

REPORT DOCUMENTATION PAGEForm Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

1. REPORT DATE (DD-MM-YYYY) 7-April-2005		2. REPORT TYPE Briefing		3. DATES COVERED (From - To) 1-Oct-2003 - 24-Mar-2004	
4. TITLE AND SUBTITLE Intervallence Band Absorption and Carrier Heating In Type-II Sb-Based Lasers				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER 62605F	
6. AUTHOR(S) Dr. Vern Schlie, Ahmed I. Lobad				5d. PROJECT NUMBER 3151	
				5e. TASK NUMBER LY	
				5f. WORK UNIT NUMBER 18	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) AFRL/DELS 3550 Aberdeen Ave SE Kirtland AFB NM 87117-5776				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT Using a nonlinear pump-probe technique, investigations of the carrier dynamics and band structure in MIR Sb-based lasers has been conducted. Specific attention has been given to Type-II QW interband transitions. In addition, measurements of the significant carrier/lattice heating at high temperatures related to slow (~100 ms) thermal diffusion times are reported. Finally, the luminescence lifetime has been found to decrease significantly with temperature showing increased carrier/lattice heating and non-radiative recombination rates.					
15. SUBJECT TERMS Pump-probe techniques, InSb, quantum well structures					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Unlimited	18. NUMBER OF PAGES 14	19a. NAME OF RESPONSIBLE PERSON Dr. Vern Schlie
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (include area code) (505) 853-3440

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18



U.S. AIR FORCE



Intervalence band absorption and carrier heating in type-II Sb-based lasers

Ahmed Lobad and Vern Schlie
Air Force Research Lab., Albuquerque, NM

3/24/04 APS March Meeting

1

CLEARED
FOR PUBLIC RELEASE
AFRL/DEO-PA
15 MAR 04

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

20050830 025

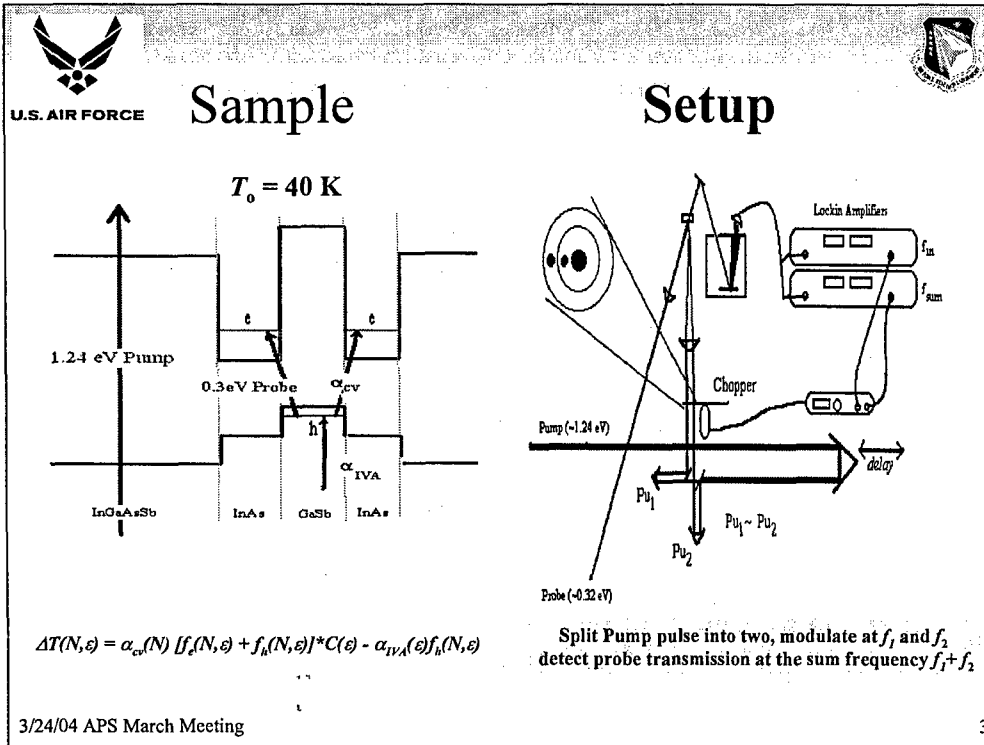


U.S. AIR FORCE



Outline

- Laser sample/ Setup
- Sum Frequency nonlinear Pu/Pr technique
- Detection of built-in electric field in type-II QWs
- Resolving the intervalence absorption
- Excess carrier/lattice heating
- Summary



Discuss the sample structure and characteristics. Highlight interband and intervalance contributions. Discuss the experimental setup and technique



Sum Frequency Pu/Pr



For a thermal distribution:

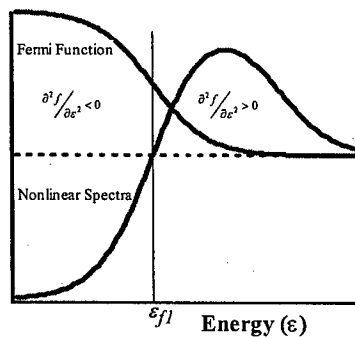
$$\Delta T(\varepsilon, t) \propto f(\varepsilon, N, T) = [1 + \exp(\frac{\varepsilon - \varepsilon_f(N, T(t))}{KT(t)})]^{-1}$$

$$\Delta T_{SumFreq} \propto \Delta T(\varepsilon, t)|_N - 2 * \Delta T(\varepsilon, t)|_{N/2}$$

$$N = \int_0^{\infty} \frac{\rho(\varepsilon)}{1 + \exp[\frac{\varepsilon - \varepsilon_f(N, T)}{KT}]} d\varepsilon$$

↓

$\varepsilon_f(N, T)$



3/24/04 APS March Meeting

4

Highlight what generic pump-probe measure and what nonlinear pump-probe measure

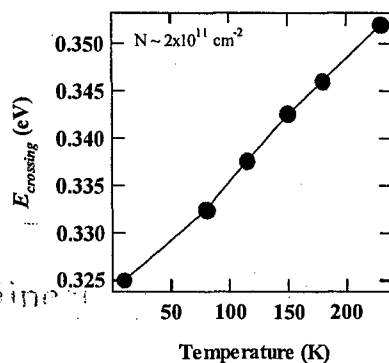


Nonlinear Spectra Crossing Energy



$$f(\epsilon_{cr}, N, T) - 2f(\epsilon_{cr}, N/2, T) = 0$$

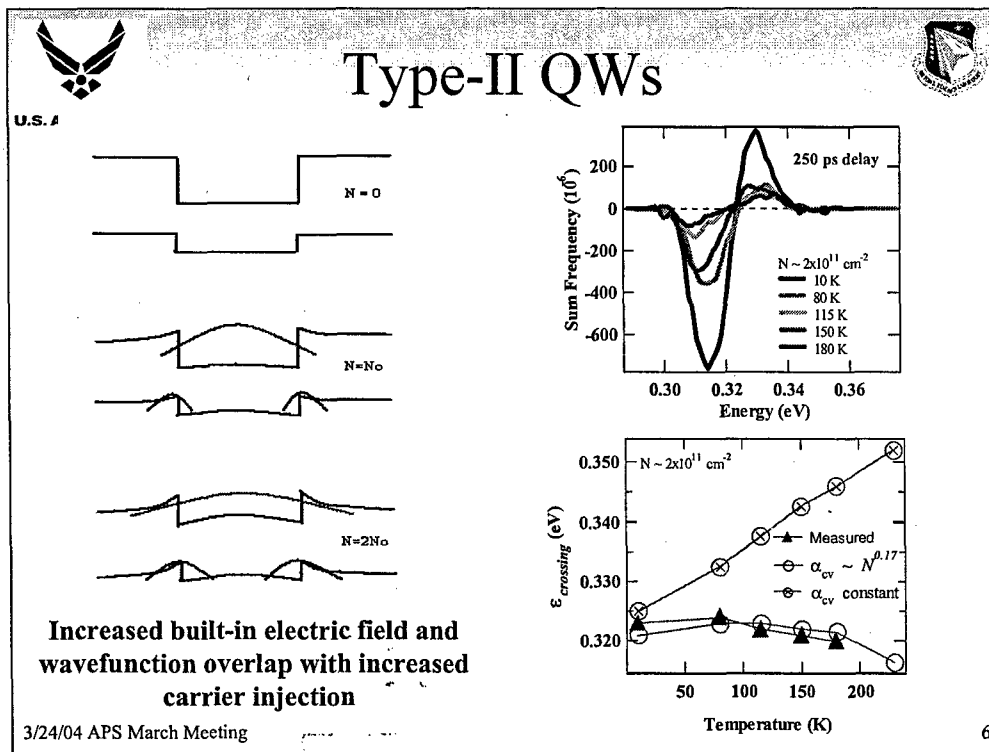
$$E_{cr} = E_{f1} + KT * \ln\left(\frac{1}{1 - 2 \exp[-(E_{f2} - E_{f1}) / KT]}\right)$$



3/24/04 APS March Meeting

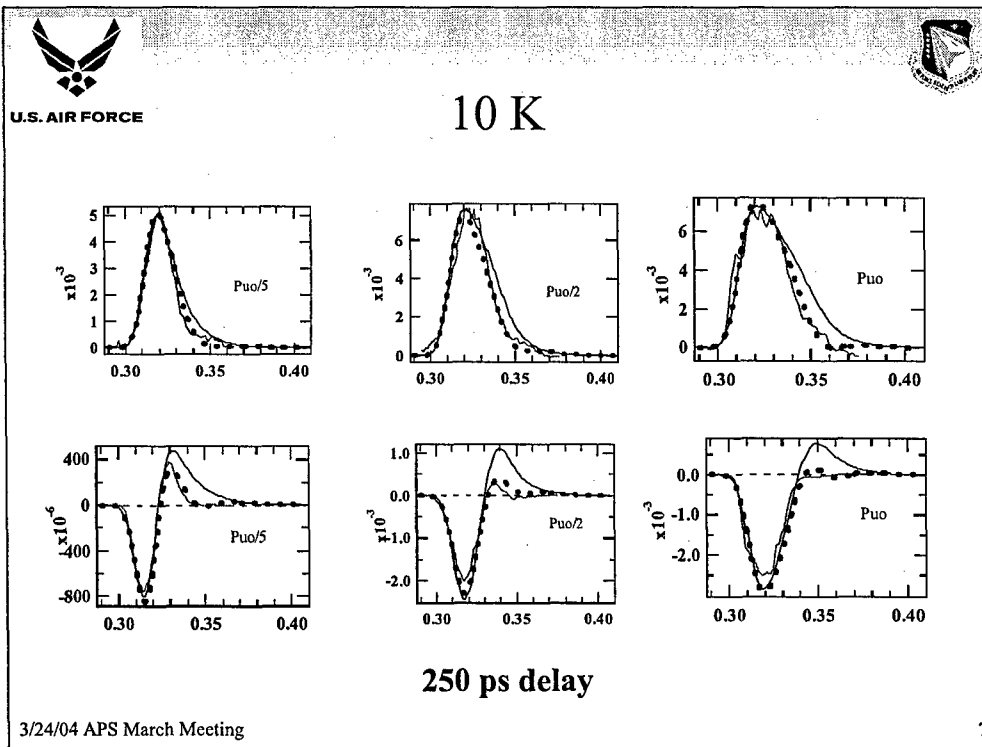
5

Calculate and plot the nonlinear spectra crossing energy for a constant transition matrix element (type-I QWs)



Discuss the increase of the built-in electric field and wavefunction overlap with increased carrier injection in type-II QWs.

Discuss the measured nonlinear spectra as a function of temperature and simulated transition matrix element that varies as $N^{0.17}$



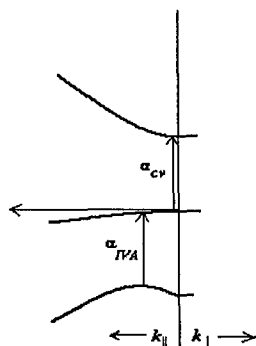
Discuss the measured linear and nonlinear spectra for different carrier injection densities at 10 K, 250 ps delay.

Highlight the curve fitting taking into account the interband transition only (black line) and the fitting curves with the interband and intervalence transitions taken into account (dotted blue)



Fitting parameters

$$\alpha_{IVA} \exp\left(-\left[\frac{E - E_{IVA}}{\Delta_{IVA}}\right]^2\right) * \left[1 + \exp\left(\frac{E_{fh} - E_o}{KT}\right)\right]^{-1}$$



$$\alpha_{cv} \sim 2000 \text{ cm}^{-1}, \alpha_{IVA} \sim 22000 \text{ cm}^{-1}$$

$$E_{IVA} \sim 0.345 \text{ eV}, \Delta_{IVA} \sim 0.013 \text{ eV}$$

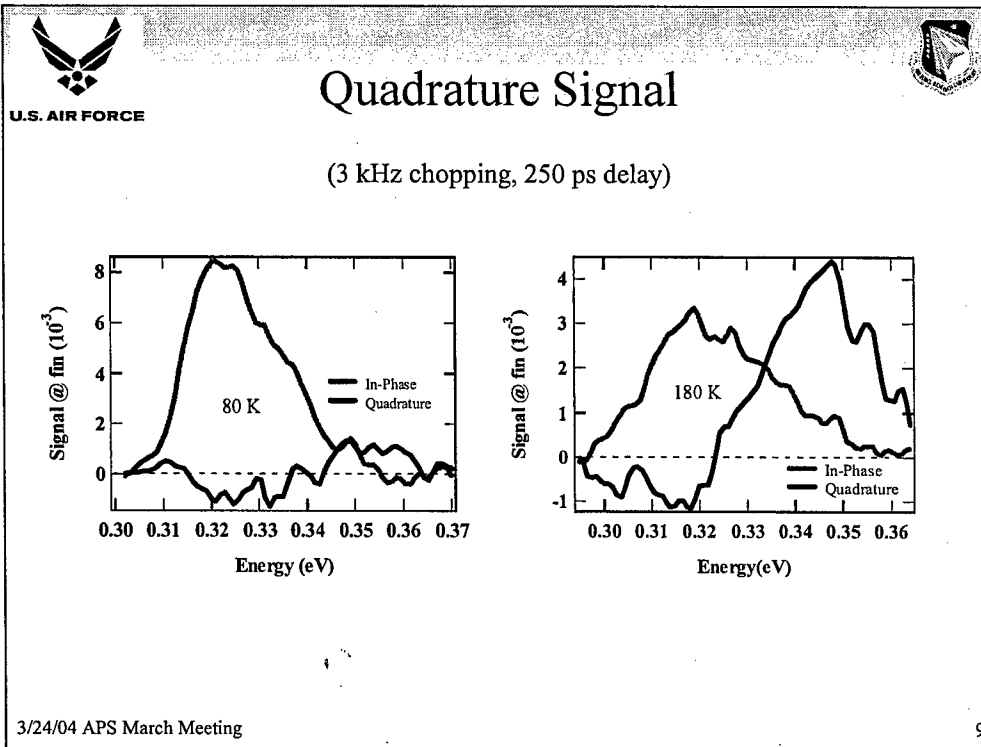
$$E_o \sim -15 \text{ meV} (k_{\parallel} \sim 0.02 \text{ \AA}^{-1}),$$

$$N(Pu) \propto \frac{Pu}{1 + Pu / (1.6 Pu_o)}$$

3/24/04 APS March Meeting

8

Discuss the formula used to fit the intervalence absorption, the fitting parameters and a schematic of the energy diagram.



Report the observed growth of a quadrature (out of phase) signal at higher temperature.



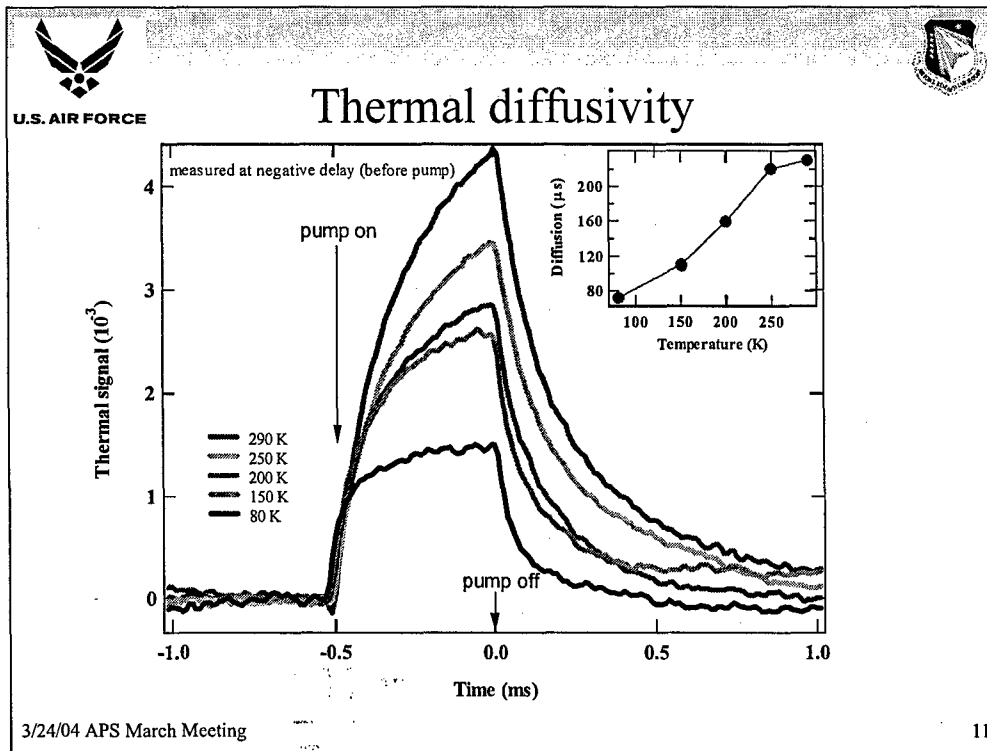
U.S. AIR FORCE



Thermal Diffusion

$$D_{th} [\text{cm}^2 \text{s}^{-1}] = K_{th} [\text{W cm}^{-1} \text{K}^{-1}] / (\rho [\text{gm cm}^{-3}] * C_p [\text{J gm}^{-1} \text{K}^{-1}])$$

Radial diffusion; $\tau_{th} = A / D_{th}$ ($\sim 100 \mu\text{s}$)



Report the time dependence of the measured thermal signal as a function of lattice temperature for negative delay.

Highlight the dependence of the thermal diffusion time constant as a function of temperature.

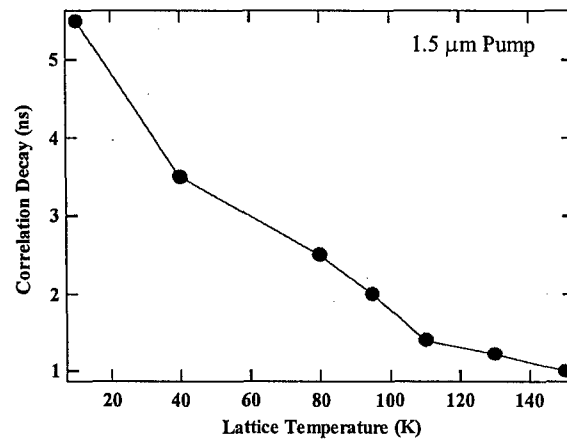
Comment about the radial vs. axial thermal diffusion.



U.S. AIR FORCE



Luminescence Correlation



3/24/04 APS March Meeting

12

Report on the carrier recombination time as a function of temperature measured through luminescence correlation decay.

Correlate with the increased excess carrier/lattice heating and the resonant effect of the intervalence transition on Auger recombination rates



U.S. AIR FORCE

Summary



- Used nonlinear pump-probe technique to investigate carrier dynamics and band structure in MIR Sb-based lasers.
- Type-II QW interband transition matrix element $\propto N^{0.17}$
- IVA absorption is not resonant with the lasing energy ($k_{\parallel} \sim 0.02 \text{ \AA}^{-1}$).
- Measured significant carrier/lattice heating at high temperatures related to slow ($\sim 100 \text{ \mu s}$) thermal diffusion times.
- Luminescence lifetime decreases strongly with temperature.
- Increased carrier/lattice heating and non-radiative recombination rates points to increased IVA resonance at higher lattice temperatures and higher carrier excitation.