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A comparative study of electroluminescence from Ge/SiO_2 and Si/SiO_2 films*

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Ge/SiO_2 and Si/SiO_2 films were deposited using the two-target alternation magnetron sputtering technique. The $Au/Ge/SiO_2$/p-Si and $Au/Si/SiO_2$/p-Si structures were fabricated and their electroluminescence (EL) characteristics were comparatively studied. Both $Au/Ge/SiO_2$/p-Si and $Au/Si/SiO_2$/p-Si structures have rectifying property. All the EL spectra from the two types of the structure have peak positions around 650–660 nm. The EL mechanisms of the structures are discussed.

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

1. Introduction

Applications in optoelectronic devices have made the nanoscale Si-based films one of interesting fields in recent years [1–8] since Dimaria *et al* [9] fabricated Au/SiO_2/Si-rich SiO_2 films/n-Si structure using the chemical vapour deposition technique. They observed visible EL under an electric field greater than 3 MV/cm, and attributed the light emission to band–band recombination of electron–hole pairs in nano-size silicon particles. In the present work, we deposited Ge/SiO_2 and Si/SiO_2 films onto p-type Si substrate and studied comparatively visible EL from the $Au/Ge/SiO_2$/p-Si and $Au/Si/SiO_2$/p-Si structure, and the EL mechanism for both types of structure is discussed.

2. Experimental results

Ge/SiO_2 and Si/SO_2 films were deposited using the two-target alternation RF magnetron sputtering technique with Ge (or Si) and SiO_2 targets. Every target was 10 cm in diameter. The substrates used in this experiment were (100)-oriented, 10 Ω cm p-type Si wafers. The thickness of the Ge (or Si) layer was 10 nm and that of the SiO_2 layer was 10 nm. The films were annealed in N_2 atmosphere at 600°C for 30 min. Finally, semitransparent Au films were evaporated onto the films to form $Au/Ge/SiO_2$/p-Si and $Au/Si/SO_2$/p-Si structures. The circular Au electrodes of each cell were about 2 mm in diameter.

The current–voltage (I–V) dependence was measured using a digital multimeter. Under forward bias, a positive polarity is applied on the p-type silicon substrate and the gold electrode is negative. The inset of Fig.1 shows the scheme of measurement, the current was obtained for each voltage setting with point-to-point resolution of 0.1 V. The I–V characteristics of the $Au/Ge/SiO_2$/p-Si and $Au/Si/SiO_2$/p-Si structures are shown in Fig.1. Both structures have good rectifying property, while for a definite forward bias, the current in the $Au/Ge/SiO_2$/p-Si structure is larger than that in the $Au/Si/SiO_2$/p-Si structure.

All the EL spectra from the structures were measured under forward bias from 5 to 12 V. For both structures, visible EL was observed uniformly on the cell by the naked eyes when the forward bias exceeded 5 V, and became stronger with increasing forward bias. However, no EL emission was observed under a reverse bias for both structures.

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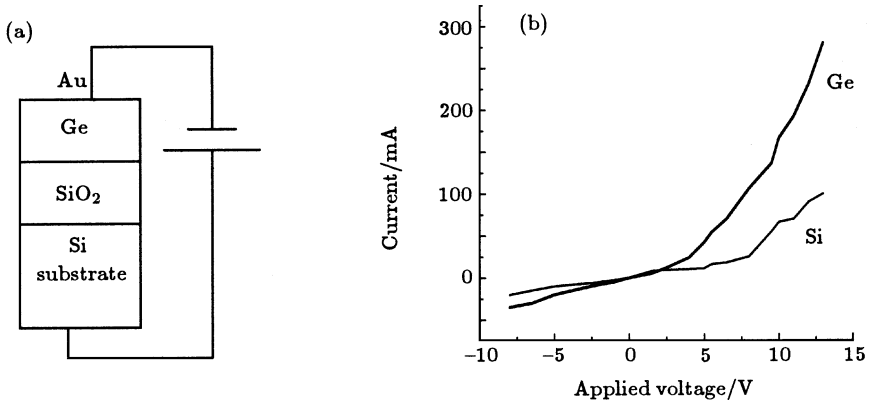


Fig.1. I–V characteristics of the Au/Ge (or Si)/SiO_2/p-Si structure. (a) Schematic representation of the Au/Ge (or Si)/SiO_2/p-Si device; (b) I–V characteristics at room temperature of the Au/Ge/SiO_2/p-Si and Au/Si/SiO_2/p-Si structure.

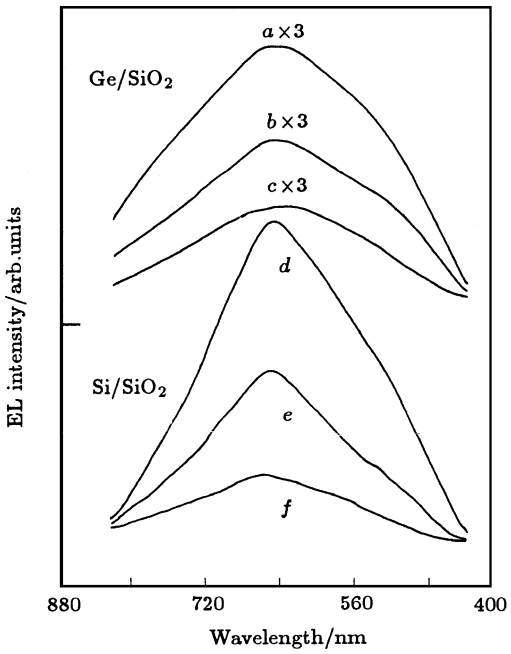


Fig.2. EL spectra from the Au/Ge/SiO_2/p-Si and the Au/Si/SiO_2/p-Si structures. Measurement conditions: for Ge/SiO_2, curve a: 11 V, 182 mA; curve b: 8 V, 106 mA; curve c: 5 V,42 mA; for Si/SiO_2, curve d: 11V,67 mA; curve e: 8 V, 24 mA; curve f: 5 V, 11 mA.

Figure 2 shows the EL spectra of the structures under three different forward biases (5, 8 and 11 V). For Au/Ge/SiO_2/p-Si structure, EL-band peak is located around 650 nm, and shows no evident shift with increasing forward bias; while for Au/Si/SiO_2/p-Si structure, the peak of the 660 nm (at 5 V) band blue-shift to 655 nm when the forward bias increases to 8 V, and then sequentially blue-shift to 650 nm when the forward bias increases to 11 V. Moreover, all the EL spectra show asymmetric shapes. For the Au/Si/SiO_2/p-Si structure, the EL intensity increases rapidly with increasing forward bias; however, for the Au/Ge/SiO_2/p-Si structure, the EL intensity increases relatively slowly. In addition, the widths of the spectra of the structures are different, the FWHM of the Ge/SiO_2 peaks are wider than that of the Si/SiO_2.

Figure 3 gives the relationship of the EL integrated intensity from the Au/Ge/SiO_2/p-Si structure with input electric power, and its comparison with that from the Au/Si/SiO_2/p-Si structure. It can be seen that the efficiency for the Au/Si/SiO_2/p-Si structure is higher than that for the Au/Ge/SiO_2/p-Si structure.

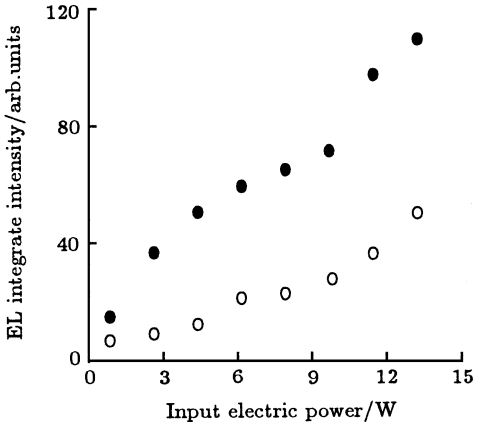


Fig.3. The variation of EL integrated intensity with input electric power for Au/Ge/SiO_2/p-Si(circles) and Au/Si/SiO_2/p-Si(dots) structures.

3. Discussion

Both Au/Ge/SiO_2/p-Si and Au/Si/SiO_2/p-Si structures show clear diode-like behaviour, just as light-emitting diodes, so they have good rectifying

property. If the explanation of Dimaria *et al* suggested for EL from the $Au/SiO_2/Si$-rich Si oxide/n-Si structure [6] is proper for explaining the EL from the $Au/Ge/SiO_2$/p-Si (or $Au/Si/SiO_2$/p-Si) structure, i.e. the EL is attributed to the nanometric Ge (or Si) layer in the Ge/SiO_2 (or Si/SiO_2) film, then for both structures, red-shift of the EL peaks should occur when the forward bias and current increase, because the energy gaps of the nanometric Ge (or Si) layer should decrease with the input power and, correspondingly, the temperature of the nanometric Ge (or Si) layer increases.[10,11] In fact, as shown in Fig.2, the EL peak energies have almost no shift with increasing input power for the $Au/Ge/SiO_2$/p-Si structure, and have small blue-shift with increasing input power for the $Au/Si/SiO_2$/p-Si structure.

Based on the above reasoning, we rule out the possibility that the excitation and recombination processes of observed EL both being from the nanometric Ge (or Si) layer, as described by Dimaria *et al*. We propose a possible process in which EL originates from the luminescence centres (i.e. defects, impurities, or self-trapped excitons) in the SiO_2. During this EL process, electrons and holes tunnel into the luminescence centres in the SiO_2 and recombine radiatively. However, more probably, electrons from the Au electrode and holes from the p-Si substrate tunnel, respectively, into the excited electron states and excited hole states in the nanometric Ge (or Si) layer in Ge/SiO_2 (or Si/SiO_2) film. All these excited states and ground states are affected by the quantum confinement effect (the band gaps of nanometric Ge (or Si) layer widen), but electrons and holes do not recombine radiatively within the nanometric Ge (or Si) layer since Ge(or Si) is an element with indirect energy band. During the relaxation process, electrons and holes can transfer to (most possibly tunnel into) the luminescence centres in the neighbouring SiO_2 and recombine radiatively.

The present experimental results can be explained as follows.

In the SiO_2 if there is only one type of luminescence centre with a luminescence wavelength around 650 nm or there are several types of luminescence centres with very close luminescence wavelengths around 650 nm, just like the situation in the Ge/SiO_2, then the peak wavelength at 650 nm should not change with increasing forward bias. If there are at least two types of luminescence centres with a little different luminescence wavelengths near 650–660 nm responsible for the EL band around 650–660 nm, the increasing forward bias should slightly affect the peak wavelength. So a little blue-shift of EL peaks can be realized, just like the situation in the Si/SiO_2. On the other hand, two distinct PL peaks from amorphous SiO_2 at energies of 1.9 eV (650–660 nm) have been reported in a number of papers.[12,13] In other words, we consider the processes of carriers' radiative recombination to be similar to each other in the two types of structure. Thus we can easily explain the experimental facts that the EL spectra from the $Au/Ge/SiO_2$/p-Si and $Au/Si/SiO_2$/p-Si structures under forward biases have very similar shapes, with their EL peaks located at the 1.9 eV position. Since the EL spectra are influenced by the two processes (excitation and emission), the corresponding different width of the peaks can be realized.

In fact, the quantum confinement effect has an effect on EL. From Fig.2, the input power obviously affects the intensities of the EL band at 650 nm for both structures. This indicates that the quantum confinement effect in nanometric Ge (or Si) layer does play an important role in the EL process.

4. Conclusion

In this paper, EL from $Au/Ge/SiO_2$/p-Si and $Au/Si/SiO_2$/p-Si structures were studied comparatively. For both structures, EL can be observed when positive voltage applied to Si substrates exceeds a critical value. Although the process for carriers' transportation and the widened band gaps of nanometric Ge (or Si) layer are very different for the two elements, the mechanisms of light emission are the same, i.e. electron–hole pairs radiatively recombine via the luminescence centres in the SiO_2 layer rather than via the nanometric Ge (or Si) layer.

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