Annealing effects on photoluminescence spectra of self-assembled multilayer Ge QDs

Quan Lu, Yingjie Ma, Zhenyang Zhong, Xinju Yang, Yongliang Fan, Zuimin Jiang
State Key Laboratory of surface physics and Department of Physics, Fudan University,
Shanghai 200433, China
E-mail of Corresponding Author: zmjiang@fudan.edu.cn

Eleven layers of Ge quantum dots separated by 6 nm thick Si spacer layers were grown on Si(001) substrates at a growth temperature of 550 ℃ by solid source molecular beam epitaxy. In order to improve the photoluminescence (PL) properties of the multilayer Ge QDs, 120 s rapid thermal annealing at 600, 650, 700 and 750 ℃ was carried out in forming gas (H_2:N_2=5%:95%), respectively. The PL spectra measurements were performed at different temperatures with an excitation of 488 nm line of Ar^+ laser.

Figure 1 shows PL spectra measured at 16 K for the as-grown sample and those annealed at different temperatures, a great enhancement in PL intensity was observed for the sample annealed at 700 ℃, which means that point defects formed at the low growth temperature of 550 ℃ could be removed significantly via thermal annealing. However, compared with that of the sample annealed at 700 ℃, the PL intensity for the sample annealed at 750 ℃ is much reduced with a redshift in peak energy, which may imply dislocations generation and therewith a significant strain relaxation at the high annealing temperature of 750 ℃. Figure 2 shows temperature dependence of the integrated PL intensity for the as-grown sample and the sample annealed at 700 ℃. The activation energies are found to be 9, 73 meV and 5, 55 meV, respectively by fitting the curves with the formula shown in the figure caption. Both values are reduced for the annealed sample, indicating a significant increase in dot size and a significant decrease in the band offset between Si and QDs. And thus a significant atomic intermixing might take place at the temperature of 700 ℃. PL peak energy as a function of excitation power is shown in Fig. 3, the blueshift in peak energy with increasing excitation power reflects a type-II band alignment between Si and QDs. Power dependent PL intensities for different samples are shown in Fig. 4, and the coefficients m are calculated according to the formula $I \propto P^m$. The coefficient m for the as-grown sample is found to be 0.46, much smaller than those for the samples annealed. It indicates that the point defects formed at low growth temperatures may have a very different quenching mechanism for PL.

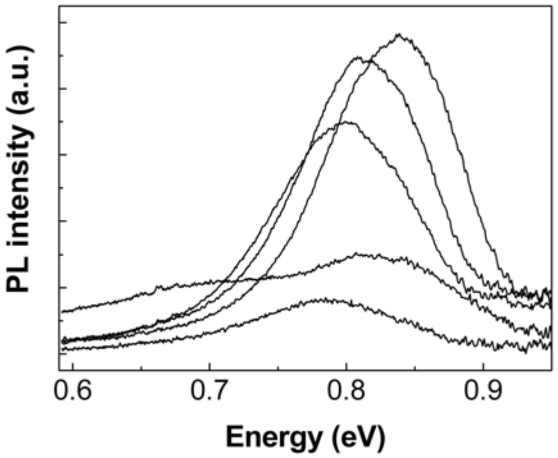

Fig. 1. PL spectra measured at 16 K for different samples. The curves from buttom to top are for the as-grown Ge QDs sample and those annealed at 750, 600, 650, and 700 ℃, respectively.

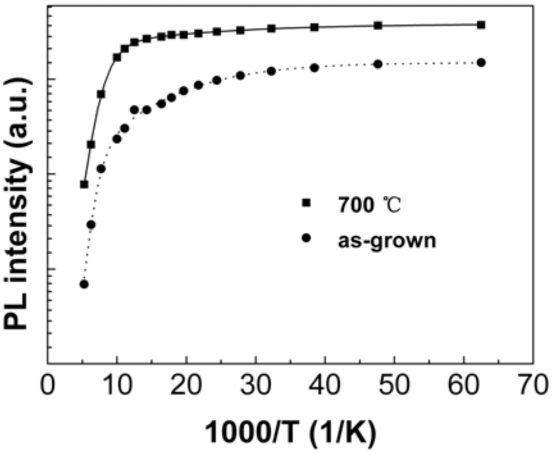

Fig. 2. Temperature dependence of integrated PL intensity for the as-grown QDs sample and that annealed at 700 ℃. The activation energies are found to be 9, 73 meV and 5, 55 meV by the formula $I(T)=I(0)/[1+C_1\exp(-E_1/kT)+C_2\exp(-E_2/kT)]$ for the as-grown sample and the annealed sample, respectively.

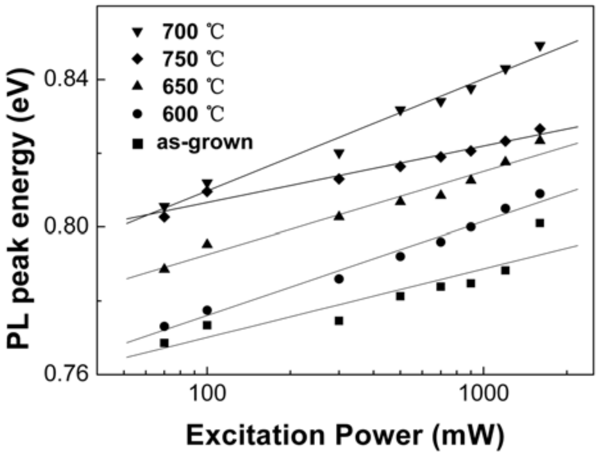

Fig. 3. PL peak energy as a function of excitation power for the as-grown QDs sample and those annealed at different temperatures.

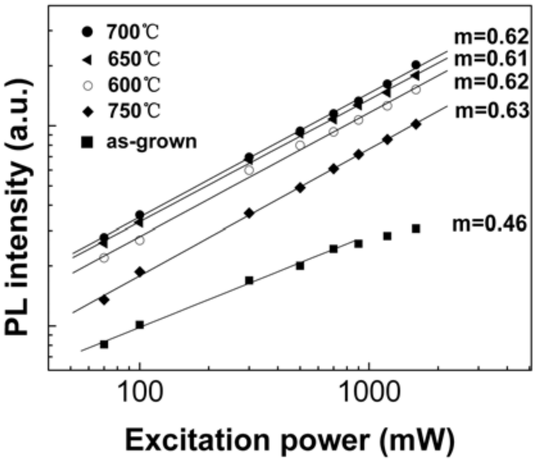

Fig. 4. Power dependence of PL intensity for the as-grown QDs sample and those annealed at different temperatures.