Superlattices and Microstructures xxx (2016) 1–6

Contents lists available at ScienceDirect

Superlattices and Microstructures

journal homepage: www.elsevier.com/locate/superlattices

Bi-directional dual color mid-IR light emitting diodes

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ARTICLE INFO

Article history:
Received 13 September 2016
Accepted 14 September 2016
Available online xxx

ABSTRACT

We demonstrate a two-contact, bi-directional, dual color light emitting diode with superlattice active regions operated at wavelengths near 4 μm and 8 μm. The operational wavelength of the device is controlled by the bias polarity. A modification of the long wavelength superlattice facilitated hole transport into the corresponding active region and lead to a more than fourfold increase in output optical power.

1. Introduction

Dual Color Light emitting diodes (LEDs) operating in the spectral range from 3 μm to 12 μm have shown increasing potential in mid-wavelength infrared (MWIR) and long-wavelength infrared (LWIR) optoelectronic applications, such as chemical sensing and infrared scene projection [1–3]. A dual color LED is an ideal emission source for a chemical sensor since one device can be used to generate both the probe and reference spectral channel. Both channels operate at the same temperature using a single optical path for improved sensor stability and cost and volume savings. Independently controlled dual color LEDs allow IR scene projection in two spectral regions from one LED array [1].

GaSb based dual color mid-IR LEDs previously demonstrated [1–3] have three electrodes: two – for independent control of the "colors" and one common ground. The three-electrode package greatly complicates the device fabrication and increases the cost of the LED. In this work we demonstrate bi-directional dual color LEDs with the operation wavelength controlled by the polarity of the bias. The idea of a light emitter with wavelength controlled by the bias polarity was demonstrated earlier by C. Gmachl et al. [4] with a specially designed QCL whose wavelength was controlled through the bias polarity.

Applying this approach to high brightness LEDs utilizing interband optical transitions,yields important advantages which make it attractive for both chemical sensing and IR scene projection. The bi-directional LED has two electrodes, greatly simplifying the device processing as it is not necessary to establish a contact to an intermediate semiconductor layer. This is especially important for the fabrication of a two-color addressable LED array since the required fabrication process is similar to a single color LED array. The lateral geometry of the emission area is identical for both colors, which ensures the same optical path and emitter temperature for both the probe and reference channels of a gas sensor based on the bi-directional LED.

The device comprises two LED structures with different active areas grown on top of each other. The schematic band diagram of the device is presented in Fig. 1. The devices are electrically in inverse series connection. In operation one of the LEDs is forward biased while the other one is reverse biased. The operating principle of the bidirectional LED is that LEDs with a narrow gap bulk, quantum well (QW), or superlattice active region can stand high reverse currents without significant voltage penalty or device damage. Thus, at any bias polarity, the directly biased LED (say, LED # 1) emits light while the LED

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http://dx.doi.org/10.1016/j.spmi.2016.09.019

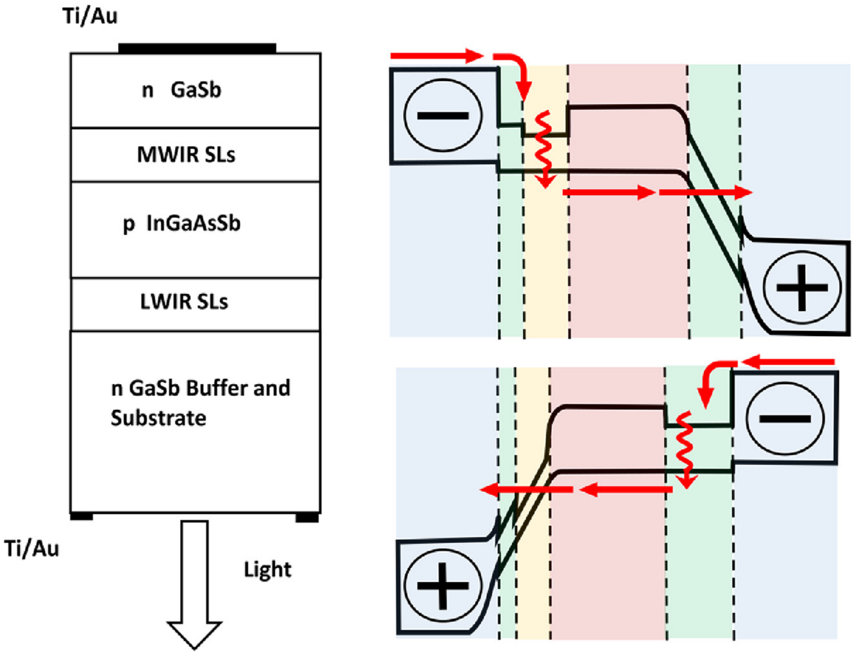

Fig. 1. Cross-section view of fabricated device with layer sequence (left). Schematic band diagrams of the bi-directional dual color LEDs under bias of different polarity (right).

which is under reverse bias (#2) is conducting current without generating light. As the bias polarity is reversed the light is emitted by LED#2 while LED#1 is carrying reverse current without generating light. Using a reverse biased p-n junction as a connection region between two cascades of a light emitting device was demonstrated in Refs. [5,6]. In Ref. [5] a quantum well was inserted in the p-n junction to facilitate interband tunneling. In our design, each active area has dual function: it works as a light emitter under forward bias and as a connection region under reverse bias.

This work we demonstrates a bi-directional dual color LED operating in mid-wave (MWIR) and long-wave (LWIR) infrared spectral regions. The flexibility of the GaSb material system allows for considerable flexibility as wavelengths from 1.8 μm to beyond 15 μm can be generated.

2. Material and methods

The SLs LEDs used in the experiment were grown by molecular beam epitaxy on n-type GaSb substrates. A total of three dual color LEDs and one reference single color LWIR LED were grown. The details of MWIR and LWIR superlattice active regions [7,8] are summarized in Table 1. Each structure except the reference LED comprises MWIR and LWIR active regions connected in inverse series. A p-doped GaSb or InGaAsSb layer works as a connection region between MWIR and LWIR active layers. Both LWIR and MWIR emission were outcoupled through the substrate. To minimize optical absorption of LWIR emission, the corresponding active region was grown closer to the substrate. The schematic band structure of a dual color LEDs is shown in Fig. 1.

The devices were processed into deep etched circular mesa emitters with a diameter of 500 μm. The devices had Ti:Au contacts on the epi side. The n-metal contact on the substrate side had a circular aperture with a diameter of 600 μm. The center of the aperture was aligned with the center of epilayer contact, as shown in Fig. 1. The electroluminescence (EL) spectra were measured at 77 K with using a Fourier Transform Infrared (FTIR) spectrometer equipped with a mercury-cadmium-tellurium (MCT) detector (cutoff wavelength 18 μm), and a lock-in amplifier. The devices were powered by pulse

Table 1
Details of the LED active area.

LED#	MWIR SLs			P doped layer	LWIR SLs		
	InAs (nm)	GaInSb (nm)	# of periods		InAs (nm)	GaSb (nm)	# of periods
1	–	–	–	GaSb	2.8	1.8	15
2	1.8	2.0	15	$In_{0.1}GaAs_{0.088}Sb$	2.8	1.8	15
3	1.8	2.0	15	GaSb	2.8	1.8	15
4	1.8	2.0	15	$In_{0.1}GaAs_{0.088}Sb$	3.2	1.8	15

Please cite this article in press as: S. Suchalkin et al., Bi-directional dual color mid-IR light emitting diodes, Superlattices and Microstructures (2016), http://dx.doi.org/10.1016/j.spmi.2016.09.019