Extended Abstracts of the 2001 International Conference on Solid State Devices and Materials, Tokyo, 2001, pp. 660

P-2-4

A Solid-State Light-Emitting Device Based on Excitations of Ballistic Electrons Generated in Nanocrystalline Porous Poly-Silicon Films

Yoshiki Nakajima, Akira Kojima, Hajime Toyama, and Nobuyoshi Koshida

Department of Electrical and Electronic Engineering, Faculty of Technology,
Tokyo University of Agriculture and Technology, Koganei, Tokyo 184-8588, Japan
Phone:+81-42-388-7128 FAX:+81-42-385-5395 E-mail:koshida@cc.tuat.ac.jp

1. Introduction

Nanocrystalline porous silicon (nc-PS) diodes operate not only as a light-emitting diode (LED) but also as a high efficient ballistic electron emitter in vacuum [1, 2]. Previously reported [3], we demonstrated that these electron emitter is also applied to a novel solid-state light-emitting device by using ballistic electrons as an excitation source for luminescence of fluorescent materials.

We have observed separately the electron emission from a nanocrystalline porous poly-silicon (nc-PPS) films [4]. From the technological viewpoints for large-area application, development of devices based on polycrystalline silicon is very important. The present paper shows that a solid-state light-emitting device based on ballistic electron excitation can be fabricated by nc-PPS flms.

2. Experimental

A heavily doped n-type polycrystalline silicon film was deposited by an LP-CVD technique on an n-type single-crystalline silicon wafer, A nc-PPS layer was formed by anodization in an ethanoic HF solution under an illuminated condition. The nc-PPS structure was controlled by modulating the anodization current. The anodized nc-PPS layer is further treated by electrochmeical oxcidation (ECO) in a sulfric acid. After that, a thin film of organic fluorescent material (Alq_3:tris (8-hydroxyquinoline) aluminum, 120 nm thick) was deposited onto the nc-PPS layer, and then a thin Au film (10 nm thick) was deposited onto the Alq_3 as an semitransparent top electrode. A schematic device structure is shown in Fig.1.

The optoelectronic properties of the device were evaluated under the forward and reverse bias conditions at room temperature in a N_2 gas ambient in terms of the current-voltage (I-V) characteristics, luminescent intensity, emission spectra, and its spatial uniformity.

3. Results and Discussion

As shown in Fig.2, the fabricated devices exhibit a rectifying behavior at room temperature, and green light is emitted when a sufficient positive bias voltage beyond 7 V is applied to the Au electrode with respect to the substrate. The threshold voltage of luminescence is lower than that of the device based on single-crystalline silicon. At voltages higher than 25 V, the luminescence is clearly discernible in the daylight. Uniform luminescence comes from the whole area of a semitransparent Au film without any local bright spots and fluctuations as shown in Fig.3.

According to the results of luminescence spectra measurements, the luminescence spectrum is almost the same as photoluminescence spectrum of Alq_3 as indicated in Fig.4. The voltage dependences of both the luminescence intensity and the spectrum strongly suggest that the light emission is due to direct excitation of the Alq_3 layer by energetic ballistic electrons generated in the nc-PPS layer.

Based on the results mentioned above, the luminescence mechanism of this device is explained as follows. When electrons injected from Si substrate are drifted in nc-PPS layer toward the outer surface under a high electric field, major part of them become ballistic electrons by multiple-tunneling through interfacial thin oxide films between silicon nanocrystallites. As a result of acceleration, the kinetic energies of electrons at the outer surface of nc-PPS become much higher than the excitation energies of Alq_3. It causes impact excitation and subsequent radiative recombination. Thus this luminescence is regarded as a sort of solid-state cathodoluminescnece induced by specific high-field conduction in a nanocrystalline silicon system.

4. Conclusions

It has been demonstrated that a solid-state light-emitting device is successfully fabricated using ballistic electrons generated nanocrystalline porous poly-silicon layer as an excitation source of a fluorescent film. This device is promisingly applicable to various photonic devices such as large-area flat panel display and surface-emitting light source.

References

[1] N. Koshida and H. Koyama, Appl. Phys. Lett. **60**, 347 (1992).

[2] N. Koshida, T. Ozaki, X. Sheng, and H. Koyama, Jpn. J. Appl. Phys. **34**, L705 (1995).

[3] Y. Nakajima, A. Kojima, and N. Koshida, Mat. Res. Soc. Symp. Proc. **638** (2001) (in press).

[4] T. Komoda, X. Sheng, and N. Koshida, J. Vac. Sci. Technol. B**17**, 1076 (1999).

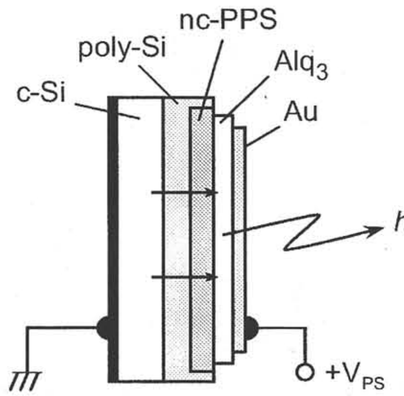

Fig.1. A schematic structure of the solid-state luminescent device based on ballistic electron excitaion.

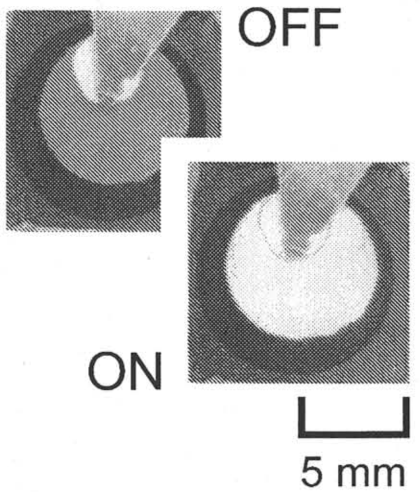

Fig.3. Photographs of the device under the off and on states. At a positive biased condition (25 V in this case), uniform green light emission is observed.

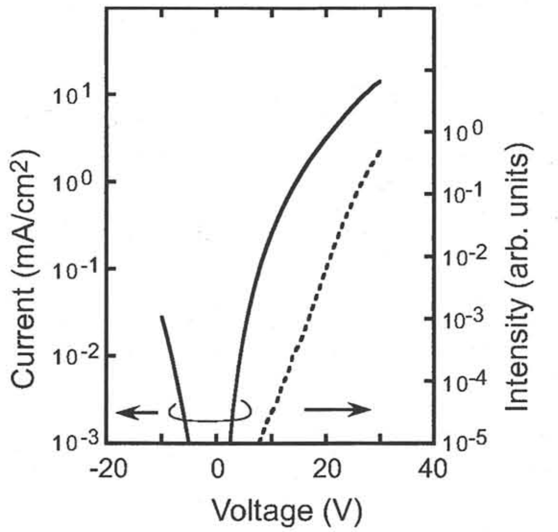

Fig.2. Current-voltage characteristic (the solid curve) and the corresponding luminescence intensity (the dashed curve) of a fabricated device.

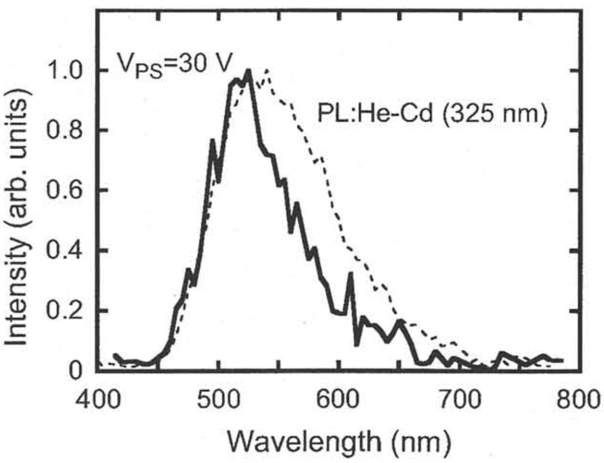

Fig.4. Emission spectrum (the solid curve) of the device. The PL Spectrum of a fluorescent film (Alq_3) is also shown by the dashed curve for reference.