Four-wave mixing in InAlGaAs quantum dots

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have some intermediate separation. They cannot be very close together—due to level repulsion—and cannot be too far apart either—due to the finite linewidth.

References

QM5 Fig. 1. Luminescence of quantum dots and laser spectrum used in the FWM experiment.

QM5 Fig. 2. Four-wave mixing signal from InAlGaAs quantum dots at 5 K. The inset shows comparison to a reference GaAs sample without dots.

The non-linear optical properties of semiconductor quantum dots are of interest, both fundamentally and for potential device applications. Large optical non-linearities are predicted due to the three dimensional confinement but the small active volume of the dots and their large homogeneous broadening strongly reduce the interaction with the electromagnetic field. Until now, four-wave mixing (FWM) in III-V quantum dots has only been reported in non-resonant amplifiers at room temperature, where the interaction length is increased by waveguiding in the quantum dot plane.

We have carried out degenerate FWM experiments in a slab geometry on a sample containing 10 layers of MBE-grown In$_{0.53}$Al$_{0.47}$GaAs quantum dots (QDs) with 50-nm Al$_{0.5}$GaAs barriers. Ground-state photoluminescence emission from the dots occurs at 1.385 eV with an inhomogeneous broadening (FWHM) close to 80 meV as shown in Fig. 1.

The spectrally integrated FWM signals of the QD sample and a GaAs reference sample measured at 5 K are shown in the inset of Fig. 2. The signals are dominated by strong peaks at $\tau = 0$ and at multiples of the pulse roundtrip time through the sample. These strong peaks are due to a two-photon transition to the GaAs substrate material and is repeated for each reflection of the excitation pulses. However, the FWM signal due to the dots is clearly visible between the sharp peaks and is shown on an expanded scale in Fig. 2. For positive delays, the four-wave mixing signal decays exponentially over more than one order of magnitude with a time constant of about $11 \pm 1$ ps, corresponding to a dephasing time of $T_2 = 46 \pm 4$ ps under the assumption of a photon echo. The negative delay signal is caused by FWM due to the reflected probe light and the delayed pump.

The maximum QD FWM signal was observed on the high energy side of the QD luminescence peak corresponding to the laser spectrum shown as a dashed curve in Fig. 1. The signal intensity reduces to below our detection limit around the center of the PL peak due to the reduced density of dot states. Similar results were obtained for FWM in CdSe/ZnSe islands.

Using microphotoluminescence spectroscopy on a single-layer sample of similarly prepared quantum dots, we have measured the homogeneous linewidth of photoluminescence lines arising from individual dots with a spectral resolution of 20 meV. Fig. 3 shows a Lorentzian fit to four individual PL lines and the statistical distri-
bution of FWHM linewidths does not vary with energy across the quantum dot ensemble. The ensemble buphasing time measured in the FWM experiment corresponds to a homogeneous linewidth of 2kT, = 30 μeV, which agrees well with a typi-
cal single-dot PL linewidth.

We will also discuss the power and tempera-
ture dependence of the QD homogeneous
linewidth as well as the dependence of detuning
corrected for the spectrometer response. This dis-
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Fig. 1. PL spectrum of InAs QDs in In_{0.7}Ga_{0.3}As quantum well.