Temperature dependence of quantum dot homogeneous linewidth

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Abstract: We examine the temperature dependence of the ground state homogeneous linewidth in InGaAs/GaAs quantum dots. Measurements using a high-resolution spectral hole burning technique are performed on quantum dots in a semiconductor waveguide.

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Self-assembled semiconductor quantum dots (SAQDs) have been studied extensively as model two-level systems as well as for their potential device applications. The homogeneous lineshape of the SAQD optical transition in this system is of particular interest as it contains valuable information relevant to the practicality of coherently controlling the excitonic-carrier population in SAQDs. Due to the extremely broad inhomogeneous lineshapes in SAQD ensembles, linear optical measurements have difficulty resolving the relatively narrow homogeneous linewidth buried beneath them. As a result, measurements to date have been carried out on either a single dot level [1, 2] or in the time domain, by measuring the decay of the 'photon echo' after ultrafast excitation [3].

In this report, we discuss measurements of the SAQD ground-state homogeneous linewidth using CW collinear spectral hole burning. The samples employed in these studies consists of a single layer of InGaAs/GaAs SAQDs embedded in an undoped semiconductor ridge waveguide. This technique permits radiatively limited coherence time (T_2) to be measured [4]. Fig. 1 shows a schematic of the experimental setup for the collinear spectral hole burning measurement. The SAQDs have a ground state transition wavelength of 1010 nm with a full width at half maximum (FWHM) of approximately 50 nm at a temperature of 10 K.

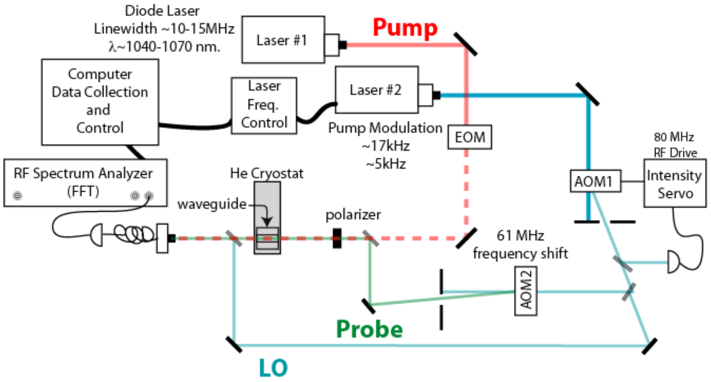

Fig. 1: Show a schematic of the collinear pump-probe experiment. The waveguide sample is placed in a modified liquid helium flow cryostat capable of temperatures down to 10 K.

These measurements are performed by coupling two narrow frequency sources into the SAQD waveguide (the laser linewidth is less than 200 kHz). The first source remains fixed in frequency and acts as a pump, burning a spectral hole in the SAQD inhomogeneous line. A probe beam generated by the second laser is swept in frequency across the hole burned by the pump, and the differential transmission due to the presence of the saturating field is recorded. Essential to this technique is the ability to measure the amplitude of the probe beam independent of the stronger pump beam present in the same mode of the SAQD waveguide. This is accomplished by combining the output of the waveguide with a local oscillator (LO) beam at a fixed frequency offset to the probe. The heterodyne beat between the probe and reference beams is free from contamination by the pump and can be detected with a radio frequency spectrum analyzer. In addition to separating the probe signal from the background, the reference beam provides amplification for the probe beam.

Using this technique we examine the variation of the observed homogeneous linewidth as a function of temperature. Fig. 2(a) show temperature dependent spectral hole data of the SAQDs at a fixed pump power of approximately 20 pW from 10 to 21K at an excitation wavelength of 1064 nm. Fig. 2(c) shows the temperature dependence of the differential transmission peaks FWHM. Even over the narrow temperature range considered there is a clear increase in the homogeneous linewidth. In addition, all of the traces in Fig. 2(a) display a clear Lorentzian lineshape. Panel (b) of Fig. 2 shows that even at the highest temperature examined in this low pump power regime the spectral hole lineshape remains Lorentzian. While the signal to noise ratio at 20 pW of pump power limits the temperature range considered in these initial measurements, data taken with higher pump fluence permit examination of a greater temperature range up to approximately 50 K. Fig. 2(d) shows preliminary differential transmission data taken at a pump power of 470 pW over a temperature range of 20 to 30 K. Despite the presence of significant power broadening in comparison to the data in panels (a) and (b), the lineshape at 20 K remains Lorentzian. However, at 30 K the data begin to deviate from the Lorentzian behavior seen at lower temperatures. Initial studies of the power broadening behavior of the spectral hole signal at these elevated temperatures indicate that the technique used here will allow the temperature dependence of the SAQD homogeneous linewidth as well as the deviation of the line shape to be mapped. In addition to these measurements, we have performed an initial search for changes in the homogeneous linewidth as a function of wavelength, allowing us to examine different subensembles of SAQDs.

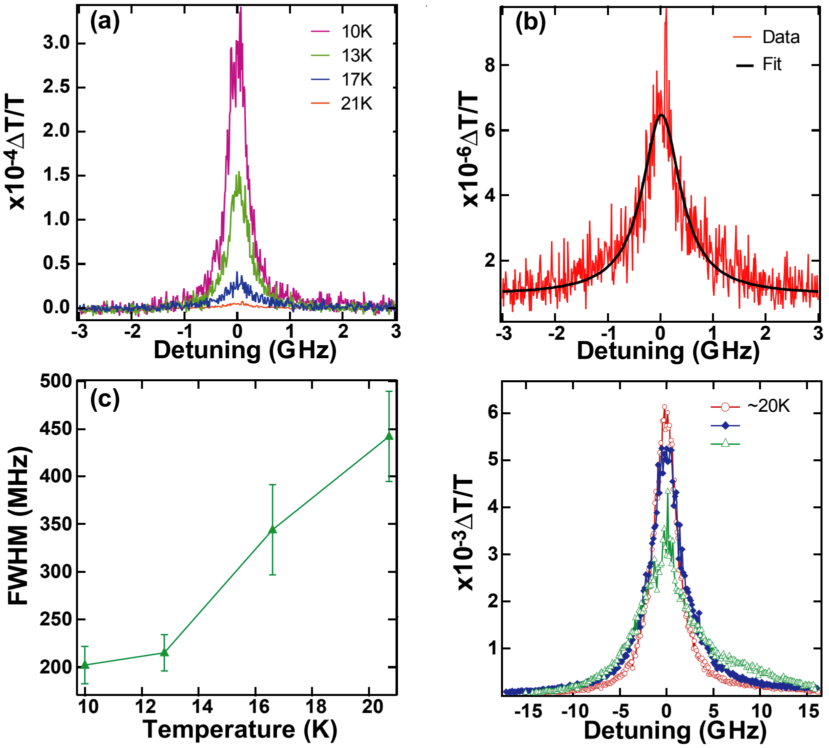

Fig. 2: Panel (a) shows spectral hole burning differential transmission data taken with 20 pW pump power over a 10 K temperature range. Panel (b) shows 21 K data taken at 20 pW pump power along with a Lorentzian fit to the data. Panel (c) shows the FWHM linewidth for curves in panel (a). Panel (d) shows differential transmission data with pump power of 470 pW taken between 20 and 30 K.

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