THEORY OF DILUTE BISMIDE ALLOYS FOR HIGH EFFICIENCY, UNCOOLED TELECOMM LASERS

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The replacement of a small fraction of As by Bi in GaAs primarily effects the valence band (VB), resulting in a strong bowing of the band gap (E_g) and spin-orbit-splitting ($\Delta_{\rm SO}$). Experiment [1] and theory [2] indicate $E_g < \Delta_{\rm SO}$ for $x > 10.5\%$ in $GaBi_xAs_{1-x}$. The condition $E_g < \Delta_{\rm SO}$ should make it possible to suppress the threshold current-dominating non-radiative CHSH Auger recombination process in devices operating at telecomm wavelengths. Dilute bismide alloys are therefore a strong candidate material system for the realisation of highly effcient and temperature stable GaAs-based photonic devices operating at telecomm wavelengths [3].

Based on an accurate $\mathbf{k}\cdot\mathbf{p}$ Hamiltonian for (In)$GaBi_xAs_{1-x}$ [4] we have calculated the band structure and gain of dilute bismide quantum well (QW) lasers. Our calculations demonstrate that $GaBi_xAs_{1-x}$/GaAs lasers with low Bi composition x suffer, due to their shallow type-I conduction band offset, from electron spillout which degrades the material gain. We show how this can be overcome by the use of AlGaAs barriers to enhance the electron confinement in such devices and we suggest an Al composition in the barrier layers which simultaneously optimises both the QW and waveguide in order to deliver the maximum modal gain from such laser structures.

Secondly, we investigate $GaBi_xAs_{1-x}$/GaAs lasers at higher x (with wavelengths approaching 1.5 μm) and show that, surprisingly, the gain characteristics are intrinsically superior to those of low x lasers. Our calculations demonstrate that this is due to a combination of enhanced electron confinement in the QWs and a reduction of the VB edge density of states, because of the increased compressive strain in the QWs at higher x.

Finally, we consider QW lasers based on the quaternary dilute bismide-nitride alloy $GaBi_xN_yAs_{1-x-y}$/GaAs, highlighting the importance of strain on the band structure in such devices and showing that low y QWs which are compressively strained or $y > x$ QWs with (larger) tensile strain optimise the gain. Co-alloying of Bi and N offers broad scope for band structure engineering over a very large wavelength range [3, 5]. This, combined with an expected low temperature sensitivity of the band gap, also provides significant possible benefits for electro-absorption modulator applications.

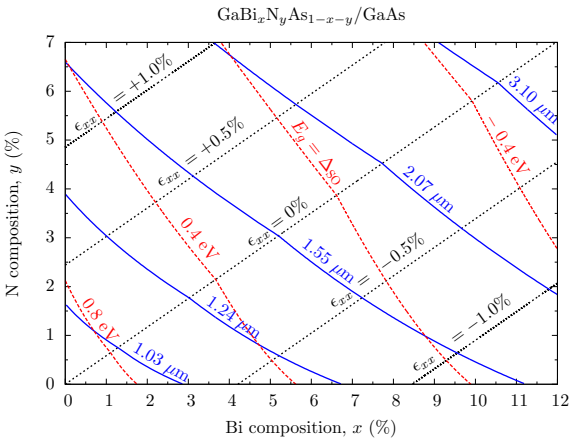

Figure 1. Calculated variation of the band gap E_g and band gap minus spin-orbit-splitting $E_g - \Delta_{\rm SO}$ with Bi and N composition in $GaBi_xN_yAs_{1-x-y}$/GaAs; solid/dashed/dotted lines denote paths in the composition space along which E_g/$E_g - \Delta_{\rm SO}$/strain is constant.

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