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Investigation of Trap States in Mid-Wavelength Infrared Type II Superlattices Using Time-Resolved Photoluminescence

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Time-resolved photoluminescence (TRPL) spectroscopy is used to study the minority-carrier lifetime in mid-wavelength infrared, n-type, InAs/$Ga_{1-x}In_xSb$ type II superlattices (T2SLs) and investigate the recombination mechanisms and trap states that currently limit their performance. Observation of multiple exponential decays in the intensity-dependent TRPL data indicates trap saturation due to the filling then emptying of trap states and different Shockley–Read–Hall (SRH) lifetimes for minority and majority carriers, with τ_{maj} (τ_{n0}) $\gg$ τ_{min} (τ_{p0}). Simulation of the photoluminescence transient captures the qualitative behavior of the TRPL data as a function of temperature and excess carrier density. A trap state native to $Ga_{1-x}In_xSb$ is identified from the low-injection temperature-dependent TRPL data and found to be located below the intrinsic Fermi level of the superlattice, approximately 60 ± 15 meV above the valence-band maximum. Low-temperature TRPL data show a variation of the minority-carrier SRH lifetime, τ_{p0}, over a set of InAs/$Ga_{1-x}In_xSb$ T2SLs, where τ_{p0} increases as x is varied from 0.04 to 0.065 and the relative layer thickness of $Ga_{1-x}In_xSb$ is increased by 31%.

Key words: Type II superlattice, minority-carrier lifetime, time-resolved photoluminescence, Shockley–Read–Hall, trap saturation, infrared

INTRODUCTION

Type II superlattice (T2SL) technology has the potential to surpass existing materials for use in mid-wavelength infrared (MWIR) and long-wavelength infrared (LWIR) photodetectors.[1] The ability to engineer the bandgap promises low Auger recombination rates.[2] In practice, however, InAs/$Ga_{1-x}In_xSb$ T2SL material is limited by Shockley–Read–Hall (SRH) recombination,[3–5] resulting in short minority-carrier lifetimes (tens of nanoseconds at 77 K) that do not approach the theoretical limit determined by Auger recombination. A number of studies have been carried out to determine the source of the SRH recombination center, including investigating the influences of varying the number of superlattice interfaces per unit length,[6] surface recombination with varying absorber width,[7] absorber doping level,[8] and interface type.[8] In each study, the varied superlattice parameter was found to have a negligible effect on the observed carrier lifetime. Therefore, it is postulated that a native defect in one of the superlattice constituents (InAs or $Ga_{1-x}In_xSb$) is the source of the dominant SRH recombination center.[9] Recent measurements of "Ga-free" InAs/$InAs_{1-x}Sb_x$ T2SLs demonstrated an order-of-magnitude improvement in nonradiative carrier lifetime when Ga was eliminated.[10,11] These results suggest that the SRH trap(s) limiting the carrier lifetime in InAs/$Ga_{1-x}In_xSb$ T2SLs is native to the $Ga_{1-x}In_xSb$ layers. As the

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