Hybrid Inorganic/Organic Light Emitting Materials and Devices for Displays and Lighting

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Abstract

We present a review of hybrid inorganic/organic light emitting materials and devices. The essence of the Hybrid I/O™ approach is to combine materials and structures from each category in such a way as to obtain best-of-both-worlds performance. Examples of Hybrid I/O™ applications to displays and solid state lighting are discussed.

Introduction

A great variety of light emitting materials and excitation mechanisms have been developed for displays and lighting applications. Two major factors are changing the landscape of light emission and causing a reevaluation of existing options as well as a search for new alternatives. In the past decade, the advent of flat panel displays for computer and television applications has greatly increased the investigation of many methods of light emission and control, including the light valve approach (as in LCDs), the gas plasma emission approach, and the solid state emissive approaches (such as inorganic and organic EL devices). Display applications have put a premium on development of lumophores with high brightness, efficiency, and contrast, and accurate RGB chromaticity. In addition, device technology requirements for displays include a thin form factor, the ability to scale up to large overall dimensions for TV-type applications and to scale down to small pixel dimensions for microdisplay applications. More recently, the solid state lighting initiative has also brought attention to the need for high power sources with excellent color rendering index, operating with very high efficiency, and at very low cost. Given this complex web of requirements, it is not likely that a single type of lumophore or a single device technology can emerge as the single dominant solution.

In this paper, we present a review of combinations of inorganic and organic materials for applications in displays and solid state lighting. The Hybrid I/O™ approach combines high power, long lifetime inorganic LED pumps with organic lumophores. The organic lumophores exhibit very high photon conversion efficiency, adjustable emission color, can be easily deposited over large areas, and are very low cost. This review covers optical properties of the organic lumophores, light wave coupling of the inorganic pump source to the organic lumophores, and preliminary results on Hybrid I/O™ displays and solid-state lighting devices.

The basic Hybrid I/O™ is shown schematically in the diagram of Fig. 1. Photons from UV-emitting inorganic LEDs are absorbed by organic lumophores, which in turn emit RGB photons based on their specific chemical makeup. The basis of many organic lumophores is the benzene molecule (C_6H_6) whose structure of conjugated bonds results in molecular orbitals that tend to absorb UV light and emit in the visible range. Many organic color conversion materials (CCMs) can be viewed as combinations of benzene rings with functional groups that tailor their optical properties by modifying the electron distribution through groups that either accept or donate electrons. Examples of CCM color conversion under optical pumping with inorganic (InGaN) LEDs are shown in Fig. 2. The internal color conversion efficiency ranges from 50 to 90% and can reach as high as 98%.

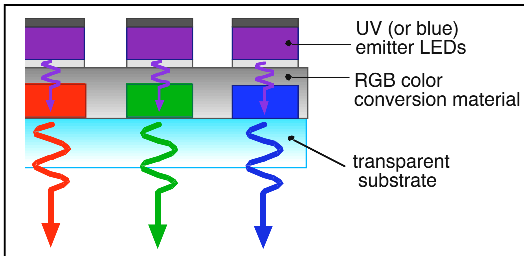
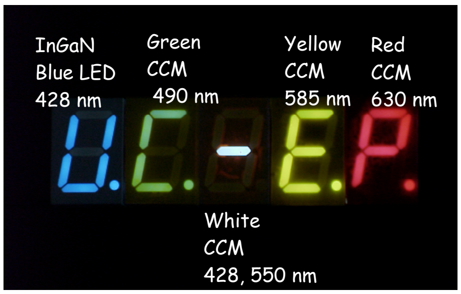


Fig. 1 Hybrid Inorganic/Organic (I/O™) approach wherein UV light from inorganic LEDs is converted to visible light by organic color conversion materials (CCM).

Fig. 2 Organic CCMs excited by InGaN LEDs: (a) RGB emission from CCM-coated glass disks; (b) conversion to GWYR (below).



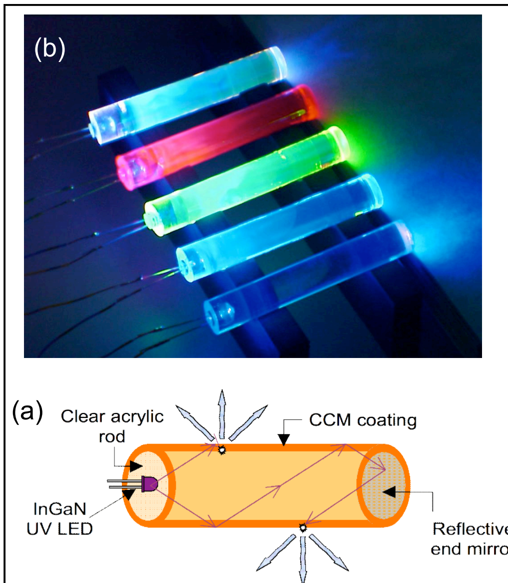


Fig. 3 Light wave coupled (LWC) Hybrid I/O™ lighting devices: (a) basic LWC concept; (b) emission from violet LED only in LWC rod (left) and from rods coated with color and white-emitting CCMs.

HYBRID I/O^{TM} White Lamps

Solid state Hybrid I/O™ lamp prototypes based on the light wave coupling [1] have been fabricated. In LWC devices, pump (UV, violet or blue) light is distributed through a transparent waveguide to an index-matched CCM which converts the pump wavelength to the desired color. LWC Hybrid I/O™ lamps with cylindrical geometry (designed to match the form factor of fluorescent tubes) are shown in Fig. 3.

Emission spectra from UV (400 nm) pumped RGB CCMs are shown in Fig. 4. The color coordinates of these CCMs are shown in Fig. 5a. The color temperature of several white-emitting CCMs (red dots) are shown in Fig. 5b along the Planckian blackbody locus. Approximate locations for common lighting conditions are shown for comparison. As an example, preliminary results with a 7500 K white lamp indicate [2] a luminous efficiency of ~ 7 lm/W and a wall-plug efficiency of ~ 3%. One of the main present limiters of the white Hybrid I/O™ lamps is actually the efficiency of the violet LED being utilized of ~ 7% wall-plug efficiency. Using higher performance violet LEDs (which are becoming available) will directly translate into improvements of the white CCM lamps.

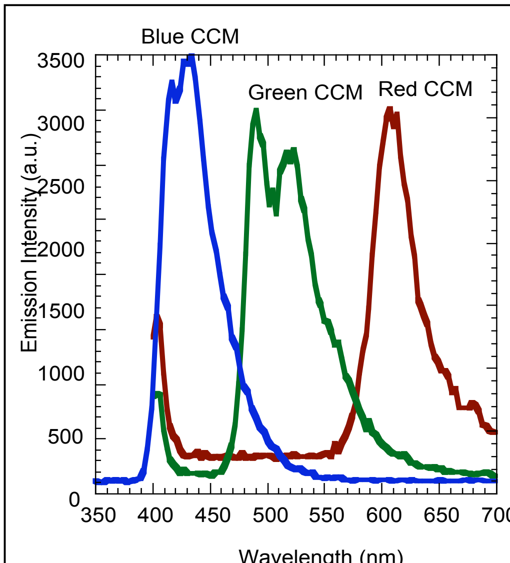


Fig. 4 Emission spectra from RGB CCMs pumped with violet (400 nm) InGaN LED.

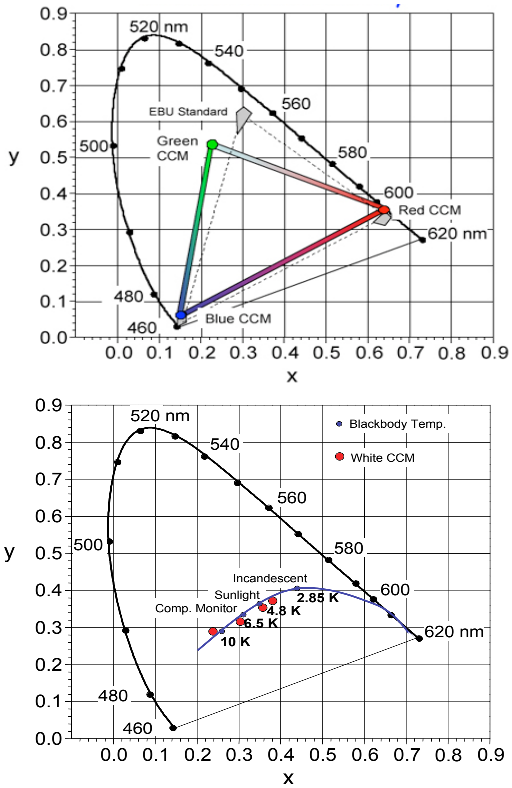


Fig. 5 Color coordinates of (a) RGB CCMs; (b) white light emitting CCMs – red dots.

HYBRID I/O^{TM} DISPLAYS

Many of the advantages of Hybrid I/O^{TM} for lighting are also applicable to displays. To reap the full benefits of Hybrid I/O^{TM} for displays, we have also chosen to utilize the light wave coupling (LWC) method. By using LWC, a display panel can be created which has the potential to exhibit the efficiency of Hybrid I/O^{TM} lamps for lighting applications. This level of efficiency is *an order of magnitude* higher than that achievable with existing display technologies. This overall high efficiency is achieved by implementation of a high efficiency light valve compatible with LWC. Previously, the best candidate light valves available were liquid crystals, which actually absorb ~90 to 95% of light even in the fully ON state (maximum light transmission). We have, therefore, sought development of a novel and near lossless light valve approach compatible with the LWC platform.

Currently, we have developed a light valve switching approach based on electrowetting [3]. EW switching functions by effectively modifying the refractive index at the surface of a large planar waveguide plate that is edge lit with high-efficiency violet LEDs. A basic representation of this switching mechanism is shown in Fig. 6a. By modulating refractive index, waveguided violet light can be selectively coupled from the waveguide plate to fluorescent lumophores. Red, green, and blue, lumophores are then spatially arranged to then create large arrays of color pixels. The electrowetting approach achieves this modulation of refractive index through microfluidic manipulation of low refractive index water and high refractive index oil. The oil is doped with lumophores that fluoresce brightly when the oil is brought into a state of optical coupling with the waveguide plate. The process is reversible, extremely fast (~10 ms), and requires very little power consumption (low capacitance). Demonstration of these fluorescent electrowetting light valves for light wave coupling displays is reported elsewhere [3]. As shown in Fig. 7, proof of concept for coupling light to lumophores on display sized waveguide plates has also been demonstrated. The powerful combination of

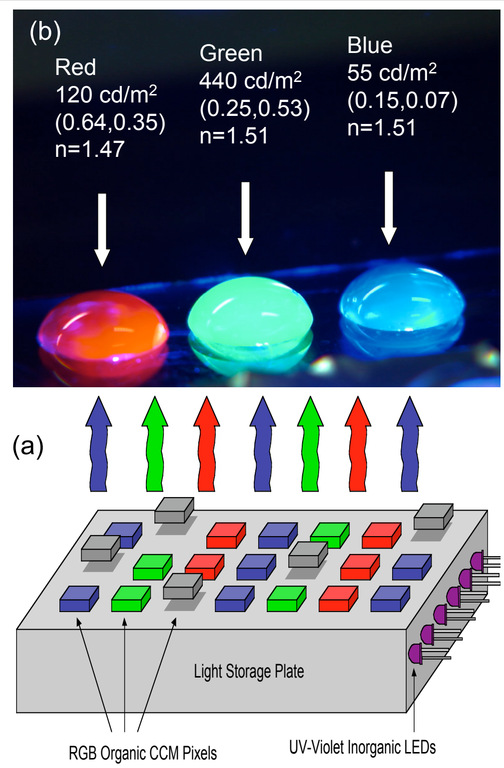


Fig. 6 Light wave coupled (LWC) Hybrid I/O display devices: (a) basic LWC concept; (b) emission from RGB CCM pixels under violet LED pumping in planar waveguide.

Hybrid I/O™ with near-lossless switchable pixels, results in a very compelling and innovative alternative display technology.

Future Development

Significant research and development is required for Hybrid I/O™ devices to realize their full potential in solid-state lighting and display applications. However, early device results are very promising. In Hybrid I/O™ lamps, new optical designs of the LWC lamps are being investigated, along with the design of the optimal CCM white emitting blend. In Hybrid I/O™ displays, new cell designs and improved materials (fluorescent CCMs and hydrophobic insulator coatings) are currently being explored. We believe that the Hybrid I/O™ LWC concept will produce a compelling new technology platform in the near future.

References

[1] J. Heikenfeld and A. J. Steckl, "A Novel Fluorescent Display Using Light Wave Coupling Technology", Proc. Soc. Inf. Display, Vol. 35, pp. 470-473, Seattle, May 2004.

[2] S. C. Allen, J. Heikenfeld, and A. J. Steckl, "Hybrid Inorganic/Organic Devices for Solid State White Lighting Applications", Electroluminescence 2004, Toronto, Sept. 2004.

[3] J. Heikenfeld and A. J. Steckl, "Demonstration of Fluorescent RGB Electrowetting Devices for Light Wave Coupling Displays", Electroluminescence 2004, Toronto, Sept. 2004.

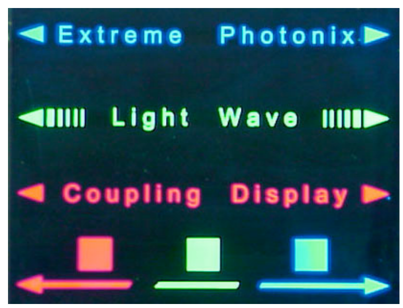


Fig. 7 Hybrid I/O™ LWC display prototype for full color signage applications.