ELECTROLUMINESCENCE STABILIZATION OF NANOCRYSTALLINE POROUS SILICON DIODES

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1. Introduction

For practical applications of electroluminescence (EL) from nanocrystalline porous silicon (nc-PS) diodes [1], the external power efficiency (EPE) should be improved beyond 1% at operating voltages below 10 V and the stability longer than 10,000 h under a cw operation. We recently developed a PS-EL device which offers the red band emission with an EPE of 0.4% at a voltage of 5 V [2], an external quantum efficiency (EQE) of 1.1% [3]. The remaining subject to be pursued further is to enhance the EL stability. For this purpose, there are two possible approaches: (a) encapsulation of the device surface by a water-proof thin film and (b) passivation of luminescent nc-Si surfaces themselves by a stable termination. The effectiveness of the former was demonstrated in our previous paper [4]. In this paper, it is reported that the latter is also very useful for stabilizing the EL emission.

2. Experiments

The EL device is composed of a semitransparent indium tin oxide (ITO) top contact, a nc-PS layer treated by electrochemical oxidation (ECO), an n^+-type Si (111) wafer, and an ohmic back contact. The post-anodization ECO produces a significant improvement in the EL efficiency [5]. To stabilize the ECO-treated nc-PS, the additional chemical functionalization by 1-decene [6] is employed along the following process.

(a) Cleaning in a buffered HNO_3+HF solution.
(b) Photoanodization by a sequential current modulation scheme such that a thin compact superficial layer (200 nm in thickness) and an active layer (800 nm thick) is formed on the outer surface and the bulk, respectively.
(c) ECO treatment in a 1N H_2SO_4 solution for a time at which the electrochemical EL reaches a maximum.
(d) Chemical functionalization for 1 h at a temperature of 90℃ in 1-decene $CH_3(CH_2)_7CH: CH_2$.
(e) Top contact formation by rf-sputtering deposition of a thin ITO film (300 nm in thickness).

3. Results and Discussion

As shown in **Fig. 1**, the diode emits a uniform red EL for either positive or negative bias voltage. The EL at a negative voltage of 5 V is discernible in the daylight. We can see that the introduction of chemical functionalization for about 1 h has no serious affects on both the current-voltage characteristics and the EL efficiently.

The diode current and the corresponding EL intensity are plotted in Fig. 2 as a function of time during the cw operation at a constant voltage. There are no signs of degradation in the driving current, the EL intensity, and the efficiency for a few hours, as in the PL case. This is totally different from the behavior of the untreated device, in which the EL efficiency rapidly degrades within 10-20 min. It is clear that current-induced oxidation followed by the formation of surface defects is successfully suppressed by surface passivation by stable Si-C bonding.

The nc-Si surfaces in PS are partially oxidized by the ECO treatment. The additional chemical functionalization in 1-decene should replace remaining metastable Si-H bondings by more stable covalent Si-C bondings. The surface termination of nc-Si is another key issue for stabilizing EL. An appropriate combination of this technique with an encapsulation of the device surface would make it possible to develop a practically stable EL .

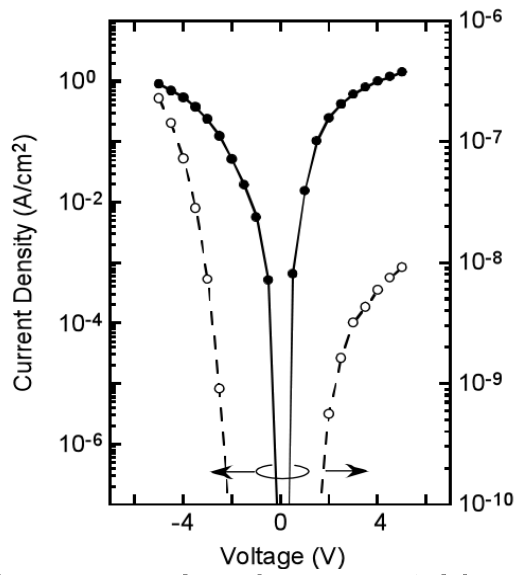

Fig. 1. Current-voltage characteristics (solid curve) of a fabricated nc-PS diode and the corresponding EL emission characteristics (dashed curve).

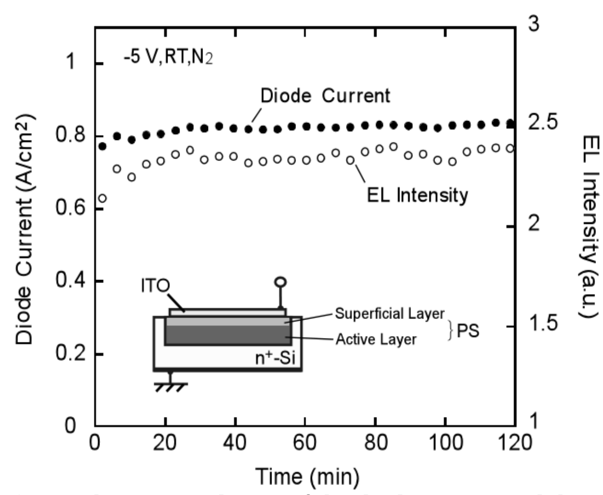

Fig. 2. The time evolution of the diode current and the EL intensity of a fabricated PS device under continuous operation for 2 h at a bias voltage of 5 V. The schematic device structure is also shown. It should be noted that no degradation is observed in the driving current, the EL intensity, and the EL quantum efficiency.

References
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