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High emissive power MWIR LED array

Naresh C. Das [a,*], Kim Olver [b], F. Towner [c]

[a] Microphotonics Branch, Army Research Laboratory, 2800 Powder Mill Rd., Adelphi, MD 20783, USA
[b] IR Materials Branch, Army Research Laboratory, 2800 Powder Mill Rd., Adelphi, MD 20783, USA
[c] Maxion Technology, 6525 Belcrest Road, Suite 523, Hyattsville, MD 20782, USA

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Abstract

Mid-IR light sources with high optical power are required for many applications. We report here the mid-IR (3.8 μm) light emission from an interband cascade (IC) LED structure with an equivalent black body emissive temperature greater than 1050 K. The IC epitaxial structure for LED comprises of 9 or 18 periods of active regions separated by multilayer injection regions. We have made an 8×7 2D LED array with different mesa sizes. The light output as well as the efficiency increases with the increase of mesa size and the number of active/injection layers in IC LED structure.
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Keywords: Light emitting diodes; IR scene generation; Interband cascade structure; Surface roughening; Black body emissivity

1. Introduction

Passive IR imaging and IR detector arrays for seekers now play a very important role in missile defense operations and systems as well as for other DOD applications. These operational capabilities can sometimes be tested by actual field operations. Effective means of synthesizing and projecting dynamic IR scenes into these IR sensors has proved to be very valuable for equipment characterization, validation, and functional testing in varying scenarios. The seeker testing requires large 2D array, high frame rate and large dynamic range IR sources. Several IR sources have been integrated into the hardware in the loop (HWIL) facility in the past, including a scanning laser array [1], resistive array [2–4] and digital micro-mirror devices (DMD) [5]. The state-of-the-art resistive array projector systems have limited frame rate capability due to the transition (rise and fall time) associated with the resistors [3]. With the scanning laser projectors [6], the smearing effect and non-uniformity are concerns. And, the optical modulator based projectors [5] produce an insufficient extinction ratio. The LED array with sufficient dynamic range should be able to provide higher fidelity IR output than the current IR projectors. Besides the IR scene projector function, other mid-IR light source applications include infrared counter measure (IRCM), chemical warfare monitoring, medical diagnostics and gas sensing [7]. Because of considerable advantages in terms of cost, volume, long-term reliability, and fast switching speed, mid-IR LEDs are desirable for many such applications.

Interband cascade (IC) electroluminescence in the 5–8 μm spectrum regions from the LED structure has been reported by Yang et al. [8]. We have reported [9] the LED light emission in the 3–4.5 μm wavelength regions with peak emission at 3.8 μm for room temperature operation. However, these LED devices exhibit very

* Corresponding author. Tel.: +1 3013945500; fax: +1 3013940609.
E-mail address: ndas@arl.army.mil (N.C. Das).

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low wall-plug efficiencies (WPE). This is due to its low internal quantum efficiency at room temperature and its low extraction efficiency associated with high refractive index of GaSb semiconductor material. Efforts have been made to improve mid-IR LED internal quantum efficiency by changing the number of cascade active/injection periods [10]. In order to simulate high temperature target in hardware in the loop (HWIL) testing, it is desirable to obtain very high LED output power. In this paper, we report our findings on the effect of different device structures on mid wave IR LED emission power. Significant increase in light output power is observed due to thinning of the substrate and roughening of the GaSb emission surface. The effective emission temperature from the LEDs is greater than 1050 K when operated at liquid nitrogen temperature.

2. Device fabrication

The band diagram of two periods of an InAs/GaInSb/AlSb type II QC device under forward bias is shown in Fig. 1. The n-type InAs/Al(In)Sb injection layer serve both as collector for the preceding region and emitter for the following ones. The active region, sandwiched between two p-type contact layers, consists of 9 or 18 cascaded active/injection periods. Each period includes an asymmetric InAs/GaInSb/InAs "W" quantum well preceded by an n-type digitally graded InAs/Al(In)Sb injector [11]. The advantage of using quantum cascade layer is that the recycling of carriers occurs for efficient photon emission, i.e., the sequential transport from an active emitting region to the downstream next active region. In this structure, carriers emit in principle as many photons as encountered active regions during their transport. It has also been demonstrated that the external efficiency of photon emission scales with the number of cascade periods.

The interband cascade LED structure was grown by Varian Gen-II molecular beam epitaxy machine on a (100) p-type GaSb substrate. Following removal of the native oxide at 570 °C, a 0.4 μm p^+ GaSb bottom contact layer was grown at a substrate temperature of 490 °C, as measured by a thermocouple located behind the wafer. The temperature was reduced to 400 °C for growth of the active/injection regions, which consisted of InAs, AlSb, GaSb, and InGaSb layers. The substrate temperature was raised to 490 °C once again for the 1.4 μm p^+ GaSb top contact layer, which is required for generating grating on the surface.

The device fabrication starts with the grating texture formation on the mesa area using wet chemical etch followed by mesa area definition by dry etching using inductively coupled plasma (ICP) system. The grating was made using a 1.5 μm line width, with 3 μm pitch and etched to 1.0 μm depth. The square mesa sizes vary from 40 to 200 μm. The etch depth for mesa isolation was 3.0 μm. Silicon nitride was deposited by plasma enhanced chemical vapor deposition technique. Contact windows were opened. Ti/Au metallization was done by e-beam evaporation technique for both top and bottom contacts. Since we intend to observe light from the bottom side of the wafer, the top mesa was completely covered by the Ti/Au metal. The 2D array of LED devices is diced and flip chip bonded with epoxy under filled to a fan-out array. Fig. 2 shows the schematic diagram of the cross-sectional view of the LED array flip chip mounted on silicon fan-out array. The GaSb substrate from the bottom side of the device was manually thinned using number 4000 (2–4 μm grit) SiC paper. The final thickness of GaSb substrate was measured by optical microscope as well as by the Fourier transform infrared (FTIR) spectrometer. The devices were mounted on a 68 pin grid array package for device testing.

In Fig. 3(a) we have shown the picture of the single LED mesa with linear grating. The middle of the picture shows the indium bump before the chip is flip chip mounted onto the silicon fan-out array. The part of the 7 × 8 LED array is shown in Fig. 3(b). The array has 100 μm^2 mesa devices with 100 μm spacing. Each

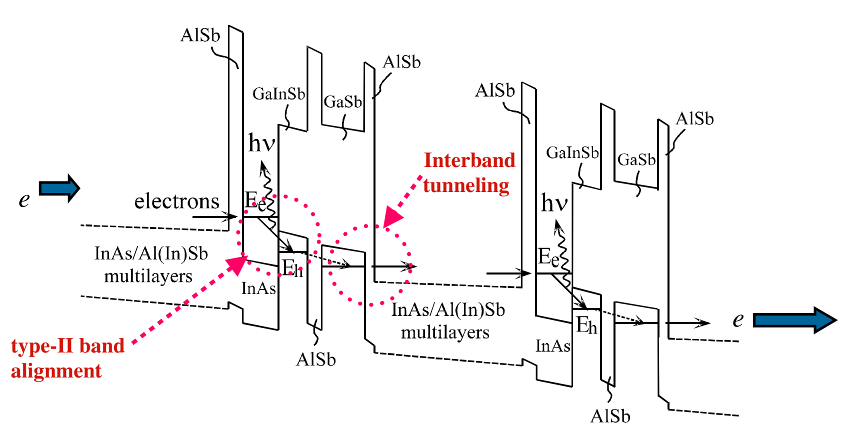

Fig. 1. The band diagram of interband cascade structure.