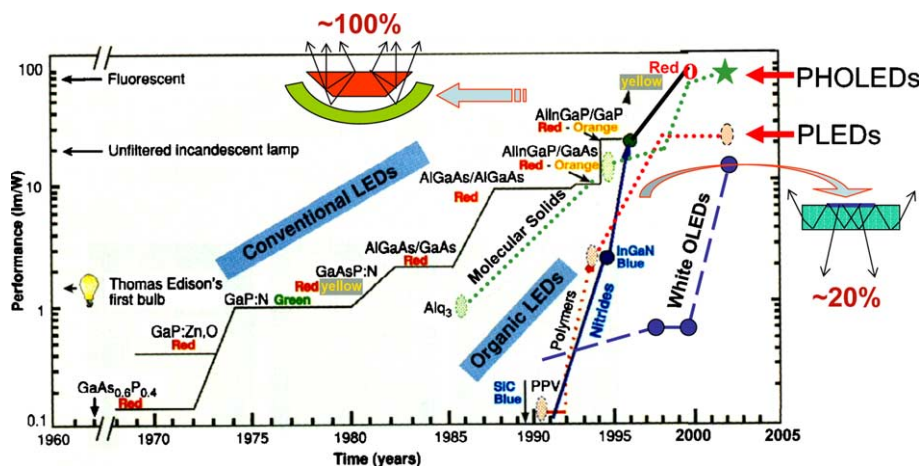


Fig. 2. Progress in various lighting and display source efficiencies over the last three decades. Insets show outcoupling typical of conventional (inorganic semiconductor) LEDs (top), and OLEDs on flat glass substrates (right). Here, PHOLED refers to molecular phosphorescent OLEDs, and PLEDs are fluorescent and phosphorescent polymer OLEDs. Figure adapted and extended from Sheats [14]. (This figure is available in color, see the on-line version.)

advances in OLED efficiencies have been made since the early 1990s, with peak efficiencies of 70 lm/W in the green for molecular PHOLEDs. In contrast, the highest polymer OLED efficiencies are ~ 20 lm/W. Note that the OLED efficiencies are measured for devices on flat glass substrates, where the total outcoupling is only $\sim 20\%$. This is compared to ultra-high brightness inorganic AlInGaP red LEDs used in, among other applications, traffic signals, where nearly all emitted light is projected into the viewing direction, leading to external efficiencies approximately equal to their internal efficiencies. Clearly, a remaining significant challenge for OLEDs is to devise schemes that improve the light coupling efficiency. If this were achieved by a simple and low cost method, OLEDs would unquestionably be the most efficient light source available. Indeed, this suggests that OLEDs may also soon compete with incandescence, and eventually even fluorescent lighting, as low cost, conformable white illumination sources. Progress in white OLEDs has continued apace, with the highest PHOLED efficiencies reported near 15 lm/W, comparable to that of an unfiltered incandescent lamp [13].

This special issue of Organic Electronics includes some of the most recent and best results in achieving high efficiency OLEDs for use in the

next generation of flat panel displays. The work discussed ranges from the synthesis of new molecules (including lanthanides, dendrimers and spiro compounds) and polymers for achieving the highest efficiency fluorescent and phosphorescent chromophores. The use of these materials in devices targeted for display and illumination applications is also discussed. In addition, there are contributions on device reliability, the use of organics as lasing media, and on the measurement of singlet to triplet formation ratios in electroluminescent materials. Overall, this issue should be considered as a “snapshot” of the very rapid progress made over the last few years in developing OLEDs as the most efficient display source available. Should this progress continue into the near future, we will undoubtedly witness the beginning signs of dominance of OLEDs in flat panel displays, and perhaps in solid state illumination applications, for years to come.

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