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A Solid-State Multicolor Light-Emitting Device Based on Ballistic Electron Excitations

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1.Introduction

Si based multi-color light-emitting devices are desirable for low-cost, VLSI compatible display purposes and any application requiring light sources. Currently, electroluminescence (EL) from nanocrystalline porous Si (nc-PS) is not ready for practical usage since it can emit light efficiently only in the red part of the visible spectrum [1].

Diodes including nc-PS layer can also operate as surface-emitting ballistic electron sources in vacuum [2]. This cold emission is presumably caused by generation of energetic electrons via multiple-tunneling transport through interconnected Si nanocrystallites. Application in display area has been demonstrated using both crystalline and polycrystalline Si [3]. Electrons emitted from a layer of nc-PS excite a luminescent film. This later film could be either placed in vacuum, at a small distance away from the electron emitter [4], or directly deposited onto the electron-emitting surface (electrons are not emitted into vacuum in this case) [5].

Green emission has previously been demonstrated using this device [5,6]. The study presented in this paper aims at producing bright blue emission using a device in which the luminescent film is a blue emitting organic layer.

2. Experimental

A non-doped polycrystalline silicon film was deposited by LP-CVD (Low pressure-Chemical Vapor Deposition) on an n-type single-crystalline silicon wafer. The nanocrystalline porous poly-Si (nc-PPS) layer was formed by anodization in an ethanoic HF (55 wt% HF : ethanol=1:1) solution under illumination. The nc-PS structure was controlled by modulating the anodization current.

After anodization, a thin film of organic fluorescent material (TPB: Tetraphenylbutadiene) was deposited onto the nc-PS layer by evaporation in vacuum. The thickness of this layer is about 180 nm. Finally, a thin Au film (10 nm thick) was deposited on the TPB film as a top semitransparent electrode. The active area of the device was 5 mm in diameter. The schematic device structure is shown in Fig. 1.

The opto-electronic properties of the device were evaluated under both forward and reverse bias conditions at room temperature in N_2 gas ambient, in terms of current-voltage characteristics, luminescence intensity, spatial uniformity of luminescence, and emission spectrum.

3. Results and Discussion

As shown in Fig.2, the fabricated device exhibits a rectifying behavior at room temperature, and blue light is emitted when a positive bias voltage above 12 V is applied to the Au electrode with respect to the substrate. No light emission was observed under reverse bias condition. At voltages higher than 30 V, the luminescence is clearly discernible by naked eye in a little bit darkness. Uniform luminescence is emitted from the whole area of a semitransparent Au film without any local bright spots and fluctuations as shown in Fig.3.

The luminescence spectrum is almost the same as the photoluminescence (PL) spectrum of TPB, as indicated in Fig.4. The voltage dependences of both the luminescence intensity and the luminescence spectrum strongly suggest that the light emission is due to direct excitation of the TPB layer by energetic ballistic electrons generated in the nc-PS layer.

The luminescence mechanism of this device is explained as follows. Electrons injected from the Si substrate are drifted in the nc-PS layer toward the outer surface under a high electric field. Most of them become ballistic electrons by multiple tunneling through interfacial thin oxide films between silicon nanocrystallites. As a result of this acceleration, the kinetic energy of electrons at the outer surface of the nc-PS layer become much higher than the luminescence energy of TPB. The TPB film is then excited by an impact process and subsequent blue emission occurs.

4. Conclusions

Blue luminescence from the Si-based solid-state light-emitting device has been demonstrated. This device is available for various photonic applications such as large-area flat panel displays and surface-emitting light sources.

Acknowledgments

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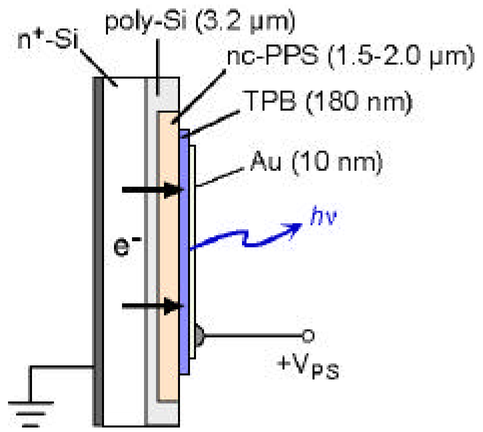

Fig.1. Schematic representation of the solid-state light-emitting device using a blue-emitting organic film as a fluorescent film. Ballistic electrons are generated in the nc-PPS layer and excite the organic film.

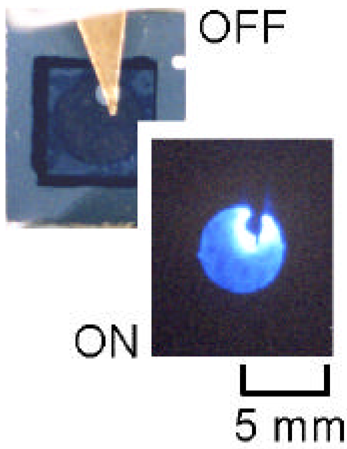

Fig.3. Photograph of the device under off and on states. Under positive forward bias, uniform light emission is obtained.

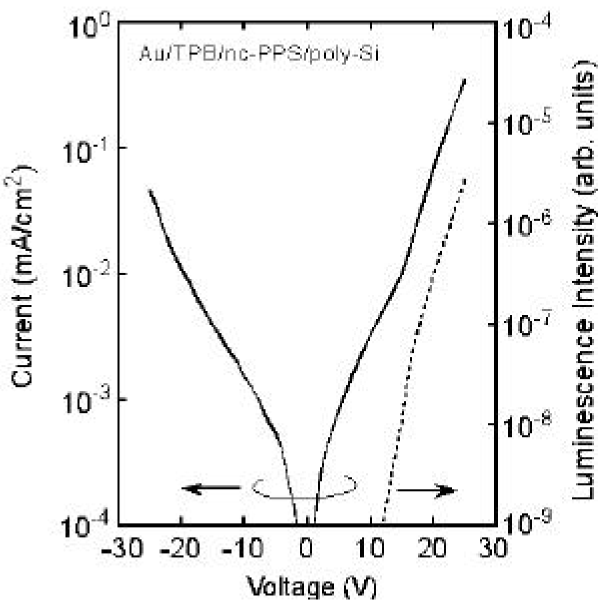

Fig.2. Current and luminescence intensity as a function of applied voltage.

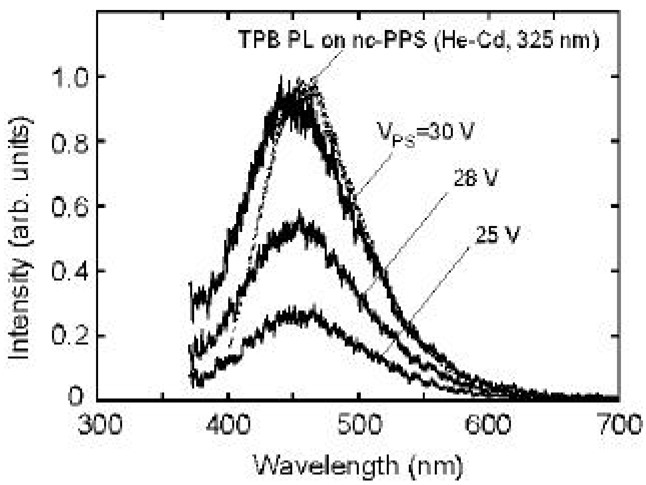

Fig.4. Emission spectra (solid curves) from the device operated at different voltages. The PL spectrum of the fluorescent film (TPB) is also shown (dashed curve).