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Efficient Electroluminescence from Porous Silicon

Bernard Gelloz and Nobuyoshi Koshida

Division of Electronic and Information Engineering, Faculty of Technology,
Tokyo University of Agriculture and Technology, Koganei, Tokyo 184, Japan
Phone/Fax: +81-(0)423-88-7433 / +81-(0)423-85-5395, E-mail: gelloz@cc.tuat.ac.jp

1. Introduction

For display purposes, the power efficiency of electroluminescence (EL) should be at least 1 %, the operating voltage below 10 V, the time response below 1 ms and the stability longer than 10 000 hours [1]. As for porous silicon (PS) based devices, the best values of the power efficiency are still below 0.1 %[1,2]. Operating voltages are usually larger than 20V [2]. The only parameter which seems not a problem is the EL time response. The stability of current devices is very poor, usually not exceeding 1 hour [3]. We have recently shown that an electrochemical treatment (anodic oxidation) of PS allows to gain several orders of magnitude as for the external quantum efficiency (EQE) [4], and then to reach high values (EQE of 1.1 % has been obtained [2]). However, the power efficiencies associated to these devices are still below 0.1 % (max.: 0.08 %[2]), due to high applied voltages (>20V).

In order to enhance the power efficiency as well as to fit the operating voltage requirements (<10V), the anodic oxidation technique has been applied to very thin PS layers. To enhance the stability of the devices, the effect of a superficial, low porosity, thin layer between the optically active PS and the top contact made of indium tin oxide, has been studied. Different problems related to the thin layers were encountered, such as reproducibility problems and conduction peculiarities. These problems have been solved using very strict procedures. Finally, very efficient and bright EL has been obtained at voltages below 10V.

2. Experiment

Active PS layers were formed by anodizing n+-Si wafers in an ethanoic HF solution. After anodization, the samples were electrochemically oxidized in 1M H_2SO_4 solutions. The EL emission is observed during the treatment, since holes and electrons are injected into confined silicon crystallites under anodic polarization mode [5]. The time of this post-anodization oxidation was controlled by monitoring the EL intensity. Finally, transparent indium tin oxide films were deposited by sputtering onto the PS layers for used as top contacts. The devices are reverse biased.

3. Results and discussion

The highly efficient (EQE of 1.1%) [2] device that we have obtained previously requires voltages above 25 V to see the EL in day light. As a result, the power efficiency is rather low, below 0.1%. The high voltage needed may be explained by the rather high thickness of the porous layer (30 μm) the device includes. Many different formation conditions of PS have been investigated in a view to obtain efficient devices operating at voltages below 10V. The strategy is to use thin n^+-type porous layers. However, reproducible results are difficult to obtain. Indeed, the probability for inhomogeneousness is quite high for thin layers and their influence on the efficiency is important. Another encountered problem is the peculiar conduction behaviors of thin layers. For example, the negative resistance effect has been reported [6].

The reproducibility problems have been solved by taking a special care in the cleaning of the wafers and in the control of the PS preparation conditions. Furthermore, if a lower porosity thin superficial layer is added to the structure, the peculiar behavior of the devices is avoided. This may imply that the interface between the top contact and the active PS may be responsible for these peculiar behaviors.

Figure 1 shows the EL intensity and the current density for the most efficient device, which porous layer has been anodically oxidized and which include a superficial low porosity layer.

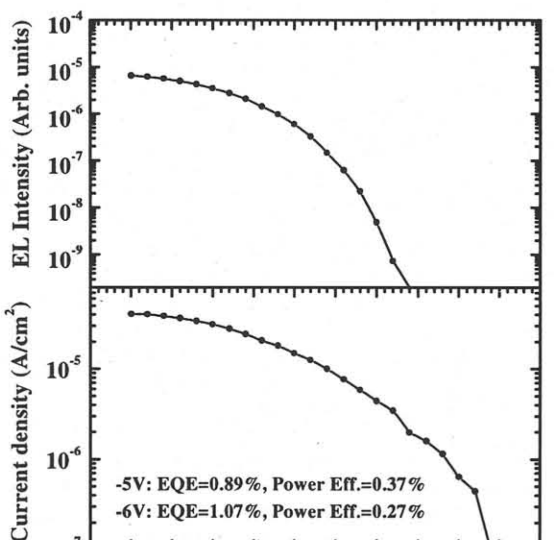

Fig. 1 Current density and EL intensity versus voltage for a device which PS layer has been anodically oxidized and which include a low porosity superficial layer. Negative voltages show that the device is reverse biased.

The EL can be seen with naked eye in day light, for an operating voltage of 5 V. At 5 V, the EQE is 0.89 % and the power efficiency 0.37 %. This value of the power efficiency is the highest obtained to date with PS. At 6V, the EQE is 1.07 % and the power efficiency 0.27 %. The power efficiency is reduced as the voltage increases even though the EQE increases. This shows the drastic influence of the voltage on the power efficiency, and highlight the necessity of using low operating voltages for getting high power efficiencies.

Figure 2 shows the EL intensity as a function of the current density for this device and for a device without the anodic oxidation treatment and without any additional low porosity superficial layer. The anodic oxidation treatment enables higher EL intensity, and higher efficiency, since it reduces considerably the current density. It clearly shows the power of the techniques used to improve the efficiency and the EL output.

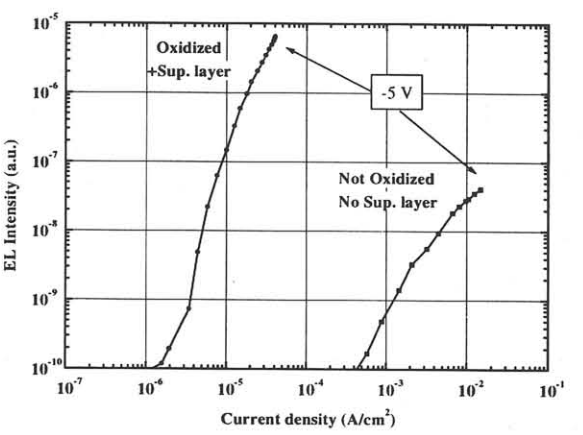

Fig. 2 EL intensity versus current density for the same device as in figure 1, and the same device without superficial layer and not oxidized.

We have previously reported the effect of anodic oxidation on the characteristics of EL of PS [4]. When oxidation is performed up to the maximum of EL during the electrochemical process, non-confined silicon is much more oxidized than luminescent crystallites. This significantly reduces the number of carriers flowing through non-confined silicon, optimizing carrier injection into luminescent crystallites. This results in enhanced EQE. It should be noted that thermal oxidation could not lead to such an enhancement since it occurs on the whole internal surface of PS (without selecting non-confined silicon from confined silicon). Moreover, contrary to thermal oxidation, anodic oxidation does not affect on both the PS structure and passivation with hydrogen [7]. It also enhances localization of carriers in crystallites [8] and enhances the luminescence-homogeneity.

The stability of the devices has been evaluated. It is found better than what is usually obtained [3]. However, the voltage needed to obtain a given EL intensity still increases with time. Then, the stability is still altered by oxidation of PS during operation [3]. We are currently working on how to enhance the stability on a basis of surface modification technique.

3. Conclusion

Our study aims at enhancing the efficiency of EL from PS. In addition to the anodic oxidation treatment [4] which enhances the EQE by several orders of magnitude, thin porous layers have been used in order to lower the operating voltage as well as to increase the power efficiency. Bright EL can be obtained below 10V. Power efficiency of 0.37 % has been obtained. This value is the highest reached with PS. The characteristics of our PS based device is now closer than ever to display requirements.

The addition of a superficial layer significantly improves the stability of the device by enhancing the electrical contact and the mechanical stability of the contact.

The stability is better than that of usual PS devices [3], but is still altered by oxidation during operation. We are currently working on enhancing the stability of our devices.

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