Vertical transport in short-period InAs/GaSb superlattices

B.V. Olson*a,b, L.M. Murraya,b, J.P. Prineas*a,b and T.F. Boggessa,b,c
*aDept. of Physics and Astronomy, bOptical Science and Technology Center, cDept. of Electrical and Computer Engineering, University of Iowa, Iowa City, IA 52242

BIOGRAPHY

Benjamin V. Olson: Received his B.S. in physics from Gustavus Adolphus College. He is currently pursuing his Ph.D. at the University of Iowa studying III/V semiconductors. His focus has been the use of ultrafast lasers to investigate the carrier recombination dynamics and transport in mid-wave and long-wave infrared InAs/GaSb superlattices.

TECHNICAL ABSTRACT

The development of InAs/GaSb superlattices (SLs) for infrared (IR) detectors and emitters has occurred at a rapid pace in recent years. This material system has proven to be very versatile owing to the flexibility in bandgap tuning and band structure engineering. A hindrance in the development of this material system has been the relatively short minority carrier lifetime [1], but as the lifetime is extended vertical transport will become increasingly more important. Recent work with InAs/InAsSb SLs has shown significantly improved lifetimes in comparison to InAs/GaSb and potentially a new avenue for IR SL focal-plane arrays [2]. Efficient operation and fast dynamic response of these IR devices requires that the carrier transport vertically through the growth stack must be understood and optimized. This research aims to provide a non-destructive method to measure vertical transport in both mid-wave (MWIR) and long-wave (LWIR) infrared structures.

While the in-plane transport can be investigated using such methods as the Hall effect and time-resolved transient grating, the vertical transport is a more difficult phenomena to measure. The method used for this research is to place a lower-band gap “marker well” on the back of the SL. When carrier pairs are optically generated near the surface of the SL using an ultrafast pump pulse, the transit time and hence the diffusion can be measured by time-resolving the arrival of carriers in the marker. As the marker is spectrally separated from the SL, time-resolved photoluminescence up-conversion is the preferred method for this measurement [3]. This method has yet to be transferred to the LWIR as the nonlinear up-conversion process becomes increasingly more difficult and less efficient, and difficulties arise in spectrally separating the up-converted signal from the pump. In this research, time-resolved differential transmission techniques are used, where the arrival of carriers in the marker is measured through the band filling effect on an optical probe tuned to the marker’s band gap energy and is illustrated in Figure 1.

As a proof-of-concept, SL structures were designed where the diffusion through an unintentionally doped MWIR InAs/GaSb SL was measured. A LWIR InAs/GaSb was grown before the MWIR SL to serve as the marker. The growth stack of this structure is shown in Figure 2. For the ultrafast measurements, a subpicosecond pulse from an amplified titanium:sapphire laser was frequency doubled to 390 nm and is the source of the pump beam. The short wavelength ensures that the carriers are generated near the surface of the MWIR SL and not in the marker. A portion of the titanium:sapphire pulse is used to pump an optical parametric amplifier, where, through difference frequency generation, a LWIR probe beam is generated. The sample was held at 77 K in a closed cycle, He cooled cryostat and the transmission of the probe through the sample was monitored with a single-element HgCdTe detector. As the probe is still sensitive to carrier-induced,

*benjamin-olson@uiowa.edu; phone 1 507 382-8035
below-band gap absorption in the MWIR SL, the transport samples were compared to a reference MWIR sample where the LWIR marker was excluded from the growth. Figure 3 shows the resulting normalized time-resolved measurements of the reference sample as well as transport samples where the MWIR SL has a thickness of 300 nm and 600 nm. The top curve shows the differential transmission for the MWIR reference sample. The results show an instantaneous response at zero delay due to free-carrier absorption and a subsequent decay due to carrier recombination. The middle curve is from the 300 nm thick transport sample. The slow initial rise of the differential transmission is attributed to the diffusion of carriers through the SL and the filling of band edge states in the marker. The bottom curve, which is from the 600 nm thick transport sample, exhibits an initial rise time similar to the reference. This suggests that only the below-band gap response of the MWIR SL is being observed and that the majority of carriers have recombined before reaching the marker. A 1-dimensional diffusion model was fitted to the middle curve to extract an ambipolar diffusion coefficient of 0.3 cm²/s. The slow vertical diffusion is a consequence of the ambipolar diffusion being dominated by holes, which tend to be highly localized in the GaSb layers in the SL. Similar measurements in doped samples would be sensitive to minority carrier diffusion. Further ultrafast measurements, as well as CW photoluminescence studies, will provide greater insight into the nature of vertical transport in these structures and will be presented.

**Keywords:** Vertical Transport, Superlattice, InAs/GaSb, Diffusion

**References**