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Electroluminescence from Si/SiO_2 films deposited on p-Si substrates*

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The structure of $Au/Si/SiO_2/p$-Si has been fabricated using the magnetron sputtering technique. It has a very good rectifying behaviour. Visible electroluminescence (EL) has been observed from the $Au/Si/SiO_2/p$-Si structure at a forward bias of 5V or larger. A broad band with one peak around 650–660 nm appears in all the EL spectra of the structure. The effects of the thickness of the Si layer in the Si/SiO_2 films and of the input electrical power on EL spectra are studied systematically.

Keywords: Si/SiO_2 film, electroluminescence
PACC: 7860F, 7865

1. Introduction

Nanoscale Si-based films have attracted much attention since they can be utilized in many kinds of opto-electronic devices, such as light emission diodes.[1] The pioneering work on electroluminescence (EL) from the Si-containing silicon dioxide film was reported by Dimaria *et al*[2] EL from porous Si and nanoscale Si particle embedded Si oxide systems have also been studied.[3,4] In this paper, we report on the EL from the semi-transparent Au film/nanometre Si/nanometre SiO_2/p-Si structures and we study the effects of thickness of the Si layer in the nanometre Si/nanometre SiO_2 (NSNSO) film and of the input electrical power on the EL.

2.Experiment and results

NSNSO films have been grown using the two-target alternation magnetron sputtering technique. The alternation targets were a pure SiO_2 target and an n-type Si target. An ohmic contact on the back side of the Si substrate was formed by evaporating thin Al film and alloyed at 540°C. Just before NSNSO film deposition, the oxide layers on the Si substrates were removed using 5% hydrofluoric acid. Then the NSNSO films were deposited on the substrates. Five types of NSNSO film with Si-layer thickness of 4, 8, 12, 16 and 20 nm have been grown. The thickness of the SiO_2 layer in all the NSNSO films was 8 nm. After annealing all the samples at 300°C in N_2 for 30 min, semi-transparent Au films were deposited with a metal mask on the front surfaces as electrodes to form Au/NSNSO/p-Si structures in the same deposition chamber. The circular Au electrodes had a diameter of about 1.5 mm. The structure is shown in Fig.1.

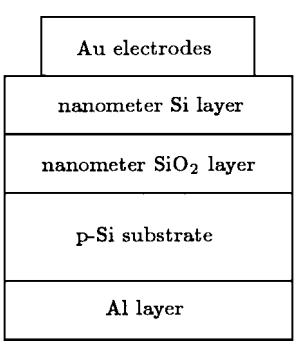


Fig.1. Schematic diagram of the EL cell.

The current–voltage (I–V) characteristics curve exhibits a good rectifying behaviour with little leak current under reverse biases. Figure 2 shows the I–V curve of the Au/NSNSO/p-Si structure with a 12 nm thick Si layer. The EL spectra from the Au/NSNSO/p-Si structures, with 4 to 20 nm Si-layer thickness, were measured under a forward bias from 5–12 V. Visible EL was observed uniformly on the cell by

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the naked eyes when the forward bias (a positive voltage is applied to the p-Si substrate) exceeded 5 V, and became stronger with increasing forward bias. However, no EL emission was observed under a reverse bias for the structures.

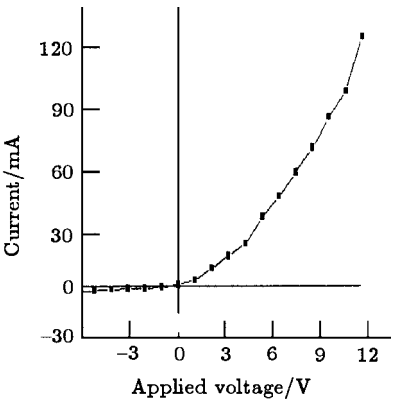


Fig.2. *I–V* characteristic of one Au/NSNSO/p-Si sample with the Si-layer thickness of 12 nm.

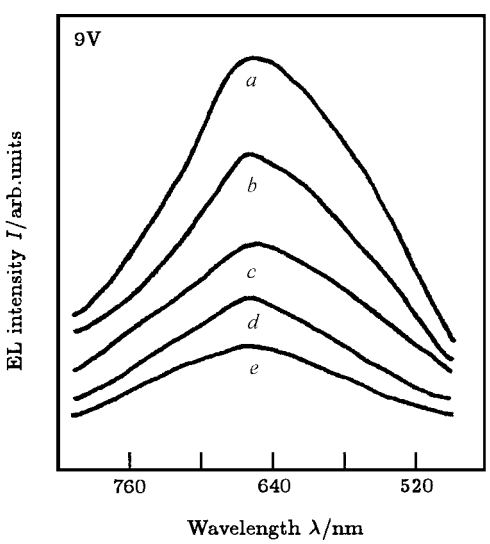


Fig.3. EL spectra measured under a forward bias of 9 V from three types of Au/NSNSO/p-Si structures with different Si-layer thicknesses: *a*, 4 nm (154mA); *b*, 8 nm (136mA); *c*, 12 nm (83mA); *d*, 16 nm (42mA); *e*, 20 nm (37mA).

Figure 3 shows the five EL spectra from the Au/NSNSO/p-Si structures with 4, 8, 12, 16 and 20 nm Si-layer thickness in the NSNSO films, measured under a forward bias of 9 V. It is found that, when the Si-layer thickness increases from 4 to 8 nm, the EL peak wavelength increases from 650 to 660 nm. When the Si-layer thickness increases from 8 to 12 nm, the EL peak wavelength decreases from 660 to 650 nm. When the Si-layer thickness increases from 12 to 16 nm, the EL peak wavelength increases from 650 to 660 nm. Finally, when the Si-layer thickness increases from 16 to 20 nm, the peak wavelength of 660 nm remains almost unchanged. So the behaviour of the 650–660 nm band is slightly complicated. The EL intensities conformably decrease with the Si-layer thickness, increasing from 4 to 20 nm. Moreover, all the EL spectra show asymmetric shapes.

Figure 4 shows EL spectra from the Au/NSNSO/p-Si structure under three different forward biases, respectively, at 5, 8 and 11 V, with the NSNSO film having a thickness of 8 nm, which has been annealed at 300°C. The EL band peak is located at around 650 nm, and shows no evident shift with increasing forward bias from 5 to 11 V.

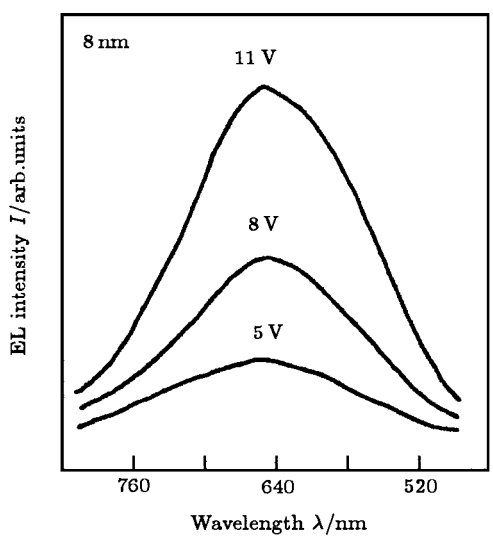


Fig.4. EL spectra dependence on the different forward biases for one Au/NSNSO/p-Si sample annealed at 300°C, with Si-layer thickness of 8 nm, under the following measurement conditions: 5 V, 31 mA, 8 V, 120 mA and 11 V, 242 mA.

3. Discussion

Dimaria *et al* suggested that EL from an Au/SiO_2 film containing tiny silicon islands/n-Si structure originates from band-to-band recombination of electrons and holes in nanometre Si particles with widened bandgaps due to the quantum confinement effect.

However, this explanation is not suitable for the present experimental results. The reasons are as follows.

(1) If the EL from the Au/NSNSO/p-Si structure is attributed to the two-dimensional nanometre Si layer in the NSNSO films, a redshift of the EL peak should occur with increasing Si-layer thickness from 4 to 20 nm due to a decrease of the energy gaps of

the Si layer. This prediction is inconsistent with our experimental results, as shown in Fig.3.

(2) For a definite sample, redshifts of EL peaks should occur when the forward bias and current increase, because the energy gaps of the nanometre Si layer should decrease when the input power, and correspondingly the temperature of the nanometre Si layer, increase.[5] This prediction is inconsistent with our experimental results, as shown in Fig.4.

Based on the above reasons, we rule out the possibility that the excitation and recombination processes of the observed EL are both from the nanometre Si layer, as described by Dimaria. We thus propose a possible process in which electrons from the Au electrode and holes from the p-Si substrate will tunnel, respectively, into the excited electron states and excited hole states in the nanometre Si layer in a NSNSO film. All these excited states and ground states are affected by the quantum confinement effect (the bandgaps of the nanometre Si layer are widened), but electrons and holes do not recombine radiatively within the nanometre Si layer since Si has an indirect energy band. During the relaxation process, electrons and holes can tunnel into the luminescence centres in the SiO_2 layer and there recombine radiatively.

The present experimental results can be explained as follows. In the SiO_2 layer, if there is only one type of luminescence centre with a luminescence wavelength around 650 nm responsible for the EL band around 650 nm, just like the situation in Fig.4, then the peak wavelength at 650 nm should not change with increasing forward bias. On the other hand, if there are at least two types of luminescence centres with slightly different luminescence wavelengths near 650–660 nm, they may be responsible for the EL band around 650–660nm. The increasing nanometre Si layer thickness should affect the excitation and tunnelling processes of electrons and holes, thus affecting slightly the resultant emission peak wavelength. The EL spectra are influenced by two processes, i.e. excitation and emission processes. The emission process is the dominant process, while the excitation process can affect the carriers tunnelling into different luminescence centres, thus affecting the EL peak position. So a little redshift or blueshift of EL peaks can be realized, just like the swing situation of EL peak position with increasing Si-layer thickness, as shown in Fig.3.

The photoluminescence (PL) peak from SiO_x at an energy of 1.9 eV (around 650 nm) has been reported.[6–8] Sullivan *et al*[9] also reported a PL band from the a-Si/SiO_2 superlattice, and they considered that the PL originated from the oxygen-related defect centres.

It can be understood for the experimental fact that no EL emission was observed under reverse bias since there is little leak current.

4. Conclusions

NSNSO films have been grown using the magnetron sputtering technique. The EL from the Au/NSNSO/p-Si structure was studied. The EL peak wavelength sways between 650 and 660 nm when the Si-layer thickness increases from 4 to 20 nm. For the same sample, the EL band peak shows no shift with increasing forward bias, which is located at around 650 nm. The experimental results indicate that the EL recombination process originates mainly from luminescence centres in the SiO_2 layer rather than from the Si layer in the NSNSO films.

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