Auger Recombination in Type I GaInAsSb/GaSb Lasers and its Variation with Wavelength in the 2-3 µm Range

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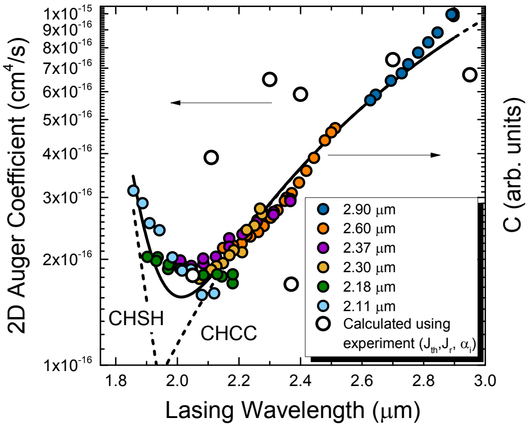
Semiconductor lasers operating in the 2-3 µm wavelength range are useful for a variety of applications including environmental monitoring, non-invasive medical diagnosis and industrial processing [1]. While type-I GaInAsSb/GaSb quantum well (QW) lasers have achieved room temperature operation up to 3.73 µm, they are limited by the effects of non-radiative Auger recombination, inter-valence band absorption and carrier leakage due to inadequate hole confinement, all of which induce sensitivity to temperature [2]. Here we report studies of the non-radiative recombination mechanisms in type-I GaInAsSb based lasers, in order to assist device optimisation [3-5].

The temperature (T) dependence of the threshold current density (J_{th}) was measured in the range 80-350 K for devices lasing at 2.3 µm, 2.6 µm and 2.9 µm at 295 K. At low T the characteristic temperature $T_0 \approx T$ was consistent with dominance by radiative recombination. Then for T >150 K, T_0 decreases towards $T_0 = T/3$, indicating that Auger recombination comes to dominate. Extrapolating the variation of the radiative component of the threshold current density, J_{r}, measured at low temperatures allows its magnitude to be estimated at room temperature. Since $J_{\mathrm{th}}=J_{\mathrm{r}}+J_{\mathrm{nr}}$, the non-radiative Auger component, J_{nr}, could also be quantified.



Modelling the gain and loss characteristics allowed the threshold carrier density N_{th} of each specific device structure to be determined. Then assuming $J_{\mathrm{nr}}=CN_{\mathrm{th}}^3$, the Auger coefficient C was calculated as plotted against wavelength in the figure. The large scatter in the data may arise from a number of factors, such as uncertainty in the optical loss used to determine N_{th}, differences in the compressive strain (which can cause C to vary even between devices with the same operating wavelength), invalidity of the relation $J_{\mathrm{nr}}=CN_{\mathrm{th}}^3$ based on a non-degenerate carrier distribution at threshold, and thermal leakage from the well causing the electron and hole densities to become unequal. To address this considerable range of potential difficulties, we undertook measurements of J_{th} as a function of hydrostatic pressure. Since the application of pressure increases the direct band gap (E_{g}) of a III-V semiconductor, the operating wavelength of a single device can be varied in a reversible manner without altering the device structure, enabling us to span the range λ = 2.9-1.85 µm. By normalising the results for different devices, a smooth curve was obtained which exhibited a clear transition from a CHCC (hot electron) to a CHSH (hot hole) Auger process as E_{g} approaches the spin-orbit splitting energy (Δ_{SO}). This curve, which was fit to theoretical values of the Auger coefficient, provides a helpful guide for the design of lasers operating in the 2-3 µm wavelength range.

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