Polarized Emitting qLEDs based on Aligned Quantum Rods as Active Materials

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ABSTRACT

Several applications in display technology rely on linearly polarized light. Commonly, polarized emission is obtained by combination of an unpolarized light source with a subsequent polarizer. Following this conventional approach, a significant amount of energy is lost, as the polarizer simply blocks light having the wrong polarization direction.

While there are different approaches to partially recover light reflected by the polarizer, the preferred solution is a light source which directly converts electrical energy into linearly polarized light. In this contribution we present polarized emitting qLEDs based on aligned quantum rods as active materials, which are promising devices to fulfill this task.

1 INTRODUCTION

Several devices and fields of applications in display technology rely on linearly polarized light. Contrast generation in LCDs is achieved by switching polarized light provided by a back-light unit and a polarizer using liquid crystals, to either be transmitted or blocked by a second polarizer. Further, linearly polarized light is mandatory for different embodiments of emerging technologies, such as 3D projection or holography. Additionally in the field of mobility, head-up-displays (HUDs) are increasingly used in vehicles such as cars and planes. Here an optimized image replication can be obtained by using polarized light.

Today, linearly polarized light is commonly obtained by combination of unpolarized light sources such as conventional LEDs with subsequent polarizers (cf. Fig 1a). Following this approach, the portion of the incident light having the undesired polarization direction is blocked by the polarizer and not available for further image generation. There are technologies for recovering portions of this blocked light but they always come along with significant energy losses.

A smart way to minimize or, if possible, avoid these losses is the use of linearly polarized emitters, directly converting electrical energy into linearly polarized light. However, the fabrication of such devices is not straightforward. While lasers commonly emit linearly polarized light, these types of light sources are not suitable for many applications which require the illumination of larger areas. Novel, promising materials for the generation of linearly polarized light for these applications are anisotropic, elongated nanoparticles, i.e., quantum rods (QRs).

a)

b)

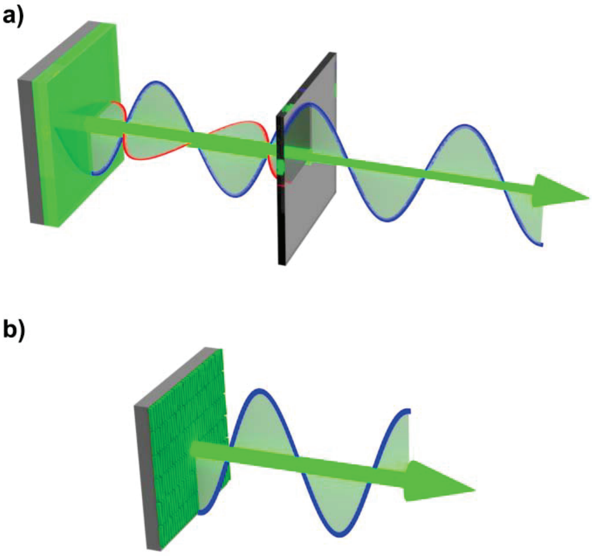

Fig. 1: Generation of linearly polarized light by a) using an unpolarized light source and a subsequent polarizer and b) utilized a light source based on electroluminescent aligned quantum rods.

Recently, semiconductor nanoparticles, commonly referred to as quantum dots (QDs) attracted significant interest in the display and lighting community. Due to their narrow emission bands, which are virtually continuously tunable over the visible wavelength range by size or composition,[1] the use of QDs as emitters in displays enables obtaining a large color gamut. In current display technologies, QDs are embedded into polymer matrices and employed as color converters, as part of the back-light unit.[2]

Besides their narrow emission bands and tunable emission wavelengths, semiconductor nanoparticles can be engineered to posses other unique properties. The growth of anisotropic, elongated QDs, commonly referred to as quantum rods (QRs), yields particles that provide a strong linear polarization of their photoluminescence along their long axis.[3,4,5] CdSe/CdS core/shell nanorods are a prominent material, achieving photoluminescence quantum yields considerably exceeding 90% and degrees of polarization (DOP) $P=(I_{max}-I_{min})/(I_{max}+I_{min})$ of their emission exceeding 0.8.[5]

Currently, many research activities target the fabrication of electroluminescent devices employing QDs as emissive layers, i.e., QD based LED (qLEDs), as successors of OLEDs.[6] By the incorporation of aligned, anisotropic QDs as emissive layers into qLEDs polarized-emitting qLEDs (PEqLEDs) can be fabricated.[7,8]

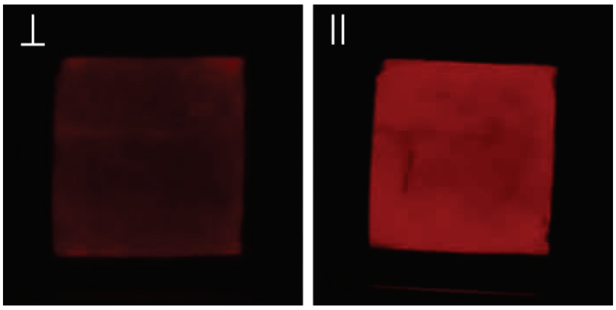

Fig. 2: Square centimeter-sized film of electro-statically aligned CdSe/CdS QRs.

2. Polarized-Emitting LEDs based on aligned Qunatum Rods

2.1 Polarized-Emitting QR Ensembles

To take advantage of the high DOP of single QRs in consumer applications, i.e., as polarized emitters, macroscopic ensembles of aligned QRs have to be fabricated.

Different approaches for QR alignment, such as stretching of QR/polymer composites[9] or contact ink-jet printing[10] have been reported. However, for further incorporation into qLEDs the use of a bulky polymer matrix is commonly not desirable due to its insulating nature. In our experiments we utilize electrostatic alignment[3,11,12] of colloidal QRs in AC electric fields to obtain aligned films with lateral extensions up to the cm^2 range. An exemplary film is depicted in Fig 2 showing photographs of a ~1 cm^2 sized aligned QR film excited with UV light, recorded through a polarizer aligned in parallel as well as orthogonally to the preferred polarization of the QR ensemble's emission, respectively. The linear polarization of the PL is clearly visible. Polarization measurements showed a DOP of ~0.4 for the depicted structure.

2.2 Polarized-Emitting qLEDs

For the fabrication of PEqLEDs, aligned ensembles of QRs are further incorporated into qLED stacks. For this purpose, a hole injection layer (HIL) and a hole transport layer (HTL) are deposited on a transparent anode material. Subsequently an aligned QD layer is deposited into this stack, followed by the deposition of an electron transport layer, as well as a metal cathode.

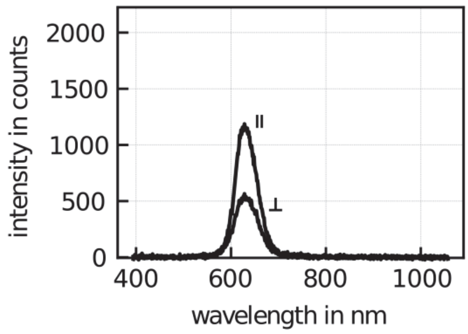

Fig. 3: Emission spectra of a PEqLED recorded in parallel and orthogonally to the desired polarization direction.

Figure 3 shows emission spectra of a PEqLED device recorded in parallel and orthogonally to the desired polarization direction. The polarization of the electroluminescent emission is clearly visible. Using a fabrication method that is based on electrostatic alignment of the QRs, PEqLEDs with record DOP values significantly exceeding 0.3 were fabricated.

3 CONCLUSIONS

PEqLEDs are of great interest for applications requiring polarized light. Here, these devices can be employed as the energy-efficient light sources reduce the power losses in polarization filters, or even make them obsolete in certain applications.

We present a scalable PEqLED fabrication process based on electrostatic alignment of QRs that enables the reproducible fabrication of large-scale PEqLEDs with yet unachieved DOP values.

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