Carrier Dynamics in InSb Based Quantum Well Structures

R. N. Kini, K. Nontapot, G. A. Khodaparast*
Department of Physics at Virginia Tech., Blacksburg, VA, 24061, U.S.A
N. Goel, S. J. Chung, M. B. Santos
Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma,
Norman, OK, 73019, U.S.A.

Abstract— **Semiconductor quantum wells (QWs) based on InSb have potential applications for ultra-fast and low power digital logic devices due to their high electron mobility. Here we report our measurements and control of the carrier relaxations in InSb based QWs with symmetric and asymmetric doping profile using time resolved spectroscopy. We used pump/probe spectroscopy to study the dynamics at different excitation wavelengths, power densities, and temperatures. We observed that relaxations depend on the density of photoinduced carriers and can last from 50ps to 5ps. Our measurements can provide important information regarding the relaxation mechanisms in this narrow gap system.**

I. INTRODUCTION

Due to the possibility of developing fast and low consumption devices, there is a renewed interest in the science and engineering of narrow gap semiconductors such as InSb based heterostructures. Narrow gap semiconductors offer several scientifically unique electronic features such as a small effective mass, a large g-factor, a high intrinsic mobility, and large spin-orbit coupling effects. Here we report the dynamics of photoexcited carriers in InSb based QWs using standard pump-probe spectroscopy. The characteristics of the samples are summarized in Table 1 where the samples are single modulated doped QWs with $Al_xIn_{1-x}Sb$ barriers. The energy-gap discontinuity [1] as well as the band offsets [2] in this system has been determined earlier.

Our InSb single quantum wells (QW) are grown by MBE at the University of Oklahoma on GaAs (001) substrates. The $Al_xIn_{1-x}Sb$ barrier layers are δ-doped with Si. The Si layers are located either on one side of the QWs (asymmetric sample, “A”) or equidistant on both sides of the QWs (symmetric sample, “S”). The δ-doped layers within the barrier layers are typically located 70 nm from the well center. The detailed growth conditions were described previously [3]. We expect the shape and symmetry of the wells to be determined only by the well/barrier mismatch (symmetric in all samples) and the mismatch in doping layers. In these samples only the ground-state subband is occupied.

II. EXPERIMENTAL TECHNIQUE

We measured dynamics of photoexcited carriers using standard pump/probe techniques (both degenerate and two-color). In the degenerate measurements, the pump was near infrared (NIR) pulses from a Ti:Sapphire laser which produces tunable radiation from 750 nm to 850 nm with a pulse duration of ~100 fs at a repetition rate of 80 MHz. The maximum average power of the pump was about 400 mW (energy per pulse of ~ 5 nJ). A small portion (~10%) of the NIR beam was split off to be used as the probe beam. In the two-color pump/probe, the source of the pump beam were mid-infrared (MIR) pulses from an optical parametric amplifier (OPA) pumped by a chirped pulse amplifier (CPA) with maximum average power of ~ 1.1 W, a pulse energy of ~1 mJ, and duration of ~100 fs at a repetition rate of 1 kHz. Small fraction (~ 10^{-5}) of the CPA signal was used as a NIR source for the probe beam. We used the reflection geometry to probe photoexcited carrier dynamics as a function of time delay between the pump and the probe.

TABLE I
SAMPLE S CHARACTERISTICS

Sample	Density ($x10^{11}$) cm^{-2} 4.2 K	Mobility 4.2 K	QW Width (nm)	Al concentration (x %)
“S” (S769)	2.0	100,000	30	9
“A” (S360)	2.2	73,000	30	9

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*Corresponding author: G. A. Khodaparast, phone: 540-231-8729; fax: 540-231-7511; e-mail:khoda@vt.edu.

III. RESULTS

Figure1 shows differential reflectivity as a function of time delay for the two InSb QWs at room temperature at different MIR pump wavelengths. The pump fluence was of the order of 5mJ/cm^2 with the probe beam fixed at 800nm. The carrier relaxation lasts for ~ 5 ps where photoinduced carrier density is expected to be 10^{19} cm^{-3}. We observed a similar carrier relaxation time (not shown here) at 77 K. As shown in Fig. 2, we observed slower relaxations when the photoinduced carrier density is of the order of ~ 10^{17} cm^{-3} using the Ti:Sapphire laser with a fluence ~ 50μJ/cm^2. Our observation suggests that momentum relaxation can be a dominate relaxation mechanism in these structures.

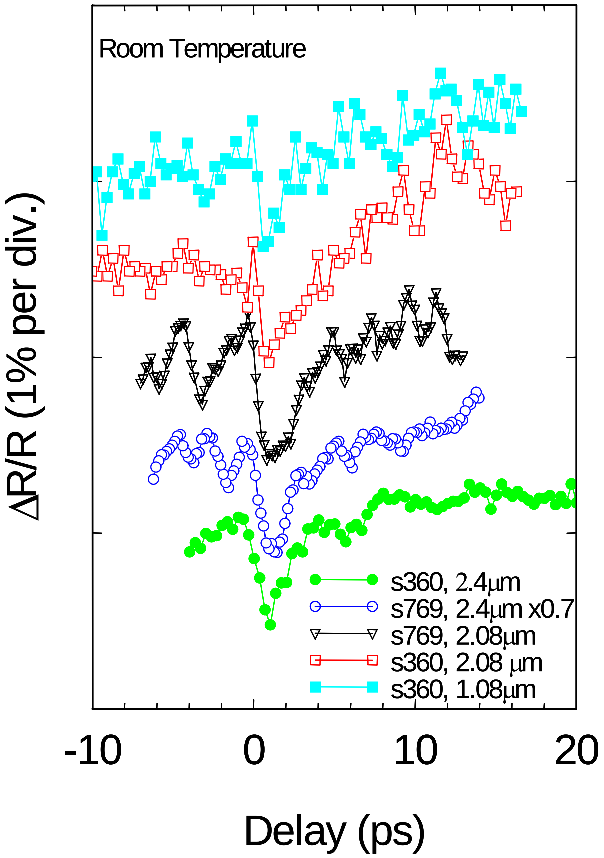

Fig. 1. Differential reflectivity as a function of time delay for two InSb QWs at room temperature with different MIR pump wavelengths. The pump fluence was of the order of 5mJ/cm^2 with the probe beam fixed at 800nm. The carrier relaxation lasts for ~5 ps where photoinduced carrier density is expected to be ~ 10^{19} cm^{-3}.

IV. CONCLUSION

Exploring carrier dynamics provides a better understanding of many phenomena such as scattering, quasi-equilibrium carrier distribution, and carrier cooling. Furthermore, as the switching rates in electronic devices are pushed to even higher frequencies, it is important to understand carrier dynamic phenomena in semiconductors on femtosecond time-scales. Optical spectroscopy with femtoscecond time resolution allows us to generate and monitor coherent optical polarization and carrier distribution in real time [4]. Our observations provide new information regarding the relaxation time and optical control carrier lifetime in InSb QWs. We are exploring to understand and control spin relaxation in this system as well.

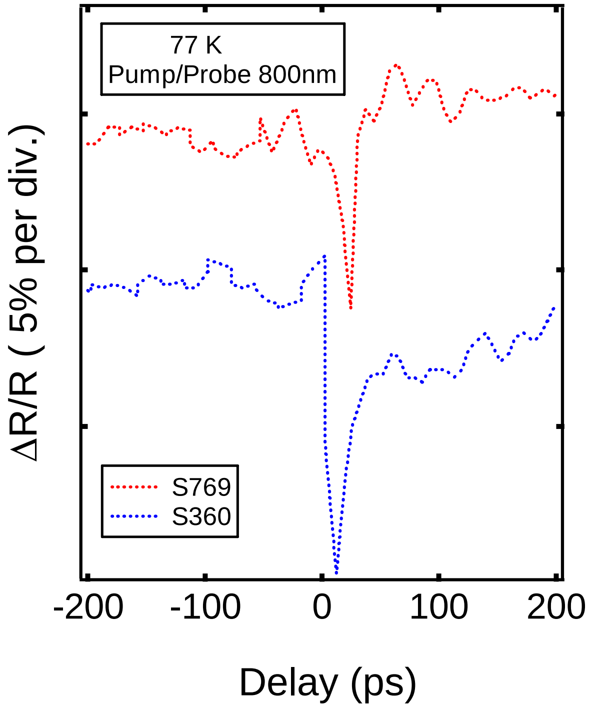

Fig.2. Differential reflectivity as a function of time delay for two InSb QWs at 77 K in a degenerate configuration where the pump and probe have the same wavelengths. The pump fluence was in the order of 50μJ/cm^2 where the carrier relaxation lasts for ~ 50 ps. The photoinduced carrier density is expected to be ~ 10^{17} cm^{-3} in this pumping regime.

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