FORMATION AND LUMINESCENCE STUDIES OF Ge/Si CORE-SHELL QUANTUM DOTS

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Si-based quantum dots (QDs) have attracted much attention as an active element in Si-based optoelectronic applications because their light emission properties due to carrier confinement have the potential to combine photonic processing with electronic processing on a single chip. We have focused on CVD formation and characterization of Si-QDs with Ge core and reported their photoluminescence (PL) properties attributable to type II energy-band alignment between the Ge–core and the Si-shell [1-2]. In addition, we have also demonstrated stable electroluminescence in the near–infrared region from diode structures having a 3-fold stacked Si-QDs with Ge core with an areal dot density of $\sim 2.0\times10^{11}$ cm^{-2} under pulsed bias applications [3]. To gain fundamental knowledge and better understanding of the PL properties and to enhance the radiative recombination rate in photoexcited QDs, it would be effective to increase electronic states assisting radiative transition with impurity doping into the QDs and to reduce or not to increase in non-radiative centers if any.
In this work, we have focused on impurity doping to Ge core and post-annealing to evaluate their impact on the PL properties.

A highly dense layer of Si-QDs with Ge core was formed by controlling thermal decomposition of GeH_4 and SiH_4 alternately on thermally-grown ~2.0 nm-thick SiO_2. During the Ge deposition, delta doping of boron and phosphorus atoms in QDs was carried out by pulse injection using 1% PH_3 and 1% B_2H_6 diluted with He, respectively. No changes in dot size and density with either P- or B-doping were confirmed by AFM topographic images.
Under 976 nm light excitation, stable PL signals were observed in the energy range from 0.62 to 0.85 eV at room temperature. From the spectral analysis using a Gaussian curve fitting method, relatively narrow components peaked at ~0.68 and ~0.64 eV were verified with P-doping and with B-doping to Ge-core, respectively, in addition to four components attributable to radiative transitions through quantized states seen in undoped QDs. Based on the previous study on undoped QDs, the ~0.68 eV and ~0.64 eV components can be assigned to the radiative transitions from the P-donor level to the 1st quantized state for holes in Ge core and from the 1st quantized state for electrons in the Si clad to the B-acceptor level in the Ge core, respectively.

With increasing B-doping from 1 to 4 in pulse number, the integrated PL intensity was enhanced by a factor of 2.4 compared to that of the undoped QDs while no significant change in spectral shape except a marked increase of the 0.64 eV component involving the B acceptor level was observable. The result suggests that, increasing in the number of holes confined the Ge core with the addition of B acceptor states is effective to enhance the carrier recombination rates in the type II energy band structure of Si-QDs with Ge core.
In addition, with H_2 post-anneal at 100°C, the integrated PL intensity of the B-doped QDs was reduced by ~35% and the 0.64 eV component disappeared. With increasing post-anneal temperature up to 350°C, the PL intensity was increased to ~1.4 times the initial intensity before post-annealing, and the 0.64 eV component was recovered with no detectable changes in dot size and density as verified by AFM observations. The observed PL changes with post-anneal are attributable to hydrogen-induced passivation of B acceptors at 100°C and thermal dissociation of B-H complexes at 350°C accompanied with hydrogen passivation of residual dangling bond defects.

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References
[1] S. Miyazaki, K. Makihara, A. Ohta, and M. Ikeda, Technical Digest of Int. Electron Devices Meeting 2016, 826–830(2016).
[2] S. Miyazaki, K. Yamada, K. Makihara, and M. Ikeda, ECS Transactions, 80 (4) 167–172 (2017).
[3] K. Makihara, M. Ikeda, N. Fujimura, K. Yamada, A. Ohta, and S. Miyazaki, Applied Physics Express 11, 011305(4pages) (2018).