Highly efficient individually addressable diode lasers at 830 nm grown by solid source molecular beam epitaxy

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Over 55% power efficiency in 830 nm wavelength range has been demonstrated for four-element individually addressable laser diode mini-arrays. Diodes' performance indicates excellent uniformity, repeatability and quality of epi-wafers grown by solid source molecular beam epitaxy (SS MBE). Slope efficiencies of as high as 1.33 W/A and over 1.7 W CW optical outputs at 1.5 A driving current have been achieved from each of the four 55 μm wide aperture diodes constituting the mini-arrays.

Keywords: High power laser diodes; Infrared laser mini-diodes; Molecular beam epitaxy

1. Introduction

Laser diodes emitting in the range of 830 nm find important application in the graphic art industry [1]. To enhance the printing quality and speed up the process the industry requires high power highly efficient individually addressable mini-laser diode arrays. One of the most sophisticated products is the MEP-4, multi-emitter four-element package [1]. In this package each of the four 55 μm wide aperture diodes is fiber coupled into an individual 60 μm-diameter optical fiber. The schematic configuration for the MEP-4 package is shown in Figure 1. Here we report on high power, high efficient performance of individually addressable mini-arrays processed and packaged in this configuration.

2. Characterization

The laser structures used for this work were grown via Solid State Molecular Beam Epitaxy (SS MBE) on n-type 2" diameter GaAs substrates. Needle valve cracker cells were used to generate arsenic and phosphorus fluxes, while standard effusion cells were used to evaporate gallium, indium and aluminum. Specifically, this structure was comprised from two different types of quaternary solid solutions: $(Al_xGa_{1-x})_yIn_{1-y}P$ [2] and $Ga_xIn_{1-x}As_yP_{1-y}$ [3]. Such approach allows combining the advantages provided by these two different material systems: high reliability and high performance of the laser diode devices. Careful layered structure design and optimization of the MBE deposition conditions resulted in excellent laser material quality. The quality and uniformity of SS MBE-grown epi-wafers was confirmed by high resolution X-ray diffraction and photoluminescence mapping techniques. In production, due to high uniformity of MBE-grown bulk and quantum size (thinner than 100 Å) ternary and quaternary layers, the photoluminescence peak wavelength position across two-inch wafers did not vary more than two nanometers. The standard deviation of the photoluminescence peak position recorded for over 300 production runs is shown on Fig. 2.(a). Over 50% of the wafers have PL peak position uniformity better than 1nm, with the remaining wafers uniformity not exceeding 1.5 nm. Typical photoluminescence wavelength distribution across the two-inch substrate recorded non-destructively for 830 nm range laser material gives standard deviation of peak wavelength position of 0.102 % or 0.84 nm as showed in Fig. 2.(b)[4].
To further characterize the material quality, the wafers were processed into 100 μm wide broad area contact diodes. Diodes with the cavity length varying from 600 μm to 2000 μm were bonded p-side down to LT heat sinks. Pulsed current measurements were performed for these devices with the following test conditions: pulse width of 1-5 μsec, duty cycle of 1–10 %. Heat sink temperature was varied in the range of 20-to-70°C. The cavity length analysis yielded the following material parameters: internal loss, $\alpha_i < 2$ cm^{-1}, internal quantum efficiency, $\eta_i \approx 100\%$.
Characteristic temperatures T_0 and T_1 were measured to be as high as ≈ 220°K and ≈ 900°K, respectively for the diodes having 1300 μm cavity length. To provide efficient lensing and fiber coupling with 60μm-wide core diameter fibers, devices having 55μm apertures were manufactured. An optimized cavity length was selected for this packaging configuration to ensure high efficient device performance at 1.5A specification current. The mini-bars were bonded junction side down to patterned metallized ceramic heat sinks utilizing proprietary assembling technique [1]. Preliminary burn-in data on the devices with uncoated facets did not reveal any failures or degradation after more than 700 hours of CW operation at constant current condition of 1.5A. This test was performed in regular room ambient environment; optical power density on the uncoated facet was as high as 10 - 16 mW/μm. Devices with the facet coating were also tested under high driving current conditions. Typical free-space power curve for the 55 μm wide diode for a MEP mini-bar is presented in Fig. 3. As one can see from this plot, optical power density on the facet of about 45 -50 mW/μm does not result in catastrophic optical damage. The thermal process typically limits high power devices' operation.
Special efforts were undertaken to minimize the lateral divergence of the diodes. Series of improvements in processing steps was implemented in order to keep the

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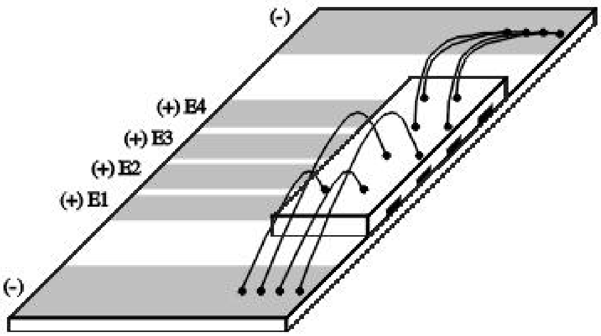
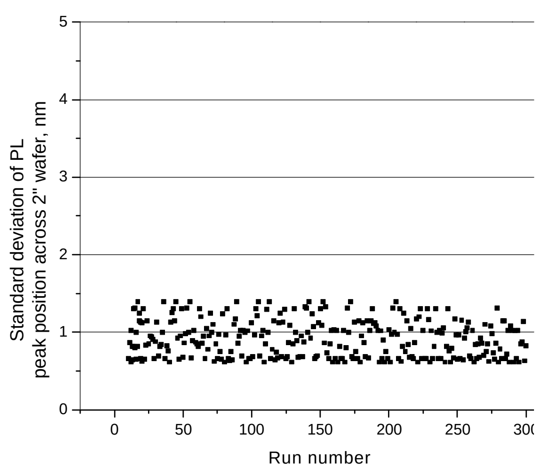
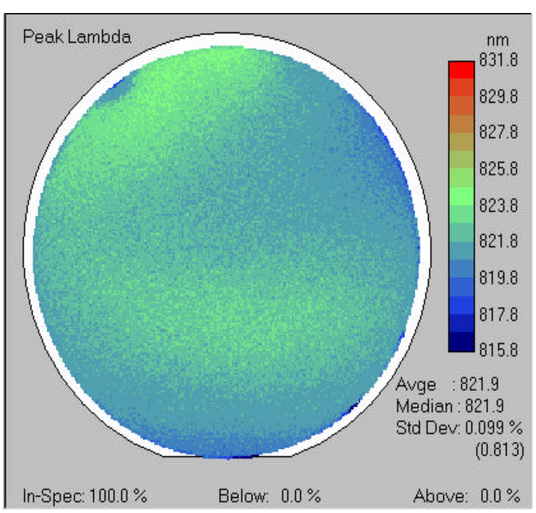


Figure 1. Schematic representation of the MEP-4 MINI ARRAY mounted onto a submount carrier. Electrical contacts for emitters 1 – 4 are indicated by (E1) thru (E4).



(a)



(b)

Figure 2. (a). Standard deviation of PL peak position as a function of an epitaxy run number; 2.(b). PL mapping profile of two inch wafer.

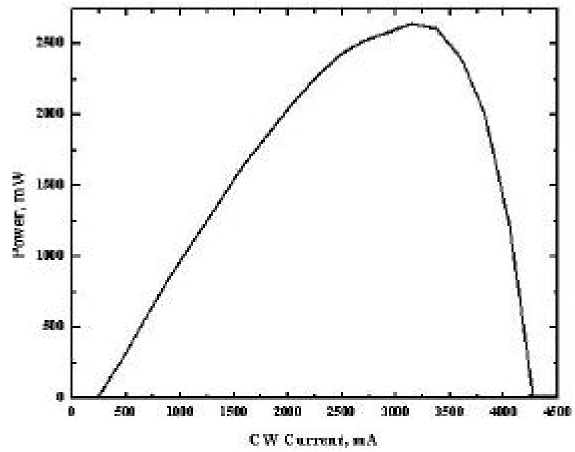


Figure 3. Typical free-space CW light output-current curve of a 55 μm wide diode of a MEP mini-array at high current driving conditions.

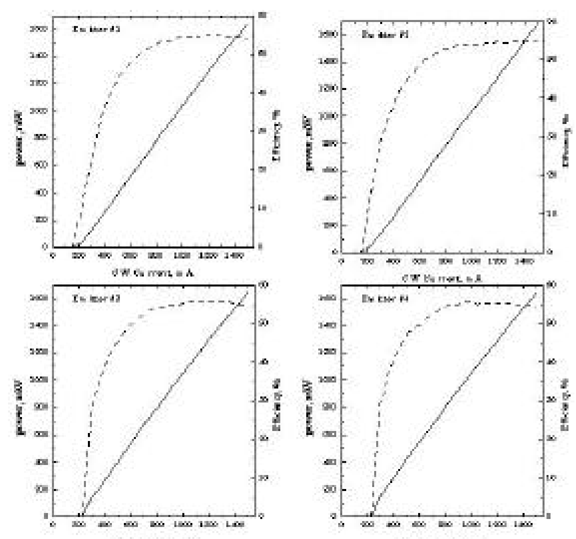


Figure 4. Lasing spectra for each emitter comprising the individually addressable MEP-4 device at a driving current of 1.5 A CW.

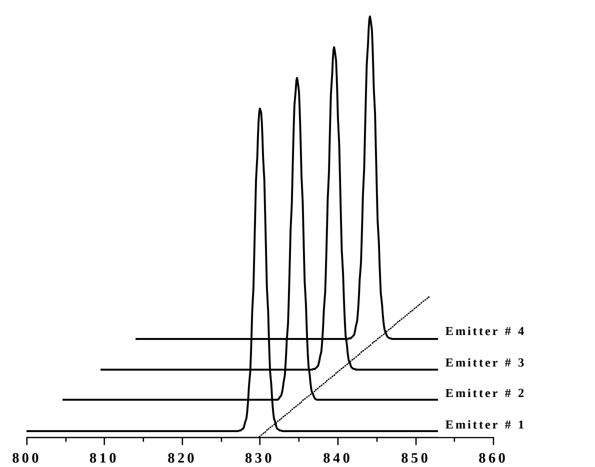


Figure 5. Average per emitter output power of MEP-4 devices as a function of an epitaxy run number. Driving current is 1.5 A at 25 ^{o}C.

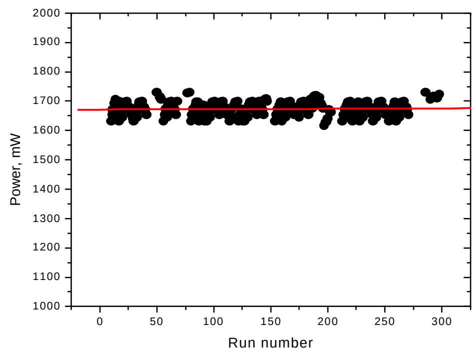


Figure 6. Optical power of MEP-4 device recorded from more than 300 epi-runs.

lateral divergence lower than 10°. Such low lateral divergence in combination with relatively narrow transverse divergence of ≈ 32-34°, yielded the overall coupling efficiency of > 60-65 %.

Fig. 4 demonstrates the CW free-space performance of an individually addressable MEP-4 device for each emitter. Maximum power achieved at a specification CW current of 1.5 A for the four elements ranges from 1700 to 1730 mW, peak power efficiency varies from 54.9-to-55.2%, peak slope efficiencies were around 1.33 W/A. Figure 5 shows the lasing spectra for each emitter at a driving current of 1.5 A CW. As one can see the lasing peak position for all elements differs from each other by only ± 1 nm. The data presented in Figures 2, 4 and 5, confirm excellent uniformity of processed laser wafers and the overall assembly process. In production environment, however, repeatability of the process plays more important role that any record parameters. Fig. 6 shows typical optical power of the MEP-4 devices recorded from over 300 epi-runs during almost a year of production.

3. Conclusion

High power efficiency operation of individually addressable laser diode mini-array manufactured from MBE-grown material was demonstrated. SS MBE has proven to be very reliable and reproducible technique for high power laser applications. In terms of reliability, the initial data on high optical density operation screening of the uncoated devices demonstrate high potential for these diodes. Over 50% power efficiency for a 55 µm-wide emitters was maintained in the wide range of driving currents; peak power efficiency over 55% was recorded. Slope efficiencies were as high as 1.33 W/A.

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