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Temperature dependence of single quantum dot luminescence: influence of inter-dot coupling

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InAs quantum dots (QDs) grown on InP substrates can be used as sources of single photon and entangle photon pairs in the telecommunication bands. However, molecular beam epitaxy (MBE) growth of the InAs/InP system results in QD ensembles of rather high density (~10^{11}cm^{-2}) and thus photon generation from QDs may be affected by inter-dot coupling among neighboring QDs. In this paper we study the photoluminescence (PL) characterization of single InAs QDs grown on InP(311)B substrates and report a peculiar temperature dependence of single QD luminescence intensities. The observations are well explained with inter-dot carrier transfer through coupled excited states (CES) with correlated electron-hole escape mechanism.

4-ML InAs/$In_{0.53}Al_{0.22}Ga_{0.25}As$/InP(311)B QDs were grown by MBE at 470°C. The samples were etched into pillar structures with 100-nm diameters to select limited number of QDs. One of the pillars was excited with a 632-nm He-Ne laser with the power of 200 nW through an objective lens with NA=0.4. We observed sharp emission lines from individual QDs as shown in the inset of Fig. 1. Temperature dependence of the integrated PL intensities of individual sharp emission is shown for three major lines in Fig. 1. All the three lines show similar tendency but are not simple. For comparison, macroscopic-area PL measurements were performed on the as-grown InAs QD sample. The temperature dependence of the integrated PL intensity is shown in Fig. 2. Below 140 K, the integrated PL intensity is weakly temperature dependent. This suggests that the temperature dependence shown in Fig. 1 is not necessarily due to the change of recombination quantum efficiency.

We have studied the thermal activation energies from the data shown in Fig. 2 and derived two components; one with 22 meV dominating T<140 K and the other with 157 meV dominating T>140 K [1]. In the low temperature region corresponding to that of Fig. 1, we have measured the excited states of the QDs and compared with the thermal activation energy. The latter was almost half of the former, indicating the correlated electron-hole pair transfer from QDs to the neighboring QDs through coupled excited states [1]. Therefore the increase of the single QDs arises with the carrier transfer into the single QD and the decrease with the carrier escape to the neighboring QDs. In this temperature range the average lifetime increases with temperature and the overall intensity decreases with temperature. The mutual relation is quantitatively discussed based on the inter-dot carrier transfer indicated by Fig. 1. This work was supported in part by the SCOPE from the MIAC and Nano-macro materials, devices and systems alliance.

References: [1] N. A. Jahan, C. Hermannstädter, J-H. Huh, H. Sasakura, T. J. Rotter 2013 *J. Appl. Phys.* **113**, 033506.

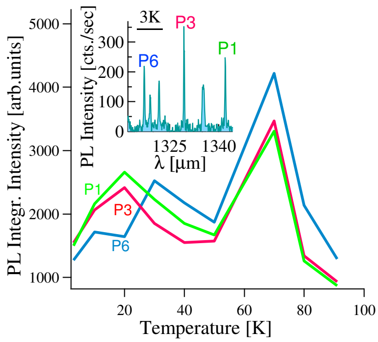

Fig. 1 PL spectrum observed from a 100-nm pillar and the temperature dependence of the integrated PL intensities of three individual sharp emission lines.

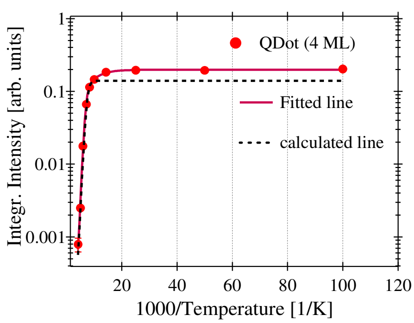

Fig. 2 Temperature dependence of the integrated PL intensity measured on macroscopic-area of QDs. Dashed line is for the purpose of identifying dominant temperature range of the two activation components [1].