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Theoretical study of electroluminescence from device based on silicon nanocrystals

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ABSTRACT

In this work, we have proposed a theoretical model allowing the calculation of electroluminescence (EL) from a light-emitting device, taken from the literature, composed of a silicon nitride film (containing silicon nanocrystals (Si-ncs)) between an indium thin oxide (ITO) layer and an aluminum (Al) anode.

The EL model suggests that following the application of an electric field, carriers are injected by the Fowler-Nordheim process. The carriers transporting process to the cathode is modeled by the Hopping conduction and causing the generation of other carriers inside Si-ncs by ionic impact. The EL is created by the recombination of the carriers inside Si-ncs.

Results exhibit that selective size distribution centered at a Si-nc radius of less than 1 nm allows blue emission for thin active film. The optimal carrier injection is obtained for bias voltages lower than 27 V that allowed the potential barrier diminution.

A comparison between the experimental and the theoretical results indicated that the present model is able to satisfactorily explain the highest observed EL peak.

1. Introduction

The luminescence in silicon nitride film (SiN_x) containing Si-ncs has been the subject of many studies in photoluminescence (PL) and second position in EL. Several EL origins have been identified. These origins are defects in nitride, Si-ncs [1], electron-hole recombination in the silicon substrate [2,3] or surface plasmons of the polarized metal electrode [4,5].

The first attempt to obtain an electroluminescent device using porous silicon (PS) as a base material was reported in 1991 by Richeter et al. [6]. The big handicap of PS-based electroluminescent devices is their porous structure. Indeed, they are unable to support chemical post-anodization or thermal treatments inherent microelectronics manufacturing. Thus, the use of structures made from Si-ncs encapsulated in an insulating matrix (SiO_2 or SiN_x) seems to be a cure for this problem.

In 2005, Chen et al. [7] observed visible electroluminescence from a film composed of Si-ncs embedded in an amorphous matrix of silicon nitride. The initial Si-ncs / SiNx film was deposited by evaporation of silicon in inductively coupled nitrogen plasma. The electroluminescent device was synthesized by depositing on the Si-ncs / SiNx film an aluminum anode and an indium tin oxide (ITO) cathode. By tunnel effect, the electrons and holes were respectively injected from the cathode and the anode towards the Si-ncs through the high gap of SiNx. The threshold voltage allowed the EL is less than 10 V, and the emission efficiency is 0.16 *Cd / A*. The EL spectrum consists of two broad bands centered at 2.5 and 2.8 eV.

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In the same year, Cho et al. [8] fabricated a light emitting diode (LED) from a transparent Si-ncs layer encapsulated in SiN_x matrix and deposited by a plasma enhanced chemical vapor deposition (PECVD). Under direct polarization, an orange electroluminescence with a peak of 600 *nm* was observed at room temperature. The position of the peak EL is very similar to that found in the PL, and the emitted EL intensity is proportional to the current density through the device. The authors suggest that the origin of PL is the recombination of electron-hole pairs in Si-ncs.

Actually, short-wave emitting devices [9–11] (blue to ultraviolet) with a short variance and high efficiency can only be obtained from quantum dots of zinc oxide (ZnO) [9] or gallium nitride (GaN) [10].

In this work, the EL mechanism is theretically investigated, assuming that the generation and the transport of carriers are attributed to Fowler-Nordheim and the hopping process respectively, and that the EL is due to the recombination of carriers inside Si-ncs.

The EL is then studied according to the Si-ncs size distribution, the film thickness, the anode nature and the bias voltage in order to highlight the influence of each parameter on the EL characteristics.

2. Electroluminescence model

We theoretically study the electroluminescence from an electroluminescent device, issue from the literature [7], and represented in Fig. 1. The system was synthesized with Si-NCs/a-SiNx film as the active layer (of thickness *d*) using the Al anode and the indium tin oxide cathode.

The model is an extension of several theoretical approaches concerning the analysis of conduction mechanisms [6–13].

The model taking into account both a field effect and Hopping conduction is shown schematically in Fig. 2 and is formulated based on the following assumptions:

- The EL is due to recombination of charge carriers inside Si-ncs;
- The carriers are injected from the metal electrode (Al) by a field effect (E) which results in a flow of electrons from the metal anode. The corresponding current density is simplified from the Fowler-Nordheim equation described as:

$$J_{FN} = \frac{1.54.10^{-6}E^2}{\phi} exp\left(-\frac{6.83.10^9\phi^{3/2}}{E}\right) \quad (1)$$

Where :

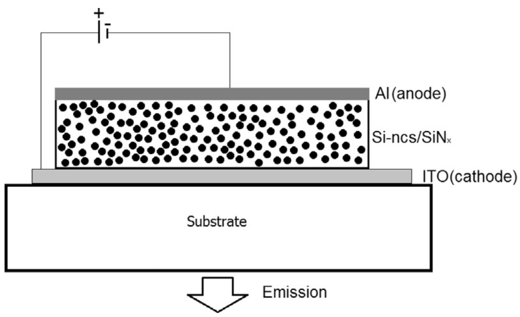

Fig. 1. Electroluminescent device composed of Al / (Si-ncs / SiNx) / ITO [7].

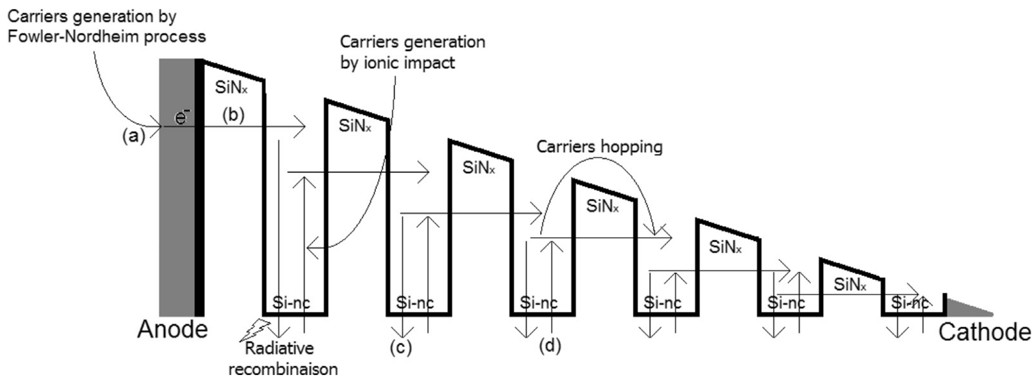

Fig. 2. Mechanism of EL. (a) Generation of carriers by field effect (b) jump of the carriers from one Si-nc to another (c) Radiative recombination inside the Si-ncs (d) Generation of the charge carriers by impact ionic.