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Mid-IR deep mesa LEDs

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Recent years have seen extensive research of the mid-IR (2-5 μm) diodes and resonant cavity LEDs [1] as well as conventional LEDs have already broken the 1 mW output power barrier that is necessary for most practical applications. In the latter case the main contribution to the power and extraction efficiency enhancement have originated from the implementation of the immersion lens technology together with episide-down bonding and broad mirror anode of a LED chip. However, curtain applications, such as spectroscopic measurements with gratings and detector system calibration, call for high brightness/apparent temperature rather than high power devices and thus the latter should be free of lenses that magnify the image dimensions. InAs LEDs with flat out-coupling surface emitting at 3.3 μm at room temperature have already shown the ability to simulate the black body heated up to 593 K (positive contrast ΔT = 300 K in the 3-5 μm range). In spite of high output power values that could be found in the literature for the flat uncoated LEDs it is clear that there is still a room for device performance improvements of the chip design.

Deep mesa that narrows the internal radiation diagram due to the reflections from the inclined mesa sidewalls contribute to the out-coupling enhancement and is thus a useful feature of the high brightness sources. The effect of the above geometrical factor is well known for the InSb (6 μm) negative luminescent devices [2] and efficient NIR and visible LEDs, however, to the best of our knowledge there have been no attempts so far to investigate the impact of the mesa dimensions on output power of the Mid-IR LEDs with wavelengths shorter than 6 μm.

We report on double heterostructure (DH) LEDs grown onto heavily doped n^+-InAs or undoped n-InAs (111) substrates with 2-7 μm thick active layers from n-InAs (λ=3.3 μm), n-InGaAsSb (λ=3.7 μm) and n-InAsSb (λ=4.3 μm) and p-InAsSbP claddings (for all LED types). Due to absorption in n-InAs the 3.3 μm LED structures additionally contained 30-40 μm thick lattice matched n+-$InGaAsSb_{0.06}$ (Te)/InAsSbP buffer that supports the structure after chemical removing of n-InAs substrate. Te concentration was in the order of (1-5) 10^{18} cm^{-3} that makes $InGaAsSb_{0.06}$ transparent for the radiation leaving p-n junction vicinity due to the Moss-Burstein effect. DH LEDs emitting at 1.94-2.3 μm were grown onto n-GaSb(100) substrates with GaInSbAs active parts. DHs were treated by two stage wet photolithography process that enable us to achieve 30-40 μm high sidewalls in a ~250 μm wide mesas with a 210 μm wide circular Au-anode in a flip-chip device.

Common features of the fabricated LEDs were superluminescence and blue shift of the emission spectrum at 77 K due to dynamic Moss-Burstein effect, current/emission crowding above the anode contact at 300 K and superiority of the negative luminescence power conversion efficiency over the forward one at elevated temperatures (say, at 480 K) due to suppression of the Auger recombination in a depleted active layer.

The report will focus on the discussion of experimentally observed impact of several geometrical factors (active layer thickness, mesa diameter and side walls height) on near and far field patterns, emission spectrum and output power including the best achieved light extraction enhancement factor of ~2 for the InAsSb (λ=4.3 μm) DH LEDs.

[1] A.M.Green et al , Physica E: Low-dimensional Systems and Nanostructures, Vol. 20(3-4), pp. 531-535 (2004)
[2] G.R.Nash et al , Physica E: Low-dimensional Systems and Nanostructures, Vol. 20(3-4), pp. 540-547 (2004)