# Direct Comparison of Biexciton Binding Energy in a Quantum Well and Quantum Dots

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**Abstract.** Periodic oscillation is observed in transient four-wave mixing signal in strain-induced GaAs quantum dots. The oscillation is assigned to biexcitonic beat based on its polarization dependence and its initial phase, and the biexciton binding energy is deduced. Since strain-induced dots are produced by adding lateral confinement to a quantum well, direct comparison of the biexciton binding energy in 2D and in 0D system is possible. The beat period in quantum dots is found to be shorter than that in quantum well, and the enhancement factor by the reduced dimensionality is 1.5. Magnetic field dependence of the biexciton binding energy is also studied. It is independent of the magnetic field up to 8 T, and exciton g-factor in the strain-induced dots is obtained.

Strain-induced quantum dots (SID) are formed in a single quantum well (QW) by introducing additional lateral confinement in the plane of the QW by stressors grown on the top surface of the QW [1]. In this kind of quantum dots (QD), almost parabolic confinement potential is realized, providing unique properties such as equally-spaced energy levels. In addition to the characteristic optical properties, SID is useful in itself to investigate the different dimensionality between 2D system and 0D system, because QW and SID are in the same sample and they are quite identical except their dimensionality. In this work, we discuss the enhancement of the biexciton binding energy due to the three-dimensional spatial confinement in QD by using GaAs SID. The effect of the additional lateral confinement is directly revealed by comparing a biexcitonic beat in degenerate four-wave mixing (FWM) from QW and that from SID. Later part of the paper is devoted to describing the effect of magnetic field on the FWM signal.

The GaAs SID studied here were formed in a single GaAs QW of 3.8 nm in width using InP stressors of 90 nm in diameter. The areal density of the stressor was $3*10^9$ /cm$^2$. To detect very weak FWM signal from SID, we have constructed heterodyne detection system by using two acousto-optic modulators and a spectrum analyzer [2,3]. This system allows us to measure FWM signal even from single layer QD. The sample was kept in a magnetocryostat, and the magnetic field, B, was aligned perpendicular to the QW plane.

In Fig. 1(a), a photoluminescence spectrum of the sample at 2 K is shown. The weak peak centered at 1.647 eV is due to the GaAs QW, while the intense peak centered at 1.600 eV originates from the GaAs SID. Time-integrated FWM signals under B = 0 T are plotted in Fig. 1(B). At 2 K, the decay curve of the FWM signal from SID excited by co-linearly polarized pulses consists of a single exponential decay with a decay time of 12 ps and a clear damped oscillation with a period of 1 ps. The FWM signal from QW has shorter decay time and longer beat period. The corresponding dephasing time of 24 ps in SID seems rather short for 0D system at low temperature. The short dephasing time in SID may be explained by 1 near surface impurity states"[4]. The beat is explained by the exciton-biexciton beat in SID, and biexciton binding energy can be deduced. This assignment was confirmed by measuring polarization dependence of the beat signal. When SID was excited by two pulses of the same circular polarization, the beat disappeared as shown in the inset of Fig. 1(b). This fact strongly supports our assignment, because

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biexciton should be excited by two photon of the opposite circular polarization [5]. The initial phase of the beat, minimum at time origin, also supports this assignment [5]. The beat period in QW was 1.5 times longer than that in SID. From these results, we can conclude that the biexciton binding energy was enhanced 1.5 times by the additional 2D lateral confinement in the SID.

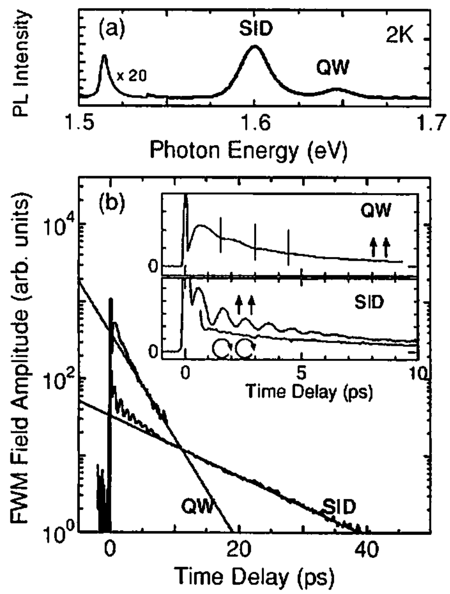


**FIGURE 1.** (a)Photoluminescence spectrum of the sample at 2 K. (b) FWM signal in QW and SID in logarithmic scale. Inset: Initial part of the FWM signal in linear scale.

Next, FWM signal was measured under magnetic field in Faraday geometry at 10 K. It is known that the exciton binding energy is enhanced in the magnetic field. The biexciton binding energy is also expected to increases in magnetic field, but the beat period in SID does not change up to 8 T as shown in Fig. 2(a), although the beat disappears more quickly in strong magnetic fields. Response on the magnetic field is evaluated by the ratio between the spatial extent of biexciton wave function and magnetic length. As mentioned above, biexciton binding energy is remarkably enhanced by the additional lateral confinement, whose diameter is rather large (~ 90 nm). At B = 8 T, the corresponding magnetic length is as small as 9 nm, however, magnetic field does not change the biexciton binding energy at all. Similar independence of biexciton binding energy on the magnetic field was reported on InGaAs QWs[6].

Another beat was observed in the later part of the signal as shown in Fig. 2(b). In contrast to the biexcitonic beat, the period of the slow oscillation depend linearly on the magnetic field. The beat originates from Zeeman splitting of excitons in SID, and g-factor was found to be 0.64, which is consistent with the g-factor of excitons in SID measured by time-resolved luminescence [7]. In time-resolved luminescence measurements, strong scattering light prevent us to excite ground state resonantly. Since, in FWM measurement, resonant excitation is easily possible, it can be useful tool to investigate spin dynamics in QD in addition to the coherent dynamics of excitons.

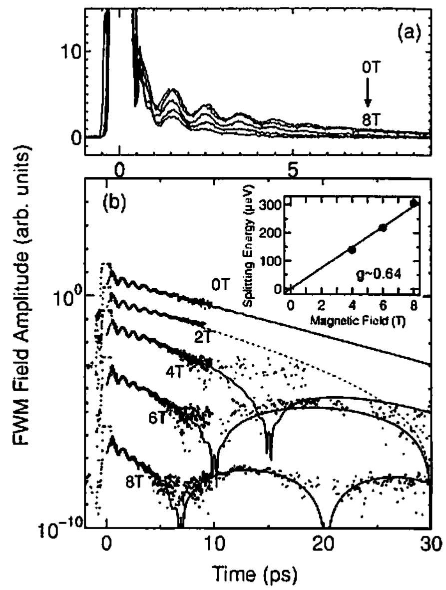


**FIGURE 2.** Magnetic field dependence of FWM signal in the GaAs-SID. (a) Initial part in linear scale. (b) Decay curve in logarithmic scale. Inset: Splitting energy as a function of applied magnetic field.

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