TWO-DIMENSIONAL ARRAY OF GaInAsP/InP SURFACE-EMITTING LASERS

Indexing terms: Lasers and laser applications, Semiconductor devices and materials, Semiconductor lasers

We have improved the mirror quality of a GaInAsP/InP surface emitting laser with a ring electrode on a round mesa cap. The minimum threshold current has been reduced to 35 mA at 77 K, and the uniformity of the laser threshold has been improved. The first two-dimensional (2 × 2) laser array has been demonstrated.

A conventional injection laser consists of two cleaved or etched end mirrors perpendicular to the active layer, so that only one-dimensional laser arrays can be monolithically fabricated. On the other hand, since the surface-emitting (SE) laser[1] utilises two surfaces of the epitaxial layers, and the light output is taken vertically from the wafer, it is possible to prepare two-dimensional laser arrays. To do this with conventional stripe lasers, a very special 45° mirror must be prepared.[2] Recently we demonstrated a GaInAsP/InP SE laser with a threshold current of 50 mA at 77 K under pulsed conditions,[3] and obtained one which operated up to 188 K by improving some of the structures.[4] However, the laser array was not obtained because the threshold current varied widely throughout the same wafer, owing to the nonuniformity of the mirror quality.

In this study, we have tried to improve a part of the SE laser structure, and the uniformity of the laser characteristics has been increased. A two-dimensionally arranged laser array (not a phase-locked array) has been demonstrated.

Fig. 1 shows the structure of a partially improved GaInAsP/

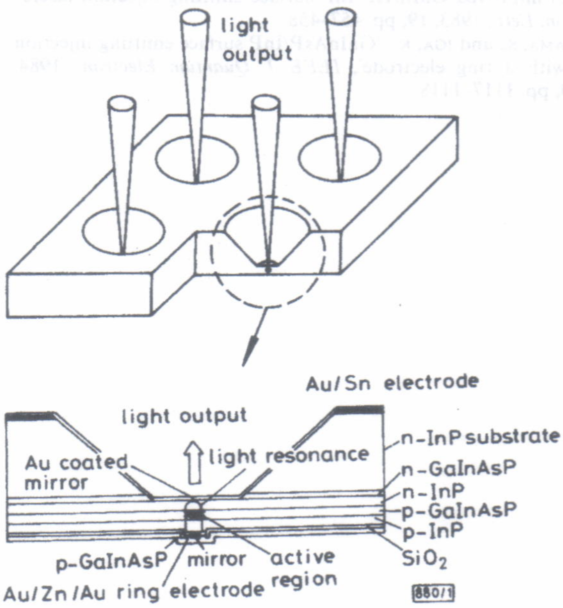

Fig. 1 *Schematic view of an SE laser*

InP SE laser. As shown in Reference 4, to increase the *p*-side reflectivity, a ring electrode, in which a reflecting mirror is separated from the *p*-side electrode, was used. In addition to this, a round mesa cap structure, which prevents current spread in the Zn-diffused GaInAsP cap layer with a low resistance, was introduced. The fabrication process of this laser is the same as one described in Reference 4, except the forming of the round mesa cap structure. The round mesa with 30 μm diameter and about 1 μm height was formed by chemical etching, and then the ring electrode with inner and outer diameters of 10 μm and 20 μm, respectively, were formed by evaporating Au/Zn/Au metal on it.

Fig. 2 shows the current/light-output (*I/L*) characteristics for laser chips (the active layer thickness $d = 1.6$ μm and the cavity length $L = 8$ μm) which were separated from the same wafer. The lasers were operated at 77 K under pulsed conditions, with a pulse width of 100 ns and a repetition rate of 1 kpps. The values of the threshold current were 35–60 mA, and the uniformity of laser quality was much better than before. The minimum threshold current was 35 mA, and this is

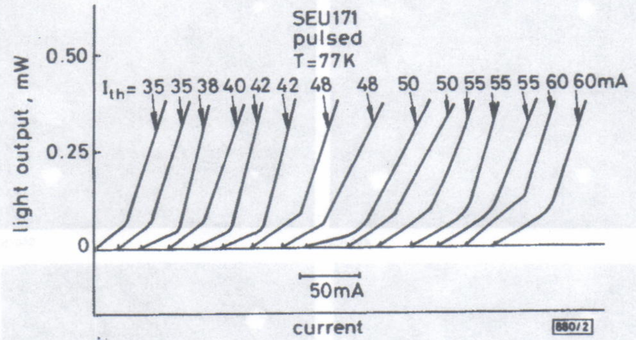

Fig. 2 *Injection-current/light-output characteristics of the SE lasers from the same wafer at 77 K under pulsed conditions*

smaller than the previous case,[1] where an annealed Au/Zn metal on GaInAsP was used as a *p*-side mirror. The thresholds were scattered from 100–200 mA, and a few with the minimum I_{th} = 50 mA were also obtained.

From this wafer, a 2 × 2 laser array (not a phase-locked array) was cut. The separation of lasers was 1 mm. These are numbered as shown in Fig. 3. The *I/L* characteristic and the

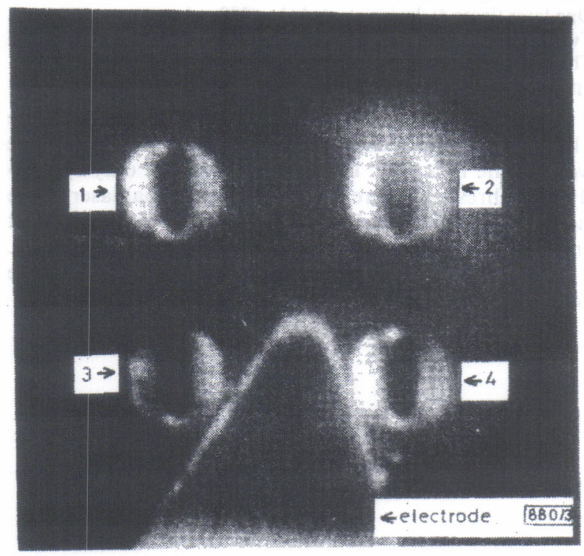

Fig. 3 *View of 2 × 2 SE laser array*

near-field patterns of this laser array at 77 K are shown in Figs. 4 and 5, respectively. Fig. 5*a* shows spontaneous emission below the threshold (I = 180 mA). When the current exceeded 200 mA, laser 4 began lasing (Fig. 5*b*) whereas laser 1 began lasing at 220 mA (Fig. 5*c*). Finally, laser 3 began

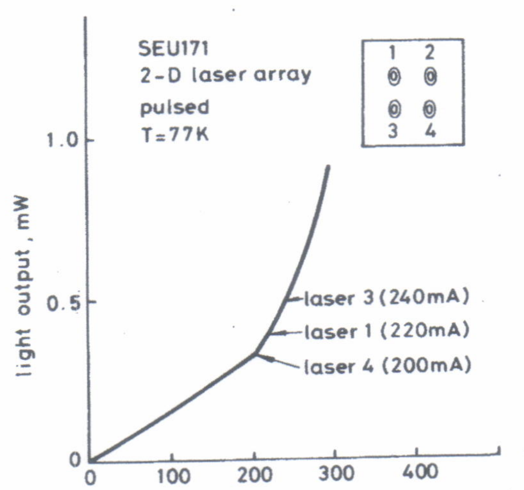

Fig. 4 *An injection current against light-output characteristic of the laser array*

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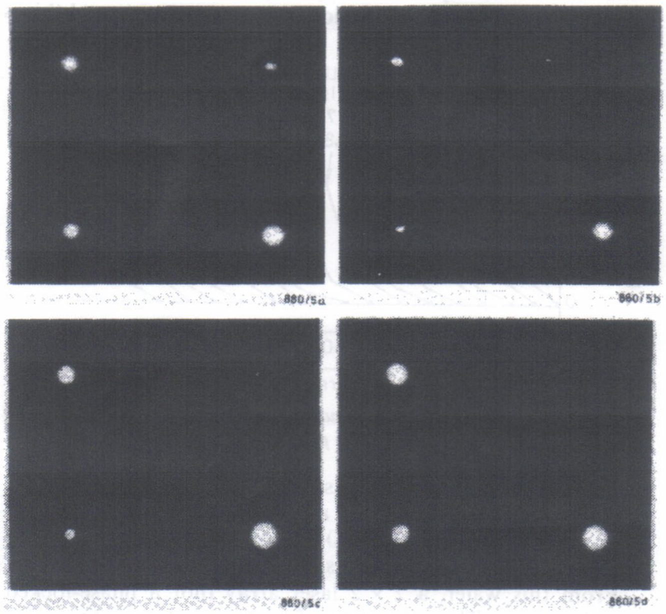

Fig. 5 *Near-field patterns*

a Below lasing oscillation (I = 180 mA)
b One laser (laser 4), lasing started (I = 200 mA)
c Two lasers (lasers 4 and 1) lasing started (I = 220 mA)
d Three lasers lasing (lasers 4, 1 and 3) (I = 240 mA)
Chip 2 was emitting light only spontaneously

lasing at 240 mA (Fig. 5*d*), and the lasing oscillation of the three lasers which formed the two-dimensional array were observed for the first time. Laser 2 emitted light only spontaneously. The threshold currents of three individual lasers were 50 (laser 4), 55 (laser 1) and 60 mA (laser 3). This experiment also presents an example of wafer level testing for an SE laser. From observation of the far field pattern of this laser, these lasers did not interfere with one another.

In summary, we have fabricated a GaInAsP/InP SE laser with a ring electrode on a round mesa cap. The minimum threshold was 35 mA, and the laser quality has been improved. A two-dimensional laser array (not a phase-locked array) and wafer-level testing of SE lasers have been demonstrated. A phase-locked two-dimensional array with closer separation is expected to be possible.

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