Optical Saturation of QW Intersubband Transitions in the Valence Band

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***Abstract*— Intersubband transitions in the valence band of AlGaAs /GaAs quantum wells have been saturated using a pulsed mid-infrared tunable laser. The quantum wells have a complex structure that engineers the transition to be much sharper than a normal valence band transition. Two samples were studied with their transitions at wavelengths 7.8µm and 6.8µm respectively and the saturation intensities recorded for each, thus allowing their valence band population lifetimes to be calculated.**

***Index Terms*— Holes, Optical saturation, Quantum wells, Valence Band**

I. Introduction

Intersubbannd transitions (ISBT) in quantum wells (QWs) have been studied for many years; however much of this work investigated only the conduction band of the wells. In the conduction band the energy gap between levels of the QW are almost independent of electron in-plane momentum, leading to strong transitions with small linewidths (6-20meV). AlGaAs/GaAs valence band levels are more complicated than the conduction band case and this results in a broadening of the valence band transitions, reducing their absorption strength and making probing of individual transitions difficult[1]. Recently a well structure was created using a 'digital alloy' as the barrier[2]. The digital alloy consists of ~1nm layers of GaAs and AlAs creating a superlattice structure. The AlGaAs/GaAs QWs were carbon doped and showed sharp heavy-to-heavy hole transitions at low temperatures (Fig. 1.). The linewidth and strength of absorption can be seen to rival those of a conduction band QW.

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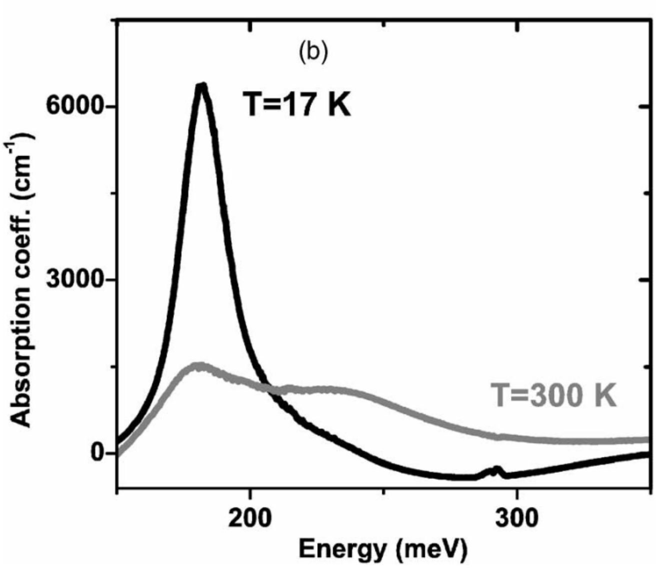

Fig. 1. A Valence intersubband QW absorption as shown in [2]. Whereas a conduction band transition is only slightly dependent on temperature, here the dependence is dramatic. The linewidth at 17K is 23meV.

This work is a study of two valence band QWs. The high intensities provided by our laser allow us to optically saturate the QWs valence intersubband transitions and characterise the sample's hole population relaxation time.

II. Optical Saturation

A. Theory

When the electrons are excited by absorbing a photon, the fastest relaxation route is often non-radiative. A good way to measure this electron/hole relaxation time (τ) is to optically saturate the transition[3,4]. The intensity of the light is increased until the excitation rate becomes comparable to the relaxation rate; this causes the upper level occupation to increase and the absorption coefficient to tend to zero. The absorption coefficient saturates according to:

$$\alpha(I) = \frac{\alpha_0}{1 + I/I_{sat}} \tag{1}$$

where I_{sat} is the saturation intensity and α_0 is the absorption for low intensities of light. Note that actual extraction of I_{sat} from the experimental results requires a numerical model of the beam's non-unifrom profile and its propgation through the sample. Knowledge of I_{sat} then allows the calculation of τ.

B. Experimental Details

For this case of a heavy hole to heavy hole transition, the selection rules for absorption require the light to be polarized perpendicular to the plane of the well, the same as a conduction band ISBT. We use a multi-bounce geometry used is a rhomb geometry[2] where the light bounces through the structure at 45^{o} to the plane of the wells using total internal reflection.

The first sample has its transition at 6.8 µm; its spectrum can be seen in fig. 1. and it corresponds to the QW with width 3.1nm in [2]. The sample contains 50 wells in order to get significant absorption. The second sample has its transition at 7.8µm and only has 25 wells; it corresponds to the 3.7nm wide well in [2].

The light used to saturate the transitions is generated by an optical parametric generator (OPG)[5] that down-converts 2.8 µm laser light to signal and idler beams that are tunable across the region 4 - 9µm. The 2.8 µm laser is flashlamp pumped at 3Hz and outputs intense 90ps long pulses.

In order to measure the saturation intensity, a detector measured the beam strength after the sample and calibrated filters were placed in various combinations either side of the cryostat containg the sample (at 17K). Calibration of the energy and size of the idler beam at sample position was necessary to calculate the intensity at the position of the sample. Intensities reached ~1GWcm^{-2}.

For one of the samples, polarisers were used to measure the transmission for orthogonal polarizations; since the sample only absorbed one polarization of light, the absolute absorption could be determined from the ratio of transmitted P-polarisation to S-polarised light.

C. Results

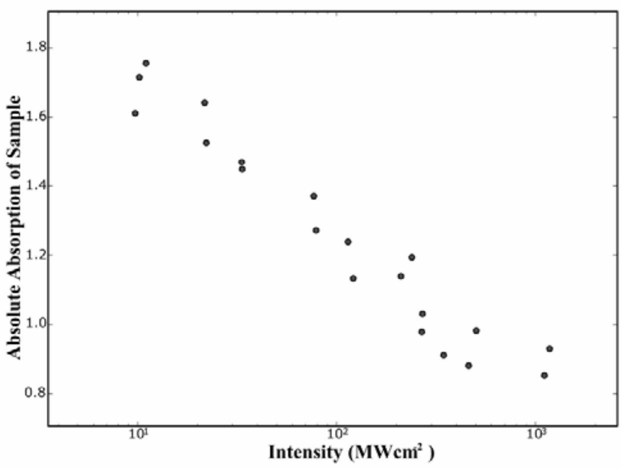

Fig. 2. The optical saturation of a valence band intersubband transition for a AlGaAs/GaAs QW. The transition's wavelength was 7.8µm. The intensity is the peak intensity of the laser pulse just outside the sample.

Both samples investigated were successfully saturated. Fig. 2. shows the saturation curve of the second sample. The results are being fitted using the numerical model and from the saturation intensities of the samples we shall extract the population relaxation lifetimes. The results will be presented at the conference.

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