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Photon Statistics in a Thick Barrier Coupled Quantum Dot

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1. Introduction

Recent years, single QD and coupled QD (CQD) system have attracted attention as a medium for quantum information processing devices,[1,2] because those maintain a single quantum state which is controllable by the ultrafast optical technique.[3,4] In fact, a quantum logic gate using the exciton-biexciton correlation in a single GaAs/AlGaAs QD has been demonstrated,[5] furthermore, an entangled photon pair emitter consisting of a CQD has been proposed.[6] Although a CQD system is considered to be essential for these quantum information devices,[1,2,7] which are also expected to require the independent control of two QDs constituting a CQD, it's physical property is less well understood. In CQD systems, one of two coupling mechanisms, quantum mechanical coupling and electromagnetic coupling, will dominate depending on the interdot spacing. Although there have been several experimental reports on a CQD system,[8-10] the distinction between the quantum mechanical and the electromagnetic couplings remains matter for discussion.

In this report, we present the photon statistics in a thick barrier CQD and discuss the photon emission process reflecting the dipole-dipole interaction between two QDs. The photon correlation experiment is well known as to be powerful measure for analyzing the competitive nature of exciton emissions in a QD.[11] Although Gerardot *et al.* have already discussed the photon statistics in a CQD,[12] the very thin barrier between QDs, they used in the report, has induced the strong quantum coupling and has made it difficult to analyze the photon emission processes. On the contrary, the CQD used in this report has the thick barrier layer which diminishes effectively the quantum coupling and enables the individual excitation of two QDs.[13] Therefore, the dipole-dipole interaction in a CQD will be discussed more clearly.

2. Experiments and Discussions

Our sample of self-organized InAs QDs was embedded in a GaAs matrix grown by molecular beam epitaxy (MBE), which was the same as one used in our previous work.[13,14] The barrier thickness of the CQD used in this study is 7 nm which sufficiently weaken quantum mechanical coupling as to neglect carrier transfer between QDs.[14] A single CQD was observed through an aluminum aperture mask fabricated on the sample surface.

Figure 1(a) shows micro-photoluminescence (μ-PL) spectrum from a single CQD. Two QDs (QD1 and QD2) constituting the CQD are individually excited at their unique energy levels because of negligible carrier transport between these QDs due to the thick barrier layer. As mentioned in our previous report,[13] a co-excitation of both QD1 and QD2 leads a noticeable phenomenon related to the interdot interaction, in which the PL intensity under two-color excitation condition is dramatically increased coming up to ten times compared with ones under one-color excitation (see Ref. 13). This feature is typical phenomenon for the weak coupled QDs (d = 7 nm) and is expected to arise from the dipole-dipole interaction between two QDs.[13]

We have investigated the more detailed emission process in the weak coupled QDs by means of the observation of a photon statistics. Firstly, we confirm the single photon emission from each QD constituting the CQD. We employed the experimental system of the photon correlation measurements pursuant to Hanbury-Brown-Twiss setup.[11] We used two monochromators in order to select the photons from an arbitrary QD (QD1 or QD2), respectively, which were leaded toward the single photon detectors. By means of start and stop signals from detectors, the time correlated counting board outputs the second-order photon correlation spectrum: $g^{(2)}_{\alpha,\beta}(t)=\langle I(t)I(t+t)\rangle/\langle I(t)\rangle\langle I(t+t)\rangle$, where the suffix α (β) indicates the selected QD as a start (stop) signal.

Figure 1(b-c) shows the auto photon correlation spectra of the QD1 and QD2 under the one-color excitation condition, where two QDs were individually excited at their unique excited levels. Both spectra exhibit the dip structures around the delay time DT = 0. These observations originate from the photon anti-bunching which evidences the single photon emission from each QD constituting the CQD as the case of a single QD in previous reports.

On the other hand, the cross photon correlation spectrum $g^{(2)}_{12}$ between QD1 (start signal) and QD2 (stop signal) under the two-color excitation is presented in Fig. 2. Remarkably, the spectrum $g^{(2)}_{12}$ exhibits the wide anti-bunching structure with long recovery time up to 4~5 nsec. This observation is attributed to the enhancement of the relaxation to the ground excited states by additional relaxation paths, such as quasi-biexciton states, that are allowed due to the dipole-dipole interaction between excitons in two QDs.

3. Summary

We have presented the correlated photon emission in an InAs/GaAs CQD with a thick barrier layer. The second-order cross photon correlation spectrum between two QDs exhibits the wide photon anti-bunching and indicates the enhancement of the exciton energy relaxation due to the dipole-dipole interaction between QDs. The detailed discussion will be mentioned in the session.

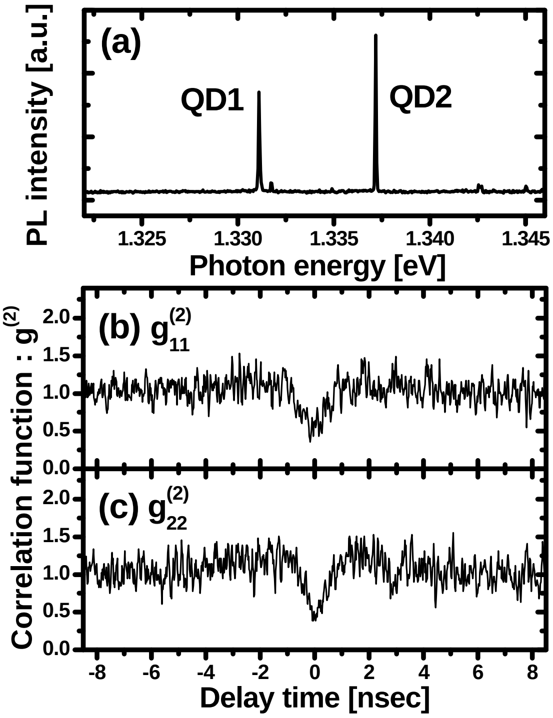

Fig. 1. (a) Low-temperature μ-PL spectrum of the thick barrier CQD. (b-c) Auto photon correlation spectra of QD1 (b) and QD2 (c).

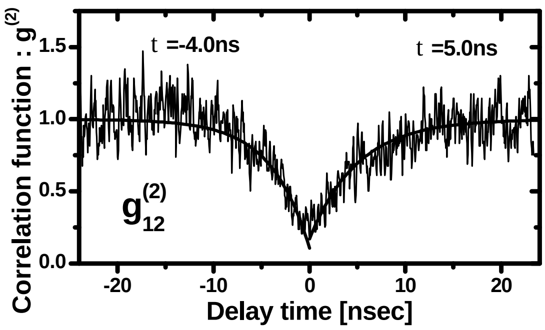

Fig. 2. Cross photon correlation spectrum between QD1 and QD2 under the two-color excitation condition.

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