Raman Lasing and Femto-Second Intersubband Relaxation of coupled GaInAs/InAlAs QWs

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***Abstract*— Raman lasing is investigated in a three level intersubband sytems (IS) of coupled double quantum wells (DQW). Our results are correlated to the intersubband relaxation of the upper lasing state determined from femto second pump and probe experiments. We observe short upper lifetime of less than 1 ps and considerable carrier heating when the carriers thermalize to the groundstate. These observations support our understanding that no population inversion builds up in such IS systems. Thus, Raman tuning persists over the entire tuning range across the resonance.**

***Index Terms*—optical pumping, three level system, intersubband relaxation, GaInAs/InAlAs quantum well**

In this letter we discuss results obtained on two kind of GaInAs/AlInAs DQW structures, both grown by molecular beam epitaxy on undoped 100-oriented InP substrate, but with/out strained layers. The active region consists of 60 periods of DQWs separated by a 3nm thick AlInAs barrier, n-doped at 3 10^{17}cm^{-3}. Each DQW is composed of 4.7nm (5nm) GaInAs, 1.0nm (1.2nm) AlInAs and 3.5nm (3.8nm) GaInAs embedded into undoped 3.5nm and 3.0nm wide AlInAs spacer barriers. The parenthesis are for the corresponding thicknesses of the strained part of structure B (strain is ~ 0.5%). The 1.1 µm thick active region is embedded into a waveguide structure made of a 0.6µm thick GaInAs cladding layer, a 50nm AlInAs core layer, and on top, a 50nm AlInAs core layer and a 1.1µm thick GaInAs cap layer.

Figure 1 shows the shift of the lasing emission energy (E_L) for tuning of the excitation energy of the pump laser generated by parametric generation in a periodically pooled (PP) Li-Niobate crystal. The wavelength is tuned by setting the temperature of the crystal between 50ºC and 200ºC or by using PP elements with different period. The IR pulses are focused on part of the ~150µm thick substrate-slab wedged at 45º. The direction of incidence is aligned with the cavity, which is defined by the cleaved edges. Pulse energies on the sample surface were of typically 1 µJ, the pulses 400ps long and repetition-rate 1 kHz. The emission spectra were resolved

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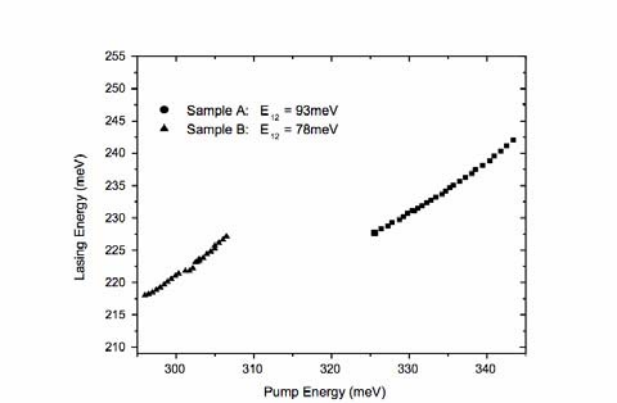

Fig. 1: Raman shifted laser energy for sample A and B.

by a grating spectrometer carefully purged by dehydrated Nitrogen. The dependence on the excitations energy (E_{EX}) for both samples, follow $E_L = E_{EX} - E_{12}$, where E_{12} is the respective energy of the intersuband transition between level 1 and 2. The center of the tuning curve coincides with the peak position E_{13} measured by linear absorption. The tuning range is of order of the FWHM of the E_{13} absorption line, see Figure 2. This observation, supported by calculations based on Eq. 1 of Ref. [1] suggests that the optical gain due to population inversion (PI) in these samples is vanishing. Otherwise, gain would be dominated by PI and the emission energy clamped

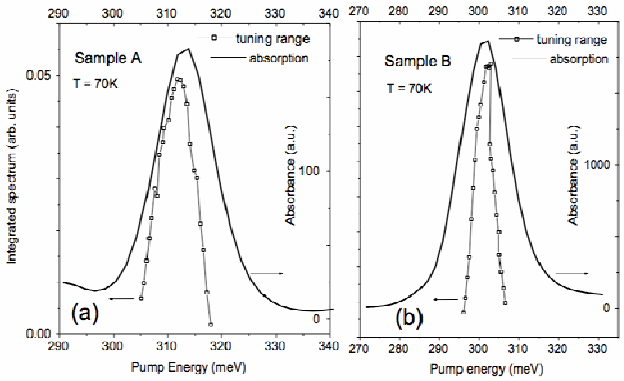

Fig. 2: Laser intensity (dotted line) versus pump energy. Y-axes to the left: measured linear absorbance.

to exactly E_{23}.

To understand the lack of the population inversion gain we

investigated the dynamics of level populations employing femto second pump and probe spectroscopy. Excitation was provided by ~150 fs long laser pulses obtained from the difference frequency generated in an ($AgGaS_2$) crystal by the signal and idler of a parametric oscillator which has been driven by a Ti:sapphire regenerative amplifier running at 1 kHz. Spectra of the probing pulse are dispersed in a grating spectrometer and detected by a LN2-cooled 64-channel MCT detector.

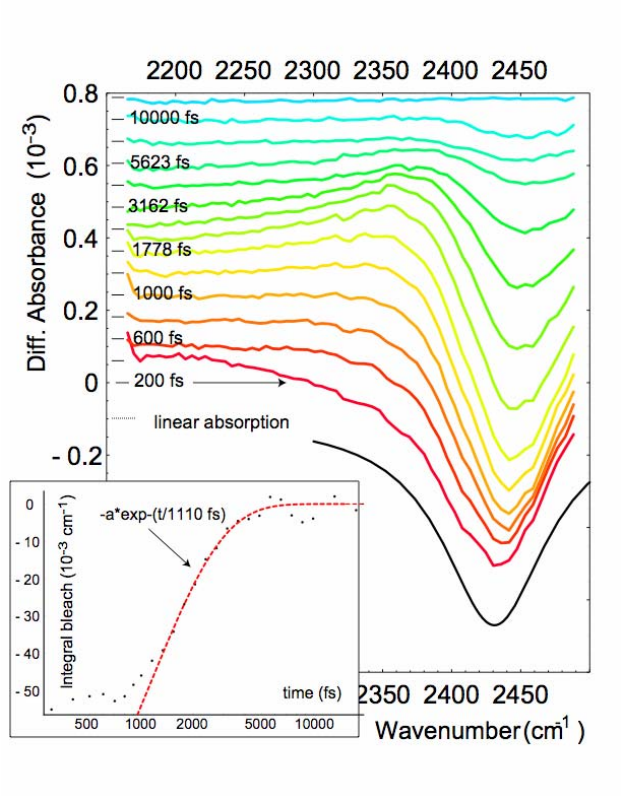

Fig. 3: Time resolved pump-probe difference spectra of sample B. Each of the curves are shifted by +0.06 units for clarity. The linear absorption, bottom curve, is shown for comparison. The inset gives the time dependence of the integrated intensities on a lin-log scale. From the fit to the data points for t > 1300 fs, the relaxation of the carriers from the excited intersubband level 3 all the way down to the groundstate in thermal equilibrium is found to be ~ 1.1 ps.

Figure 3 shows time resolved difference spectra of probing pulses, obtained in single pass of the DQW sample B set at Brewster angle. Note that the curves are shifted successively by +0.06 units for clarity. We observe that immediately after excitation (t_{delay} ~200 fs) the difference signal which consist of the reduced absorption, i.e. bleach, and the stimulated emission (SE) reproduces the linear absorption, cf. first curve from below in Figure 3. Shortly after, at t_{delay} ~1 ps, the low energy tail of the signal has "recovered", while its peak has further (slightly) decreased. At even later times, $t_{delay} \geq 3$ ps, the difference signal starts to disappear, and the groundstate population approaches thermal equilibrium [2]. Final cooling to the lattice temperature of 70 K for the experiment shown in Fig. 3 is achieved when $t_{delay} > 10$ ps. To separate cooling from carrier relaxation, the time dependence of the integral over the spectra is analyzed, see inset of Figure 4. From the fit to the data points of Fig. 4 inset, we obtain, that the relaxation to the groundstate in thermal equilibrium takes ~1.1 ps. The relaxation from subband 3 to 1 (or 2) consequently is shorter because the 1.1 ps also includes the intraband scattering (by phonon emission and electron-electron (e-e) scattering) of the electrons from the highly excited k-states in subband 1. During this process, part of the remaining ground-state electrons are excited out of the still cold Fermi-sea which explains the decrease of the signal (i.e. increase of the bleach) at the short time. The transfer of electrons out of level 3 leads to a reduction of the SE which seemingly almost counterbalances the increase of the bleach. Detailed analysis of the data at these short times will allow to extract the ratio between phonon and Auger type e-e scattering. The latter should not be neglected as by change, the electron density of 0.9 10^{11} cm^{-1} is large enough to make e-e interaction appreciable but low enough that screening is not yet important [3].

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REFERENCES

[1] M. Troccoli et al. Nature 433, 845 (2005).
[2] for a review see: T. Elsaesser, "Ultrafast Dynamics of Intersubband Excitations in Quantum Wells and Quantum Cascade Structures" published in McGraw-Hill, Nanoscience and Technology Series: "Intersubband Transitions in Quantum Structures", edited by R. Paiella, p. 135ff (2006).
[3] K. Kempa et al., Phys. Rev. B 61, 11083 (2000).