High Performance Electroluminescence from Nanocrystalline Si with Carbon Buffer

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1. Introduction

Efficient and bright light-emitting devices with low operating voltage (<5V at present and <3 V forecast for the future) are needed for optical interconnects and related applications. Electroluminescence (EL) from nanocrystalline Si (nc-Si) currently does not fulfill all these criteria [1]. The stability is very low (a few hours at best). The best power efficiency reported to date is about 0.4 % [2]. The operating voltage for bright EL intensity is over 5 V and well above 10 V in most cases [1].

The EL characteristics of nc-Si have been significantly improved in the past few years. Electrochemical oxidation has led to unprecedented high external quantum and power efficiencies (1.1 % and 0.4 %, respectively) [1-4]. The stability has been increased using nc-Si passivation and capping [1,2,5]. The operating voltage for bright EL intensity remains above 5 V.

This study aims at producing efficient and bright EL at voltages as low as possible, below 5 V. Very thin optimized nc-Si layers have been used in order to minimize the series resistance of the device. In addition, a carbon buffer layer between the nc-Si layer and the top ITO electrode is used in order to enhance the mechanical and electrical quality of the top contact. The efficient EL excitation at low voltage enables voltage tunable EL.

2. Experimental

Figure 1 is a cross-sectional view of a typical device. Nc-Si layers are formed from n^+ -type Si (100) by anodization in HF electrolyte. A compact nc-Si layer is formed first to enhance the contact between the top contact and the underneath optically active nc-Si layer formed later on. The total thickness of the nc-Si layer is about 600 nm. Electrochemical oxidation of the nc-Si layer is then carried out until the maximum of EL during the treatment [2-4].

In most cases, a few nanometer thick amorphous carbon film is then deposited by sputtering onto the nc-Si layer. The color of the carbon film was brown with darkness increasing with the film thickness. Its light transmission at 600 nm was ranging from about 95 % to 70 % depending on sputtering conditions. Finally, a 200 nm thick ITO layer is deposited by sputtering onto the nc-Si layer or the carbon film (if present) for use as the top electrode.

Positive voltage corresponds to forward condition. All experiments are conducted under CW operation in N_2 atmosphere.

3. Results and discussion

Figure 2 shows the current density and the EL intensity as a function of the voltage. The EL voltage threshold is below 1 V and about -0.5 V under forward and reverse operation, respectively. The EL excitation is most probably an impact ionization process. Only one type of carrier is injected from the substrate and the other type is generated by impact ionization across the nc-Si layer where a locally high electric field takes place.

The EL efficiency is improved due to a reduction in current density and an increase in EL intensity, as shown in Fig. 2. In addition, the reproducibility from device to device is very much improved by the carbon film. The carbon film enhances the stability. This is attributed to the capping of PS by the carbon film and the high chemical stability of carbon and Si-C bonds, which should prevent PS oxidation. The carbon film acts as an efficient mechanical and electrical buffer layer between PS and ITO, resulting in enhanced mechanical, electrical and chemical stability of the top contact and providing high reproducibility.

Rather high brightness has been obtained below 5 V. 1 Cd/m^2 has been measured. Work is under way in order to increase this value even more.

Figure 3 shows the EL spectra at different voltages and a photoluminescence spectrum. The EL peak wavelength is voltage-tunable between 700 nm to 630 nm for a voltage ranging from 2 to 5 V. This behavior should have its origin in the field-induced EL generation mechanism. Indeed, the higher the voltage, the higher the energy peak of the hot electrons generated in the nc-Si layer [6] and therefore the higher the possible luminescence excitation energy. Because EL can be efficiently excited at much lower voltage compared to conventional nc-Si diodes, the progressive excitation of nc-Si emitting at higher and higher energy can be observed as the voltage is increased. Notice that even at 5 V the EL peak wavelength is greater than the photoluminescence one, suggesting that a great deal of nc-Si are still not excited at this voltage. The EL efficiency and brightness could be enhanced, and the EL peak energy shortened, if all nc-Si could be excited. Work is under way to enable full excitation of the available nc-Si and broader voltage tune of the EL peak wavelength.

4. Conclusions

Thin nc-Si layers and a carbon buffer film have been used in order to achieve relatively high brightness EL (1 Cd/m²) at low-operating voltages (<5V). EL visible with unaided eye in room lighting has been obtained below 3 V. EL spectra are slightly voltage-tunable from 700 nm to 630 nm for voltages ranging from 2 to 5 V.

The carbon film acts as an efficient mechanical and electrical buffer layer between the nc-Si layer and the top contact. It induces a great enhancement in reproducibility.

The capping function of the carbon film provides enhanced EL stability. The carbon film reduces the contamination and oxidation of nc-Si. Furthermore, the high chemical stability of carbon and Si-C bonds provide enhanced passivation for nc-Si located at the Si-C interface.

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References

- B. Gelloz and N. Koshida, Handbook of luminescence, Display materials, and devices, Chap. V, Edited by H. S. Nalwa and L.S. Rohwer ISBN:1-58883-010-1 (2003)
- [2] B. Gelloz and N. Koshida, J. Appl. Phys. 88 (7), 4319 (2000)
- [3] B. Gelloz, T. Nakagawa and N. Koshida, Appl. Phys. Lett. **73**, 14, 2021 (1998).
- [4] B. Gelloz, T. Nakagawa and N. Koshida, *Mater. Res. Soc. Symp. Proc.* **536**, 15 (1998)

[5] N. Koshida, J. Kadokura, M. Takahashi and K. Imai *Mater.* Res. Soc. Symp. Proc. 638, F18.3.1 (2001)

[6] Y. Nakajima, A. Kojima and N. Koshida, Appl. Phys. Lett. **81**, 13, 2472 (2002)



Fig. 2 Current density and EL intensity as a function of voltage for a device including a carbon buffer and a conventional device which does not include any carbon film.



Fig. 1 Device cross-sectional view. Not to scale.



Fig. 3 EL spectra at various voltages for an efficient device including a carbon buffer.