Near infrared high efficiency InAs/GaAsSb QDLEDs: band alignment and carrier recombination mechanisms

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The development of high efficiency laser diodes (LD) and light emitting diodes (LED) covering the 1.0 to 1.55 μm region of the spectra using GaAs heteroepitaxy has been long pursued. Due to the lack of materials that can be grown lattice-macthed to GaAs with bandgaps in the 1.0 to 1.55 μm region, quantum wells (QW) or quantum dots (QD) need be used. The most successful approach with QWs has been to use InGaAs, but one needs to add another element, such as N, to be able to reach 1.3/1.5μm. Even though LDs have been successfully demonstrated with the QW approach, using N leads to problems with compositional homogeneity across the wafer, and limited efficiency due to strong non-radiative recombination. The alternative approach of using InAs QDs is an attractive option, but once again, to reach the longest wavelengths one needs very large QDs and control over the size distribution and band alignment. In this work we demonstrate InAs/GaAsSb QDLEDs with high efficiencies, emitting from 1.1 to 1.52 μm, and we analyze the band alignment and carrier loss mechanisms that result from the presence of Sb in the capping layer.

The devices consist of a p-i-n structure where a single layer of InAs/GaAsSb QDs is immersed in the intrinsic region. The QDs were always formed by depositing 2.7 MLs of InAs under the same growth conditions, and the only variation was the Sb content in the 4 nm thick capping layer, which was changed from 0 to 28 %, as measured by cross-sectional scanning tunneling microcopy (X-STM) [1]. The p and n regions were doped with $2x10^{18}$ cm^{-3} Be and Si, respectively. Mesa structures were defined by wet chemical etching down to the buffer layer to electrically isolate the devices. Top ohmic ring contacts provided proper light extraction through the front surface, whereas a back ohmic contact was deposited on the entire substrate. The devices were mounted on TOs and wire bonded.

As shown in Fig. 1, as the Sb content in the capping is increased, the QDLEDs cover successfully the 1.1 to 1.52 μm region at room temperature. There is also an increase in the electroluminescence line width for wavelengths above 1.4 μm that could arise from increased QD size inhomogeneity. However, X-STM and AFM analysis show that this is not the case. Indeed, analysis of the electroluminescence emission as a function of injected current shows very different behaviors below and above 1.4 μm. Below 1.4 μm, both the ground state and up to two excited states can be observed, with a clear saturation of the lowest energy states at high currents, and negligible blue shifts, characteristic of a type I band alignment. Above 1.4 μm, at large currents, the ground state emission blue shifts strongly with current (Fig. 2), characteristic of a type II band alignment. However, even with a type II band alignment, the QDLEDs present an external efficiency close to the type I QDLEDs, and actually much larger than that of the reference Sb-free QDLED emitting at 1.15 μm (Fig. 3).

The analysis of the electroluminescence thermal quenching shows for the type I QDLEDs an activation energy for the ground state decreasing from 225 to 100 meV, for wavelengths shifting from 1.1 to 1.3 μm (Fig. 4). This decrease is consistent with the decreased valence band offset as the Sb is increased, and indicates that hole leakage from the QDs to the capping layer is the dominant carrier loss mechanism. In the case of the type II QDLEDs, the activation energy depends strongly on the injected current. At low currents, where the bands have a large slope due to the junction built-in field, the activation energy is quite large, around 275 meV, likely arising from hole leakage from the capping layer to the GaAs barrier. However, at high currents, where flat band conditions are achieved, the activation energy decreases down to ~150 meV (Fig. 4), which can be explained to arise from electron leakage from the QD excited states to the GaAs barrier and/or GaAsSb capping. Taking together the activation energies and the emission energies of the QDLEDs allows one to define the structure band alignment as a function of capping Sb content and wavelength.

[1] J.M. Ulloa et al., *Phys.Rev.B.* 81,165305, 2010.

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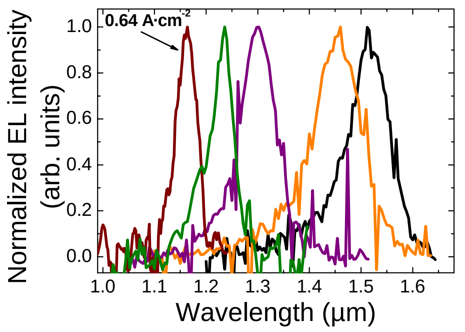

Fig 1: RT electroluminescence spectra from the QDLEDs.

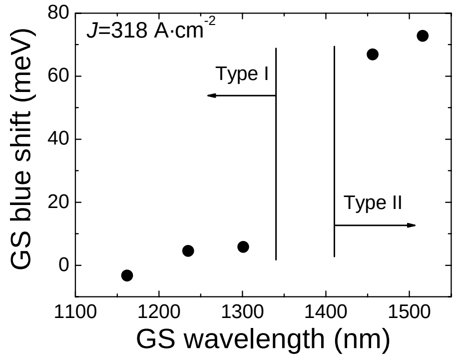

Fig 2: Ground state blue shift as a function of the emission wavelength at high injection currents.

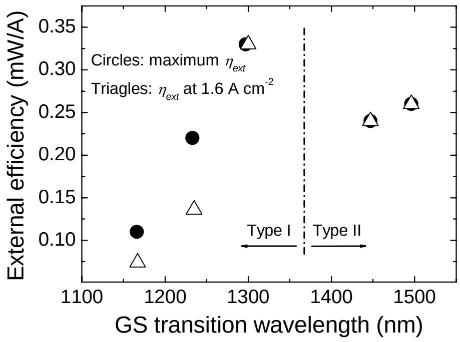

Fig 3: External efficiency of the QDLEDs at low injection current for the ground state emission.

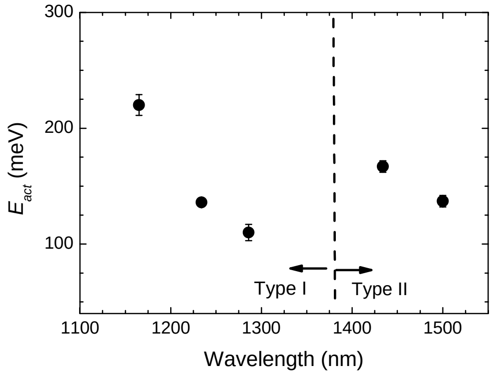

Fig 4: Electroluminescence thermal activation energy from the QDLEDs obtained between 200 and 300K under high injection current conditions.