Injection- and Temperature-Dependence of Type-II 1.2-1.3 μm (GaIn)As/Ga(AsSb) “W”-Lasers

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Abstract – Type-II (GaIn)As/Ga(AsSb) “W”-lasers offer the possibility to develop efficient and thermally stable near-infrared lasers. In this work, we investigate the temperature- and injection-dependent properties of “W”-lasers operating between 1200-1260 nm and use this to quantify the influence of radiative and non-radiative recombination on device performance.

I. Introduction

Given the ever-growing demands on data infrastructure, the development of higher efficiency and less temperature sensitive semiconductor lasers in the near-infrared (NIR) is of significant interest for the future of data communications networks. In such systems, the temperature sensitivity of both the output power and wavelength of the devices is important and often necessitates the use of active control. Removing these dependencies would improve the efficiency and reduce the complexity and cost of the system.

Type-I InP-based material systems such as (GaIn)(AsP)/InP are well-established for devices operating in key spectral regions for optical communications, such as the O-band from 1260-1360 nm. While devices based on these systems have proven to be of significant technological value, in the NIR these devices remain limited by non-radiative recombination processes such as Auger recombination (a fundamental process) and carrier leakage (due to the relatively small band offsets of InP-based alloys), while newer semiconductor material systems such as (Ga)(AsBi)/GaAs and quantum dot-based active regions often suffer from defect-related recombination and inhomogeneities associated with less mature material growth [1].

Lasers based on type-II “W”-quantum well heterostructures (“W”-QWHs), where electrons and holes are spatially separated in the active region, exhibit unique properties that offer the possibility of improved device characteristics over existing type-I lasers, such as more flexible control of operating wavelength and band structure parameters [2] as well as scope to reduce the Auger recombination rates [3]. These structures are well established in the mid-infrared [2], and have more recently been demonstrated in the near-infrared with (GaIn)As/Ga(AsSb) type-II “W”-QWH lasers (see Fig. 2(a)) emitting in the 1.2-1.3 μm range [4]. However, much of the physics underpinning the current understanding of type-II structures is not well-established, with most theoretical models based upon theory developed for simpler type-I structures which may not always be applicable to type-II structures. Thus, in order to further improve the performance of these structures an improved understanding of the characteristics and main limiting processes occurring in these “W”-QWHs is essential.

In this work, we investigate the radiative and non-radiative processes occurring in (GaIn)As/Ga(AsSb)-based “W”-lasers operating around 1255 nm. By measuring stimulated and spontaneous emission as a function of temperature and current density we investigate the key mechanisms driving device performance, comparing and contrasting their performance with standard type-I lasers emitting at similar wavelengths.

II. Results

Fig. 1(a) shows an example of calibrated power-current (L-I) measurements for an exemplar double “W”-QWH laser at elevated temperatures from 10-100°C, with lasing achieved up to the maximum tested temperature. The investigated devices show lasing emission at around 1255 nm, with pulsed output powers for 100 μm-wide stripes exceeding 1 W at room temperature and reaching 0.7 W at 100°C. The room temperature threshold current density (Jth) is observed to be around 200-300 A cm⁻² [5], which is comparable to that of good type-I devices operating around this wavelength [6] despite the reduced electron-hole wavefunction overlap expected for type-II active regions.

Additionally, the measured lasing wavelength at threshold over this temperature range (Fig. 1(b)) shows a reduced thermal red shift of dλ/dT = 0.31 ± 0.01 nm/°C when compared to both its expected flat band thermal redshift (dλ/dT = 0.53 nm/°C) as well as the shift observed in typical type-I (GaIn)(AsP)/InP devices (dλ/dT = 0.4-0.48 nm/°C [7]). This reduced (or even reversed [8]) thermal shift is due to enhanced carrier-induced band bending effects caused by the spatial separation of charge carriers in type-II active regions and highlights the potential of

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utilising these effects to develop NIR lasers with a less temperature-sensitive emission wavelength through careful device design.

Fig. 1. (a) Power-current (L-I) characteristics for heatsink temperatures between 10°C and 100°C in steps of 10°C, with inset figure showing 1255 nm lasing emission at 20°C. (b) Measured variation in lasing wavelength with temperature relative to its value at 10°C for the measured “W”-QWHs (black points and dashed line) compared against flat-band calculations of the “W”-QWH (green line) and a type-I (GaIn)(AsP)/InP device (blue line) [7].

To probe the underlying behavior of such devices, Fig. 2(b) shows the influence of band alignment on the observed current dependence of the blue shift. For a type-I (GaIn)(AsP)/InP device, this shift with increasing current density is small due to the spatially localised nature of the carriers. In contrast, the type-II nature of the band alignment in Ga(AsSb)/GaAs [9] leads to a significantly increased blueshift with current density. Meanwhile, the “W”-QWH, with a band alignment in between these two cases (Fig. 2(a)), shows an intermediate shift with some degree of tunability depending on the device structure, and highlights how “W”-QWHs can potentially provide a large design space to tune the temperature and current dependence of lasing properties, as will be discussed further.

III. References