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Review

Organic white-light emitting materials

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ABSTRACT

Full-color emissive organic materials have attracted significant attention in recent years as key components in display and lighting devices based on OLEDs. An ideal white-light emitter demands simultaneous emission of red, green and blue with nearly similar distribution of intensities covering the entire region of visible spectra. However, the design of such white-light emitters is not straightforward. Mixing several emitters is seldom successful owing to the negative effects of intermolecular interactions and energy transfer processes. Nonetheless, these fundamental questions have been addressed in recent times by several research groups of vastly different expertise leading to a considerable progress in the field of organic white-light emitters. The designs cover a large area of the chemistry ranging from frustrated energy transfer to simple protonation or from designed self-assembly to simple mixing of materials. In this review, the concepts and rational approaches underlying the design of white-light emissive organic materials are described.

1. Introduction

Our vision is biologically engineered for observing the visible spectra i.e. ~390–700 nm (VIBGYOR region of electronic spectra) [1]. In order to observe/distinguish any set of colours or colour-combinations within this region, we require the illumination of white-light (Fig. 1). From sunlight to electric lamps, we are used to the vision under white-light illumination. However, the definition of white-light is quite ambiguous. White-light, in general, is considered as the optimised composition of the three primary colours i.e. red (R), green (G) and blue (B). Interestingly, the human perceptions of white-light do not have any one particular spectral distribution of lights and can be obtained from infinite different compositions of primary colours. [2].

Although we understand the concept of white-light, can we really define it? Fortunately, the answer is yes and the problem has been solved nearly seven decades ago. In 1931, the Commission Internationale d'Eclairage (CIE) set up a standard colorimetric system, referred to as CIE 1931 [3]. CIE colour system is the most widely used colorimetric standard so far. In a CIE plot, all the colours which can be generated from the visible spectra are represented by two coordinates, x and y, which are called colour coordinates. According to CIE regulation, the colour coordinates for equal energy point of white light are (0.33, 0.33) (Fig. 2). White light can be generated by adjusting the proportions of the three primary colours i.e. red, green and blue. White-light can also be achieved by mixing any two complementary lights with certain proportions as long as the connection line of their colour coordinates can cross the white-light region. Now, as the standards are set, the question arises as to why should anyone pursue the goal of producing such white-light emission in an artificial way.

In recent times, organic luminescent materials have found their way to almost every door step with the progress in the fields of artificial lighting, display systems and fluorescent bio-medical tools [4]. Organic materials are generally preferred over their inorganic counterparts owing to their low cost, ease of fine-tuning, solution processability, low toxicity and sufficient flexibility for device fabrications [5]. Lighting, in particular, accounts for ~20% of the energy consumption worldwide and hence efficient lighting devices based on organic materials {e.g. LCD (liquid-crystal display) and OLED (organic light-emitting diodes)} have received considerable attention in the last few decades [6]. Current trends in organic-lighting have boosted the demand for white organic light-emitting diodes (WOLEDs) [5,7]. Recent commercialisations of OLED technologies have further increased the demand for successful developments of organic white-light emitting systems [8]. In most cases, white-light emitting OLEDs are made from either combinations of the individual R-G-B luminescence (or complementary colour pairs) in multi-layered, stacking and tandem devices, single polymer based electroluminescent devices or phosphor doping in single colour

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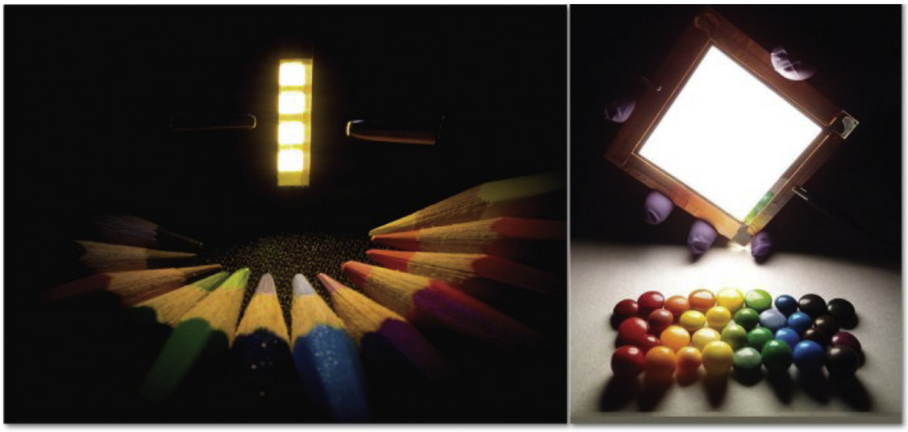

Fig. 1. White-light emitting diodes as full-colour lighting devices. Adapted with permission from references [7d,7e]. Copyright 2012–2013, John Wiley and Sons.

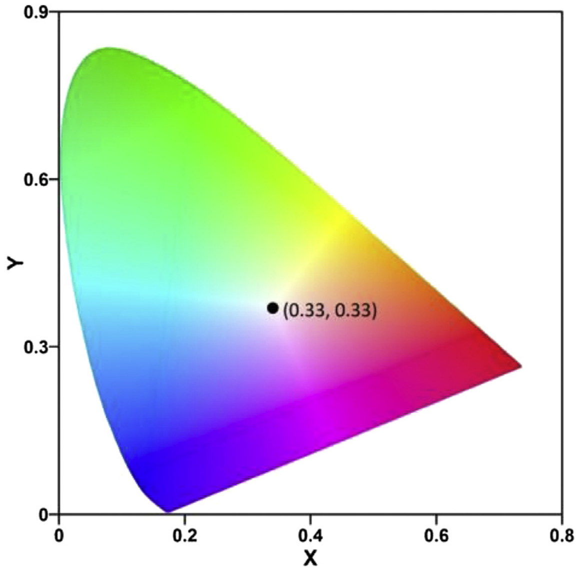

Fig. 2. A typical CIE (1931) plot sowing the coordinates of pure white-light (0.33, 0.33). (Plot obtained using the gocie.exe program available from the following website; http://www.geocities.com/krjustin/gocie.html).

OLEDs (Fig. 3) [8,9]. Although considerable progress has been made in this area, due to the occasional usage of inorganic counterparts, developments of purely organic white-light emitting materials with high outputs still remain a relatively less explored area. Recent studies have led to a better understanding of the origin of the properties of such RGB-emitting materials and several unique and versatile approaches have been developed to obtain white photoluminescent materials. Although in many cases, the generation of white-light is limited to solution-states, the design principles are being constantly explored for solid-state applications. In the following sections, different types of organic white-light emissive materials are discussed with broad classifications as per their design strategies and emission properties.

2. Molecular systems

Realisation of panchromatic white-light emission from a single molecule system is a highly challenging task. According to the Kasha's rule [10], fluorophores always tend to attain the lowest possible vibrational states resulting in monochromatic emission in general (Fig. 4). A brute-force inclusion of blue, green and red fluorophores in a single molecular backbone often results in complex intramolecular FRET (Föster resonance energy transfer) or TBET (Through bond energy transfer) processes resulting in enhanced emission from the red-emitting fluorescent units which act as the energy acceptors (Fig. 4) [10–12]. Furthermore controlling the relative intensity ratios of the individual emission bands is almost unmanageable. This is possibly the reason for somewhat scattered literature reports of white-light emissive molecules. Interestingly, a few rational design strategies have been reported in the past few years to obtain simultaneous RGB luminescence from single molecule species.

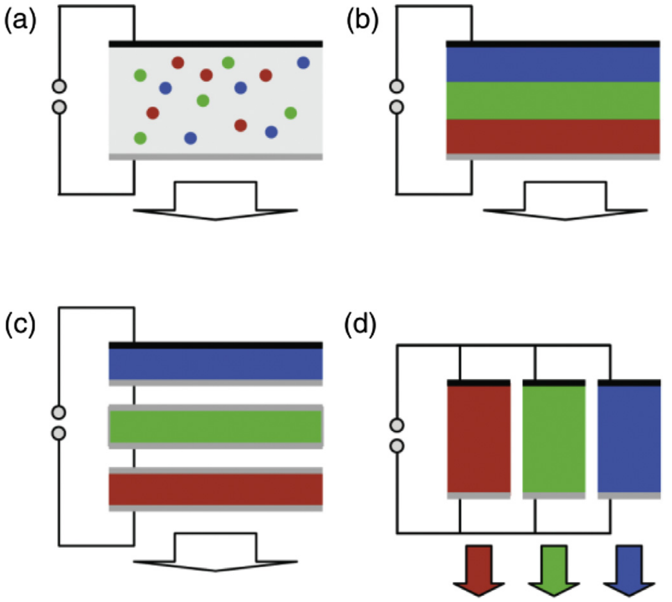

Fig. 3. Various approaches to generate white light from OLEDs include: (a) blending lumiphores emitting at different colours into a single layer, (b) using a single device stacked with several layers emitting in different regions of the spectrum on top of each other, (c) using multiple monochrome OLED stacks connected by charge-generation layers, and (d) generating the white emission by adjacent monochrome OLEDs, also referred to as spatial multiplexing. Reflective electrodes are illustrated in black; (semi-) transparent electrodes are shown in grey. Adapted with permission from reference 9a. Copyright 2011, John Wiley and Sons. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)