RAMAN LASING AND FEMTO-SECOND INTERSUBBAND RELAXATION OF COUPLED GaInAs/InAlAs QUANTUM WELL'S

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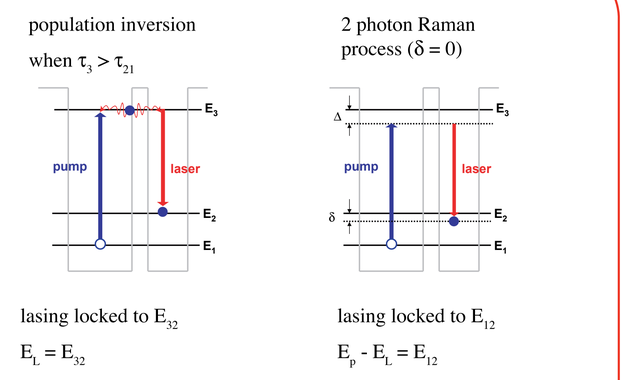
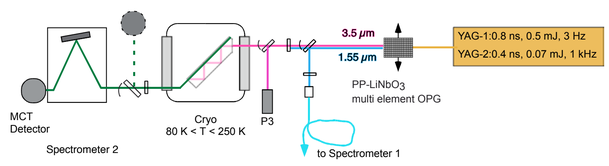
Motivation:

- study of resonant RAMAN intersubbband lasing [1]
- competition population inversion versus 2 Photon Raman [2]
- study relaxation paths
- benchmark for SiGe based quantum cascade laser [3,4]

1. prev. investigations on GaAs/AlGaAs system: F.H. Julien et al. (1999) and HC. Liu et al. (2001, 2003).
2. model calculations: A. Belyanin (2006)
3. determination of optical gain in Si based QCL: S. Tsujino et al. (2005)
4. SiGe quantum wells for optical pumping: M. Scheinert, thesis (2007)

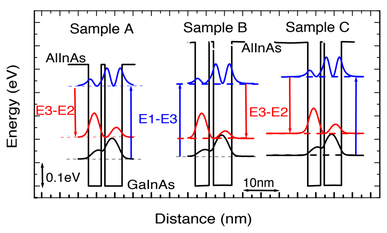


Experimental Set-Up



PPLN OPG excited by pulsed YAG	
YAG laser	System-1: RGA; System-2: Microchip laser
Tuning	4.5 μm – 3 μm
Peak Energy	1 – 20 μJ
Pulse length	400 ps (S-2) – 800 ps (S-1)
Linewidth	~ 1 meV (<< 1 cm^{-1} when SEED)
Focus diameter	~ 100 μm

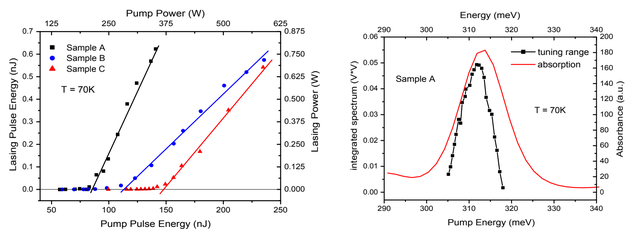
AlInAs/GaInAs DQW



E_{12}	75 meV – 95 meV
E_{13}	310 meV – 340 meV
E_{23}	220 meV – 240 meV
G	~ 10 meV
Z_{12}	~ 23 Å
Z_{13}	5Å – 7Å
Z_{32}	~ 17 Å
τ_{12} *	~ 0.7 ps
τ_{31} *	~ 1.9 ps
τ_{32} *	~ 2.9 ps
$\tau 3$ * $= (1/\tau_{32}+1/\tau_{13})^{-1}$	~ 1.16 ps

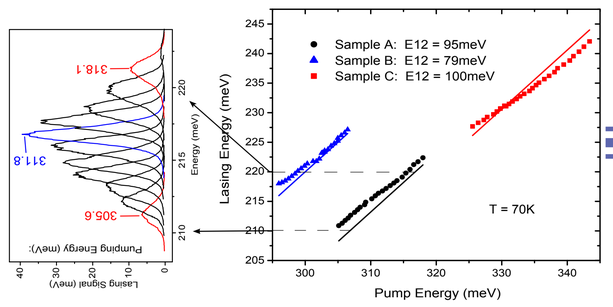
(*) at Gamma Minimum.

Laser characteristics



Maximal Power	~ 14 W	Conversion Efficiency	~ 1.4 %
Cavity Length	~ 5 mm	T maximal	~ 200 K
Periods	60	Tuning/Gain Width	~ Γ_{FWHM} (abs)
Threshold	> 250 W	Threshold (intensity)	> 50 kW/cm^2

Tuning



Laser Emision follows the pump laser wavelength over the entire range
RAMAN LASING

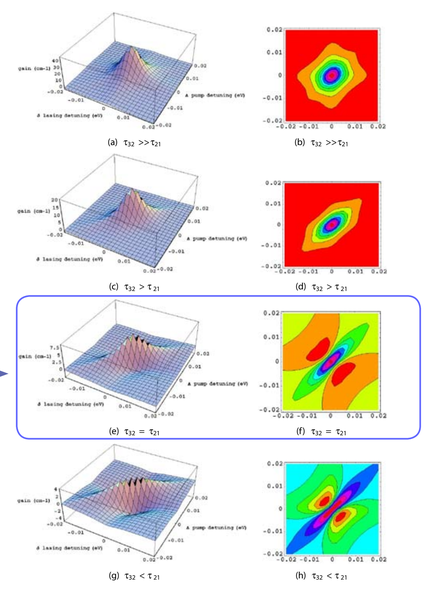
Model calculations

based on A. Belyanin, (2006)
nonlinear coupling between optical wave (P) which drives the Stokes wave (L) AND the material excitation, i.e. intersubband excitation.

$$gain[cm^{-1}] = \mathrm{Re}\left\{ \frac{\eta}{\gamma_{32} + |\Omega_p|^2 / \left(\gamma_{21} - i(\Delta - \delta)\right) + i\delta} \times \left[\frac{\Omega_p{}^2 (n_1 - n_3)}{\left(\gamma_{21} - i(\Delta - \delta)\right)\left(\gamma_{31} - i\Delta\right)} - (n_1 - n_3) \right] \right\}$$

population inversion

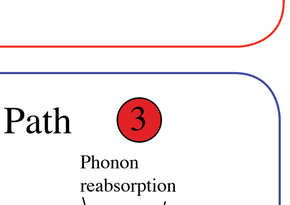
$$\eta = \frac{4\pi\omega_S z_{32}^2 \Gamma_S}{\hbar c n_r}; \quad \Omega_p = e z_{13} E_P / \hbar;$$



} locked to E_{32}

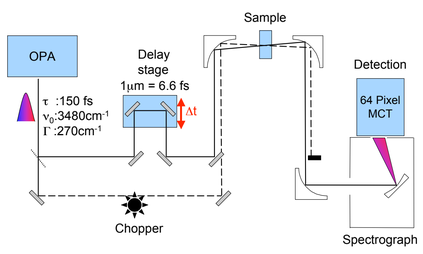
} slope < 1

Maximum gain is when $\Delta = \delta = 0$



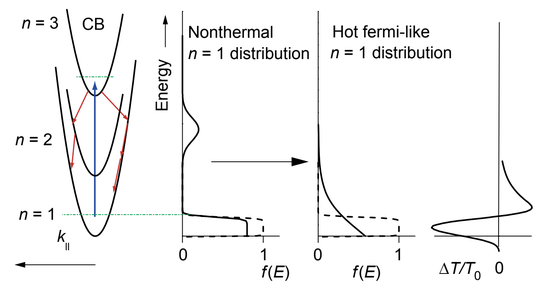
Femto Second Pump/Probe

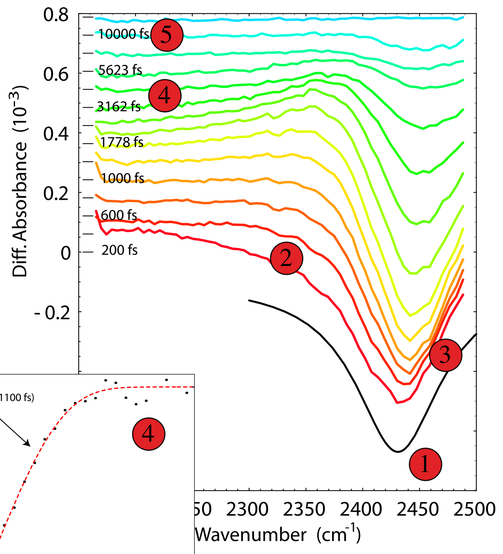
Pump Probe Scheme



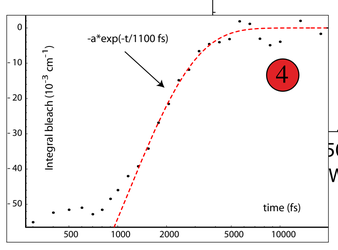
OPA/DFG driven by femto second Ti:AlO_3 reg. ampl.	
sample configuration	single pass, Brewster angle
Recording	T_{on} - T_{off} (delay averaging) using 64 Channel MCT spectrometer

Relaxation/Termalization

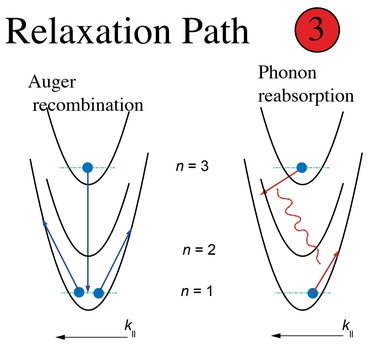




1	t ~ 600 fs	bleach at short time ~ linear absorption	non-thermal distribution
2	t < 1000 fs	recovery of low energy tail	generation of hot electrons
3	t < 1000 fs	peak of bleach almost constant	offset absorption stimulated emission
4	t > 3 ps	integrated bleach ⇒ 0	thermalization
5	t > 10 ps	bleach ⇒ 0	cooling down

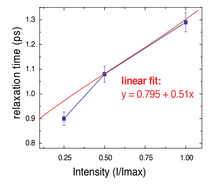


Relaxation Path



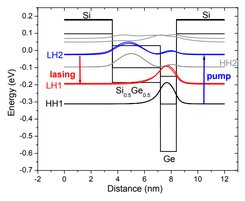
bleach amplitude conserving processes

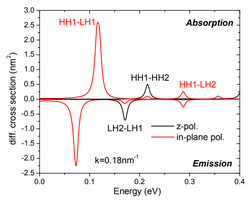
fast relaxation to the ground state.



Ge/SiGe Quantum Well

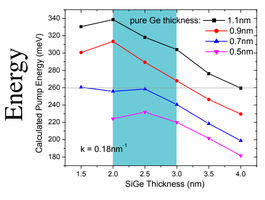
proposed structure



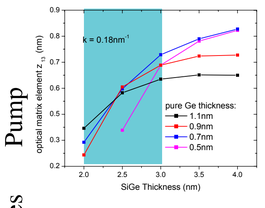


Pumping TE: HH1-LH2
Lasing: TM: LH2-LH1
depopulation: LH1-HH1

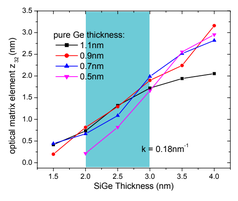
Pump Energy



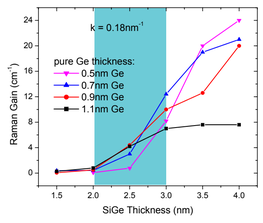
Oscillator Strength Pump



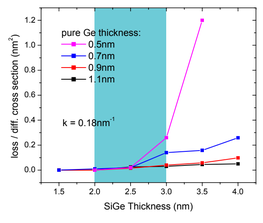
Oscillator Strength Stokes



Gain

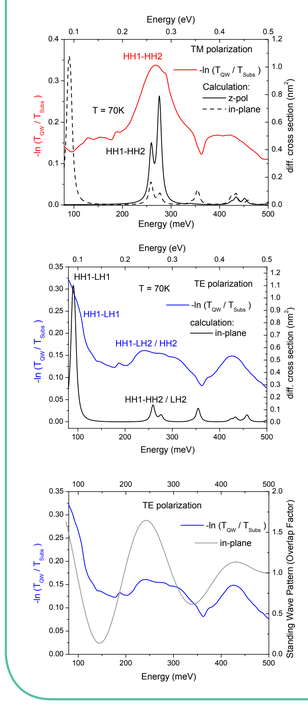


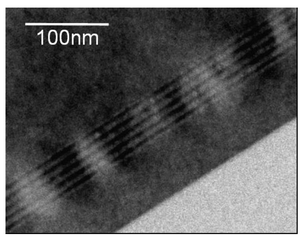
loss



SiGe based intersubband laser?

NOT YET!!





strain fields and buckling of QW layers -> inhomogeneous broadening

standing wave pattern interferes with transmission spectra

TE absorption weak

quality of relaxed buffer substrate is found to be essential

new badge under investigation

Summary/Conclusion

- Resonant intersubband Raman lasing established
- no (or weak) population-inversion is achieved
- supporting evidence for short upper state life time from fs pump/probe experiments
- bleach conserving processes (Auger and/or Phonon re-absorption) are dominant at short time (t < 1 ps)
- lasing inspite of short life time -> potential for Si-based intersubband laser

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