Effects of Dislocation Loops into Electroluminescence of Si-based Light Emitting Diodes

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Abstract— **Recently different and contradicting results regarding the influence of dislocation loops on light emitting efficiency of Si-based LEDs at room temperature were published [1-4]. We report our results on light emission of devices called DILED and DiFLED which are with and without dislocation loops, respectively. The p-n junction in the DiFLED device was realized by dopant diffusion while using ion implantation with various ion energies for DILED. Electroluminescence (EL) has been used to investigate room-temperature light-emission and the contribution of dislocation loops by comparison of the characteristics between the DiFLED and DILED devices. In this paper, the device fabrication, working principle and properties will be discussed. The electrical and optical characteristics of the different devices were measured and discussed. Some simulation results using the Sivalco code give more insight on the effects of dislocation loops.**

Keywords— **Si-based Light emitting diode; Efficiency; Recombination; Dislocation loops.**

I. INTRODUCTION

Bulk crystal silicon is an indirect band gap material and consequently shows low emission efficiency. There have been several approaches published recently showing the same purpose to produce an efficient light emitter that is more suitable with standard, silicon-based integration technology. One of these approaches is fabrication of dislocation loop array into the crystal silicon by implantation technique [1-5]. The work in [1] and [2] has described a silicon light emitting diode operating efficiently at room temperature. The dislocation loops were produced in n-type silicon substrate by Boron implantation with the peak concentration of 1 x 10^{20} B/cm^{3}. The observed electroluminescence (EL) with the dominant wavelength at ~ 1154 nm shows an external quantum efficiency of 2 x 10^{-4}. The mechanism of this approach is the spatial confinement of the injected carriers due to the local strain field introduced at the dislocation loop position. In the reference [3], the cathodeluminescence has been used to investigate light emission at room temperature from dislocation loops generated in Si substrates by ion-implantation. The efficient luminescence of Si at room temperature due to dislocation loops was independent of the presence of a p-n junction.

The extended structural defects (dislocation loops) have also been produced into Si substrates by implantation of B and P ions with a subsequent post-annealing at 700 - 1200 ^{0}C as shown in [4] and [5]. However, the internal quantum efficiency of the band-to-band EL of the devices achieved the maximum value of 0.4 % after annealing at 1100 ^{0}C, when the dislocation loops are not introduced. The paper [4] concluded that no influence of dislocation loops into the higher quantum efficiency due to the spatial confinement of injected carriers.

The purpose of this paper is to investigate more clearly the influence of dislocation loops into the light-emitting structures fabricated in the bulk silicon material.

II. EXPERIMENTAL

In order to analyze the influence of the dislocation loops in the light emitting process, we fabricated two runs of devices called DILED and DiFLED which are with and without dislocation loops, respectively. The starting material is 4-inch n-type silicon wafer with a resistivity of 5-10 Ohm-cm. The p-n junction inside DiFLED was realized by using Boron diffusion technique while using B-ion implantation technique for DILED. The dislocation loops profile inside the DILED was controlled due to changing temperature of post-annealing process in range of 850-1050 ^{0}C for 20 minutes after implantation. To change the position of the dislocation loop array in Si substrate, the implantation process was carried out with different energies while keeping a constant dose of 1 x 10 ^{15} B/cm^2. After implantation and annealing, aluminum contact areas were formed at the back- and front-sides of the device. The ohmic contacts were sintered at 400 ^{0}C for 5 minutes.

In order to get comparable profiles, the sizes and structures of the DILED and DiFLED fabricated are similar. Their sheet-resistance as well as junction depth was controlled to be in the same level by changing implantation energy and diffusion conditions. Figure 1 shows a schematic of structure of DILED and DiFLED device.

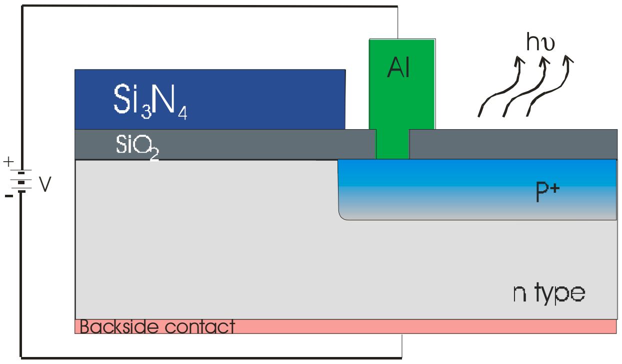

Figure 1: Schematic of structure of DILED and DiFLED

Comparison of observed light emitting characteristics between the DiFLED and DILED device is a fundament for evaluating the effects of the dislocation loop layers in the radiative recombination process of carriers.

III. RESULT AND DISCUSSION

A. *Electrical properties*

Current-voltage (I-V) characteristics were measured between the back and front contacts to make sure that the devices behave as real diodes and to see that which mechanism is dominant in the device. The I-V plots of all devices show low leakage current as the standard characteristic of diodes. This is in contrary to the result described in reference [1]. Under forward bias, the dominant contribution to the total current is the diffusion current component. It means that the recombination outside of the space charge region throughout the low injection regime. An example of the I-V measurements with DILED was given in Figure 2.

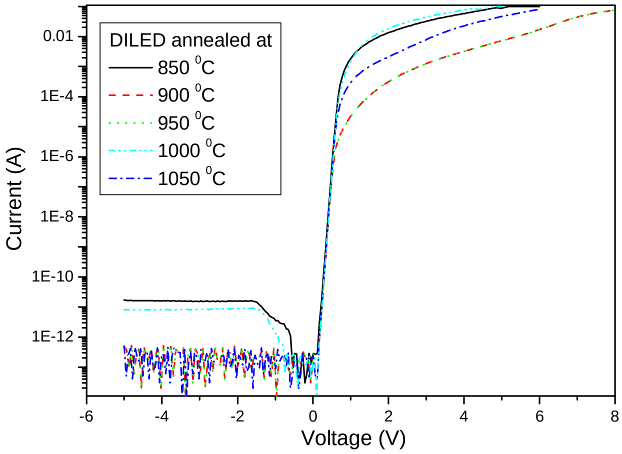

Figure 2: I-V characteristics of DILED annealed at different temperature

B. *Optical characteristics*

The electroluminescence (EL) measurement of the devices was carried out at room temperature. The EL was observed under forward bias at a constant current of 100 mA. All EL spectra of DILED and DiFLED give the same phonon-assisted band-to-band emission peak at wavelength of 1154 nm.

The evolution of the dislocation loops depends on the annealing conditions after implantation. In Figure 3 the emission spectra of DILED annealed for 20 minutes at four temperatures are displayed. The spectra show that the device annealed at 1050 ^{0}C gives the highest intensity. The trend of increasing is still continue up to 1050 ^{0}C, but we do not investigate further because in fact the dislocation loops would be completely dissolved after annealing at 1100 ^{0}C, as in [6]. However, instead of that we use DiFLED as a reference for device without dislocation loops.

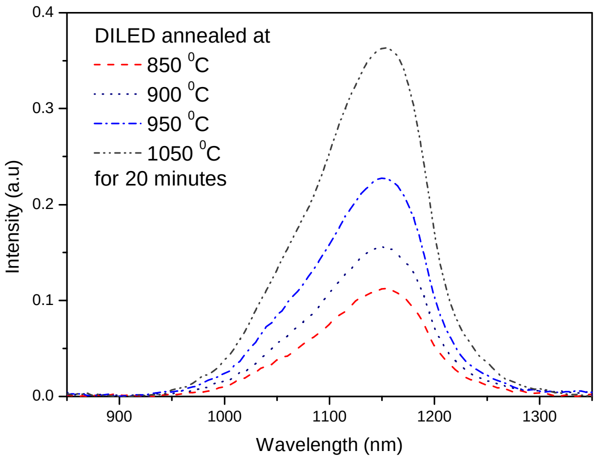

Figure 3: emission spectra of DILED as function of wavelength at different annealing temperatures.

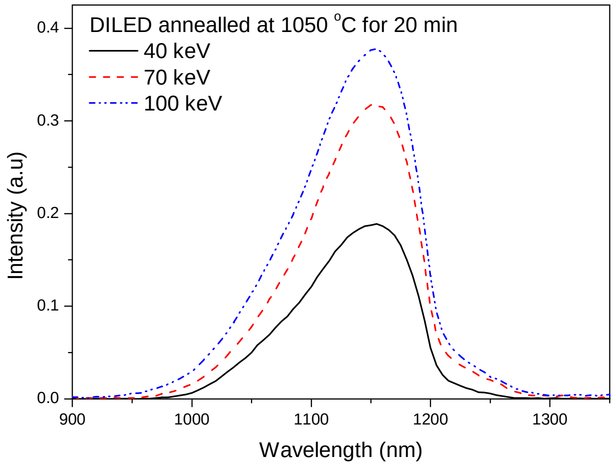

Figure 4: increasing of emitted light intensity with higher implant energy.

The EL of DILED realized with different implantation energy is observed and shown in Figure 4. The light intensity increases as we grow up the implant energy. Higher energy implants, deeper the dislocation loops formed from the surface and then a greater volume of silicon is available for recombination of carriers. It is also means that the surface recombination is limited since the p-n junction is far away from the surface. But the highest EL intensity of DILED in both cases mentioned above is still lower that of DiFLED, where the dislocation loops are not introduced, see Figure 5.

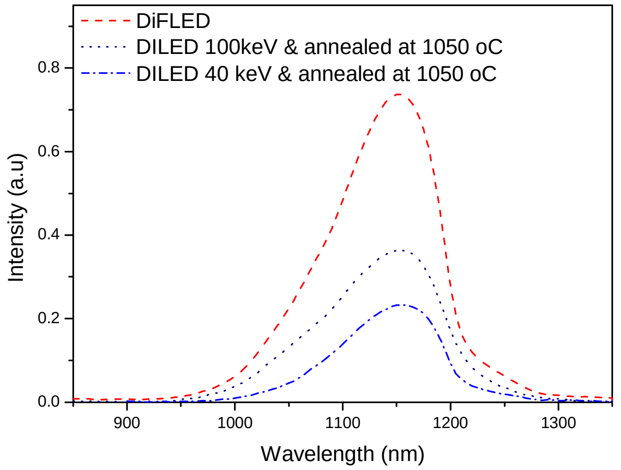

Figure 5: Comparison EL of DiFLED and DIFLED

We can see in Figure 5 that the intensity of emitted light from DiFLED is two times and three times lager than that of DILED fabricated by implantation at energy of 100 keV and 40 keV, respectively. Since the wavelength at the peak in both DILED and DiFLED is the same value of 1154 nm, we can say that in our experiment the dislocation loops did not show any effect in changing the bandgap of silicon to the nature radiative recombination process in the bulk silicon. Moreover, the devices with the dislocation loops show a lower emitted light intensity than that of devices without dislocation loops, so the extended structural defects (dislocation loops) formed in the case of DILED caused the adverse effects while they were supposed to increase the light emission as in [1][2].

IV. CONCLUSION

In our experiment, dislocation loops formed in DILED device inhibited the radiative recombination of carriers and acted as non-radiative recombination centers. The strain field in bulk silicon due to the dislocation loops did not take part efficiently in the spatial confinement of the charged carriers.

In the case of DILED the front side Boron implantation was used to fabricate p+ regions in an n type silicon substrate and also to form dislocation loops, so the dislocation loops formed is always above the p-n junction and not independent of the implanted dose.

By making the junction formation and the formation of dislocation loops independent of each other we could get more information about the role of dislocation loops. This we hope to realise by making p-n junctions by diffusion and the dislocation loops by Si implantation.

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REFERENCES

[1] Wai Lek Ng, M. A. Lourenço, R. M. Gwilliam, S. Ledain, G. Shao & K. P. Homewood, "An efficient room-temperature silicon-based light-emitting diode", Nature, Vol. 410, 192-194.

[2] M. A. Lourenço, M.S.A. Siddiqui, R.M. Gwilliam, G. Shao, K.P. Homewood, "Efficient silicon light emitting diodes made by dislocation engineering", Physica E Vol. 16 (2003) 376-381.

[3] D. J. Stowe, S. A. Galloway, S. Senkader, Kanad Mallik, R. J. Falster, P.R. Wilshaw, "Near-band gap luminescence at room temperature from dislocations in silicon", Physica B 340-342 (2003), 710-713.

[4] N.A. Sobolev, A.M. Emlýanov, E.I. Sjek, V. I. Vdovin, "Extended structural defects and their influence on the electroluminescence in efficient Si light-emitting diodes ", Physica B 340-342 (2003), 1031-1035.

[5] A. M. Emelýanov, N. A. Sobolev, and E. I. Shek, "Silicon LEDs Emitting in the Band-to-band transition region: effect of temperature and current strength", Physics of the Solid State, (2004) Vol. 46, Iss.1, pp. 40-44.

[6] G. Z. Pan and K. N. Tu, "Transmission electron microscopy on {113} rodlike defects and {111} dislocation loops in silicon-implanted silicon", J. Appl. Phys. Vol. 82 (2), 1997.