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Light-emitting diodes enhanced by localized surface plasmon resonance

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Abstract

Light-emitting diodes [LEDs] are of particular interest recently as their performance is approaching fluorescent/incandescent tubes. Moreover, their energy-saving property is attracting many researchers because of the huge energy crisis we are facing. Among all methods intending to enhance the efficiency and intensity of a conventional LED, localized surface plasmon resonance is a promising way. The mechanism is based on the energy coupling effect between the emitted photons from the semiconductor and metallic nanoparticles fabricated by nanotechnology. In this review, we describe the mechanism of this coupling effect and summarize the common fabrication techniques. The prospect, including the potential to replace fluorescent/incandescent lighting devices as well as applications to flat panel displays and optoelectronics, and future challenges with regard to the design of metallic nanostructures and fabrication techniques are discussed.

Introduction

Light-emitting diodes [LEDs] have attracted much scientific and commercial interest since the realization of a practical LED device with emission frequencies in the visible region of the electromagnetic spectrum [1]. Since then, research activities have been focusing on how to produce economical LEDs with the desired colors as well as white light sources [2]. The strong demand has also driven materials technology, and new emitting materials and configurations have been proposed to enhance the performance. For example, the use of a polymer instead of small molecules opens the door to flexible, large-area, and stable organic LEDs [OLEDs] [3]. In the past 15 years, low-dimensional emitting devices incorporating quantum dots [QDs] and quantum wells [QWs] have been extensively investigated in order to achieve the desirable emission color and enhance device efficiency [4-10]. However, LEDs suffer from inherently low efficiency due to the sometimes low internal quantum efficiency [IQE] and difficulty extracting the generated photons out of the device. Although the use of electro-phosphorescent materials with proper management of both singlet and triplet excitons has brought IQE in OLEDs to almost unity [11-13], that of LEDs with inorganic emitting materials such as GaN, CdSe, and Si QDs or QWs remains unsatisfactory because non-radiative electron/hole pair recombination dominates. Another channel of energy loss is total internal reflection at the emitter/air interface because of the typically high refractive index of the emitting materials. Several methods have been proposed to enhance the overall efficiency of LEDs, and they include substrate modification and incorporation of scattering medium, micro-lenses, nanogratings, corrugated microstructures, photonic crystals, and so on [14-17]. In spite of some efficiency enhancement, spectral changes and angle-dependent colors associated with the substrate modification techniques, the high precision needed to produce nanogratings and the high cost of photonic crystals are still challenging issues plaguing commercial applications.

Surface plasmon polaritons [SPPs] were first exploited to enhance the efficiency of InGaN QW-based LEDs by Okamoto et al. in 2004 [18]. Known as Purcell effect, when the resonant frequency of the silver SPPs overlaps the emission frequency of the InGaN QWs, the energy coupled to the SPP mode is significantly increased and thus the IQE is enhanced [19]. Scattered by the rough silver film, the energy coupled to the SPP mode can be recovered as free space photons. In their work, the enhanced IQE η^{*}_{int}

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