Nonlinearity and Response Speed Evaluation of Intersubband Transition in InGaAs/AlAsSb Quantum Well

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Efficient ultrafast all-optical switches are crucial for the operation of optical communication networks at bit rates beyond 100 Gb/s. Considerable research is going on to identify various optical nonlinear materials for developing these devices. We have proposed InGaAs/AlAsSb quantum well (QW) structures for realizing intersubband transition (ISBT) based absorption switch operating at communication wavelengths [1]. Developing practical switching devices from such a material requires the estimation of basic parameters like the switching energy and response time. To evaluate the switching energy, the determination of saturation intensity (I_S) is required. However, in this high band offset material, a direct saturation measurement is affected by two photon absorption at high intensities [2]. Thus, a reliable estimate of saturation intensity demands for an improved technique.

Here we report the first estimate of both I_S and relaxation time (τ) in MBE grown, 80 period, 2 nm $In_{0.53}Ga_{0.47}As/AlAs_{0.56}Sb_{0.44}$ QW on lattice matched InP substrate. We perform a detailed lineshape analysis on a series of temperature (T) dependent absorption spectra for a reliable estimate of the homogeneous linewidth. We estimate the I_S from a two-level model using the homogeneous linewidth and the relaxation time determined by a pump-probe measurement. The present result confirms promising feature of this material for all-optical switch applications.

Near-infrared polarization resolved transmission spectra were measured for $4K < T < 400K$ by FTIR spectrometer on a multiple-reflection guided geometry (Fig. 1). Figure 2 shows ISBT spectra at a few temperatures along with the fits. The fit used is a convolution of a Gaussian of width Γ_G to account for the inhomogeneous and a Lorentzian of width Γ_L for the homogeneous broadening similar to the exciton case [3]. We fix the Γ_G from the 4 K spectrum where the line broadening is predominantly inhomogeneous and vary only the Γ_L to fit the data at all higher T. The fact that the Γ_G is fixed from the 4 K spectrum and the shape of the low and high energy tails lead to a unique fit at all T. Figure 3 displays the estimated Γ_L as a function of T.

Using a two-level model, for an incident angle θ, I_S in QWs [4] is given by Equation(1). All terms in Eqn.(1) (n_c the sheet carrier density, n_w the number of wells, $h\nu_0$ the peak energy, $h\Delta\nu$ the homogeneous linewidth and $\int \alpha(\nu)d\nu$ the area under the absorption peak) excepting the τ can be obtained from the spectral analysis. We estimated τ to be 2.1 ps from pump-probe measurement (inset of Fig.3) using 150 fs pulses at 1.95 μm pump and 1 μm probe wavelengths. We estimate the room temperature I_S from Eqn.(1) to be 52±5 MW/cm^2. This is as large as the value reported in other InGaAs QWs at 2.7 μm [5]. From a direct measurement of power dependence of transmitted light resonantly tuned to the ISBT at 1.95 μm, we obtain a contrast ratio of 2. This can be improved by using an interferometer or a waveguide geometry.

In conclusion, we report the first estimate of both I_S and τ for intersubband absorption in InGaAs/AlAsSb QW. The absorption recovery time of about 2 ps and the I_S of 52±5 MW/cm^2 makes it a promising material for an efficient ultrafast switching device operating at communication wavelengths in ultra-high bit rate optical communication networks.

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REFERENCES

[1] H. Yoshida, T. Mozume, A. Neogi, and O. Wada, Electron. Lett. **35**, 1 (1999).

[2] A. Neogi, H. Yoshida, T. Mozume, N. Georgiev, T. Akiyama, and O. Wada, in Proc. SPIE Vol.**3940**, 2000, pp. 91-97.

[3] A. V. Gopal, R. Kumar,A. S. Vengurlekar, A. Bosacchi, S. Franchi, and L. N. Pfeiffer, J. Appl. Phys. **87**, 1858 (2000).

[4] B. F. Levine, J. Appl. Phys. **74** R1 (1993).

[5] K. L. Vodopyanov, V.Chazapis, C. C. Phillips, B. Sung, and J. S. Harris Jr., Semicond. Sci. Technol. **12**, 708 (1997).

$$I_S = \frac{n_c n_w \pi^2 h\nu_0 \Delta\nu}{2\tau \int \alpha(\nu) d\nu} \frac{sin^2(\theta)}{cos(\theta)} \tag{1}$$

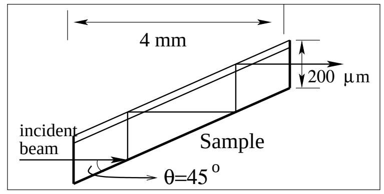

FIG. 1: A schematic of the sample structure. The two ends were polished at 45^o to enable normal incident light to pass through a multiple-reflection guided geometry.

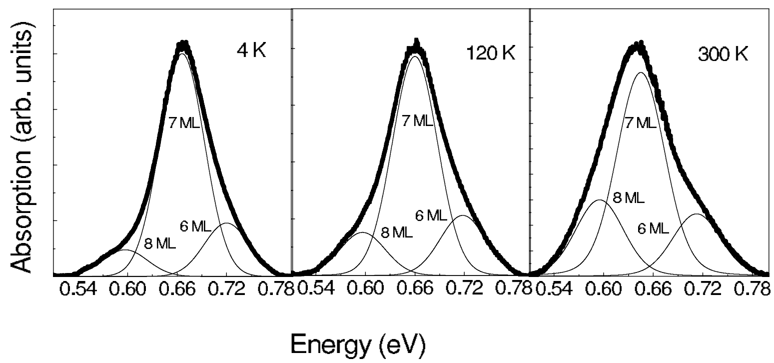

FIG. 2: The absorption spectra are shown along with the fits (solid lines) at a few temperatures. The three peaks fitted correspond to one monolayer fluctuation.

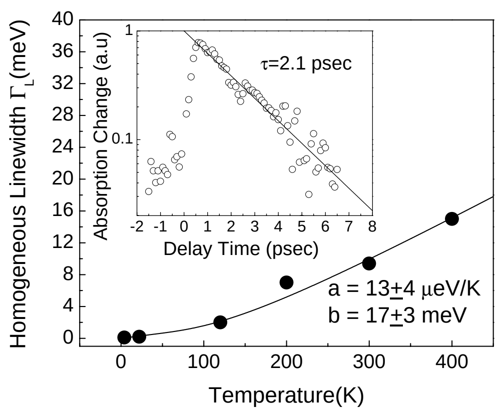

FIG. 3: Γ_L (filled circles) as a function of temperature along with a fit (line) based on acoustic and LO-phonon contributions [3]. The a and b values indicate the corresponding scattering strengths, respectively. Inset shows the transient interband absorption recovery at 1 μm due to resonant ISBT pump at 1.95 μm. Also shown is an exponential fit (line).