Electroluminescence evolution of Ge quantum-dot diodes with the fold number

K.T. Chen , **Y. H. Peng** , **C.H. Hsu** , **C. H. Kuan** , **and C. W. Liu**
Department of Electrical Engineering, and Graduate Institute of Electronics Engineering, National Taiwan University, Taipei, Taiwan
ckt.ckt@msa.hinet.net
kuan@cc.ee.ntu.edu.tw

P. S. Chen
Electronic Research & Service Organization, Industrial Technology Research Institute, Hsinchu, Taiwan

Abstract: We observed intensity enchantment and blue shift versus temperature for a LEDs consisting of 30-fold Ge QDs. The diffusion length on p- side is controlled by temperature and will active more QDs at room temperature.

OCIS codes:(230.3670) Light-emitting diode; (060.4510)Optical communications

The self-assembled Ge quantum dots (QDs) promise application for optical communication in 1.3 ~ 1.5 um wavelength because of its possibility of integration on VLSI electronics [1]. In this report, LED consisting of the 5- 10-, and 30-fold p^- Ge QDs was fabricated

The EL spectra for LEDs are shown in Fig. 1. The peaks at around 0.85eV originate from the Ge islands. At 30K, the position and shape of spectra for three LEDs are almost the same. But the 5-fold LED has a slightly red shift while the 30-fold one has a clear blue shift at 300K.

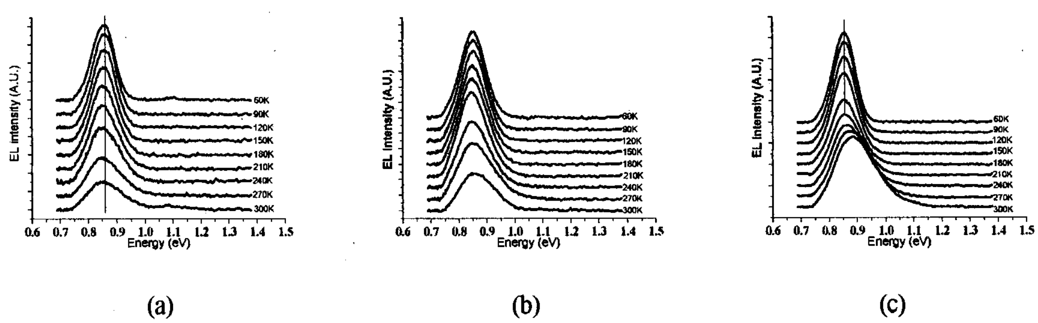


Fig. 1. The EL spectrum of (a) 5-fold, (b) 10-fold, (c) 30-fold MQDs LED at 50mA current injection. The Solid lines indicate the peak position at 30K to reveal shift at various temperatures

We sketched the plot of variation of the EL peak position with temperature in Fig 2. At temperature higher than 200K, the 5-fold QDs show a smaller recombination energy [2]. The relationship between the experimental red shift of the EL of the 5-fold QDs agrees with the band-gap shrinkage as the temperature rises. By contrast, the 30-fold QD tends to show blue shift when temperature is higher than 200K. And the 10-fold QDs is also toward low transition energy around 200K then transfers to a high energy at 250K. Figure. 3 show how the integrated EL intensity of peaks varies with temperature.

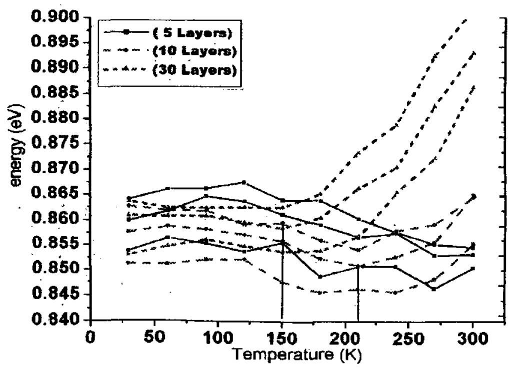
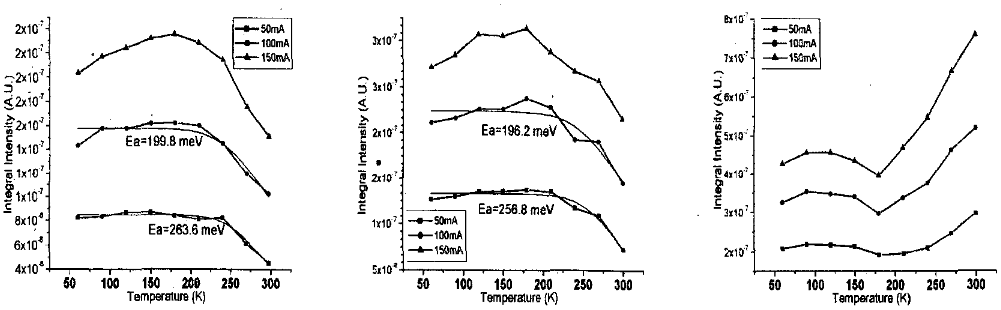


Fig 2. Peak positions of EL spectra at different temperatures for 5-fold (solid-line with square), 10-fold (dashed line with square), 30-fold MQDs (dash line with triangle).



(a) (b) (c)

Fig. 3. Integral intensity of EL spectrum vs. temperature for (a) 5-fold, (b) 10-fold, (c) 30-fold MQDs LED at 50mA, 100mA, and 150mA current injection.

At room temperature, the depletion-region thickness on the p side is 300 nm for the junction of $1x10^{+16}$ cm^{-3} p type doping and $1x10^{+18}$ cm^{-3} n type doping Si in our case. Band diagram is showed in Fig. 4(a). From the TEM, the total thickness of 30-fold QDs is about 900 nm. Therefore, 600 nm of MQDs is still outside the depletion region. Figure 4(b) shows the carrier profile around depletion region. The minority carriers outside the depletion region are dominated by the diffusion length that decreases rapidly at low temperature [3]. And we can conclude that the diffusion lengths are very small at low temperature, and then the radiative recombination only occurs in the depletion region where only the initial layers of MQD exist. Therefore, the EL spectra are almost the same at 30K, and more dots are involved in radiative recombination and then the intensity of EL from the 30-fold QDs enhances.

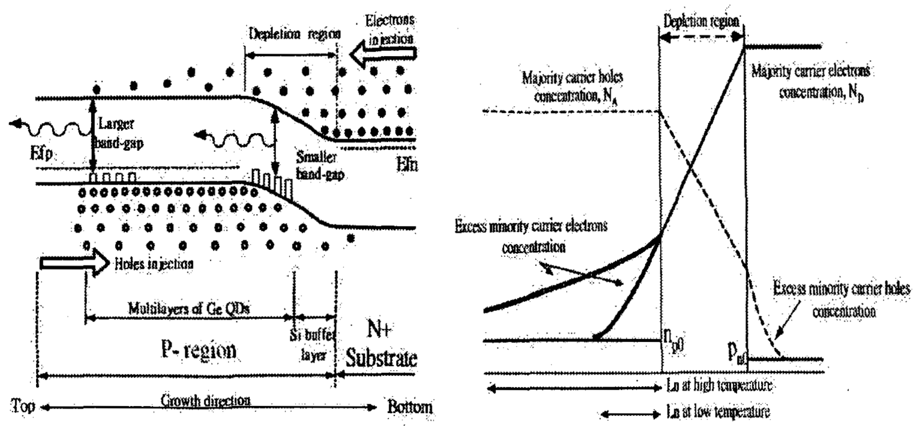


Fig. 4. Simplified band diagram for MQDs diode with p-type doping. Diagram of diffused excess minority electron profile at different temperature.

Therefore, the QDs with higher fold number join the radiative recombination while the temperature increases and causes the blue shift since their bandgap enlarges layer by layer. Fig 5 reveals that the size of QDs intends to saturate layer by layer. Considering the strain field in the QDs and Si spacers, the intermixing between QDs and Si spacer will get higher when more layers of MQDs are grown [4]. Based on these findings, the bandgap becomes larger at the QDs with higher fold number. The result of blue shift and luminescence enhancement at room temperature is reasonable because 30-fold QDs can let more QDs active. By manipulating the diffusion length, the number of the active dots could significantly increase.

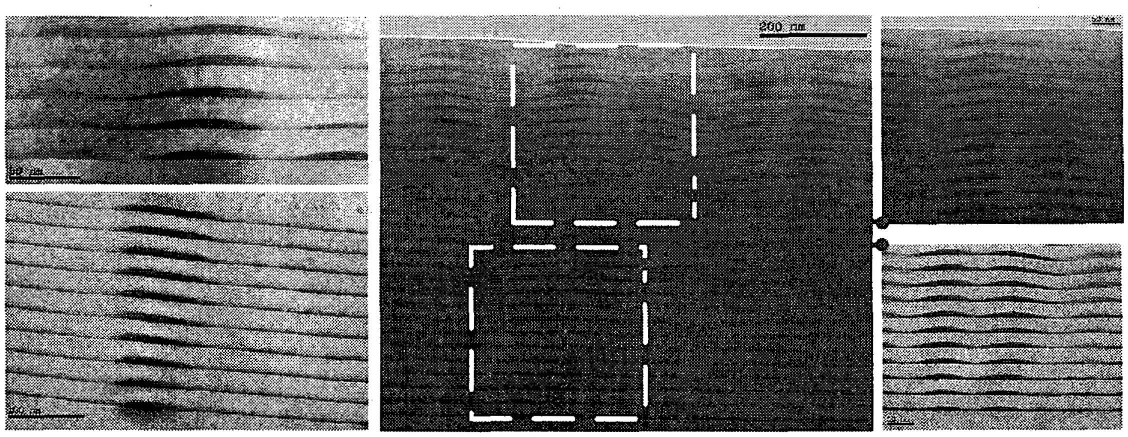


Fig. 5. TEM micrograph of (a) 5-fold, (b) 10-fold, (c) 30-fold MQDs. Figures (d) and (e) are the micrograph for the final and initial layers of 30-fold MQDs. The TEM pictures show the initial layers of 5-fold, 10-fold, and 30-fold MQDs are around 50nm wide and 10nm height.

References:

[1] J. C. Campbell, in "Germanium Silicon: Physics and Materials: Optoelectronics in Silicon and Germanium Silicon", edited by R. Hull and J. C. Bean (Academic, San Diego, 1999) p.347.

[2] L. Vescan, T. Stoica, O. Chretien, M. Goryll, E. Mateeva, and A. Mück, J. Appl. Phys., 87, 7275-7282, (2000)

[3] D. B. M. Klaassen, "A Unified Mobility Model For Device Simulation – II. Temperature Dependence of Carrier Mobility And Lifetime", Solid-State Electronics Vol. 35, No. 7, pp. 961-967, 1992

[4] O. G. Schmidt and K. Eberl, Physical Review B, 61, 13721-13729, (2000)