Double-heterostructure GaAs-GaAlAs injection lasers on semi-insulating substrates using carrier crowding[a)]

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GaAs-GaAlAs double-heterostructure lasers were fabricated on semi-insulating substrates. Laser action based on carrier confinement via the crowding effect has been demonstrated. Laser action takes place in a narrow (10–20 μm) region near the edge of the mesa where the current is injected. The threshold current is low and is comparable to that of stripe-geometry lasers.

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The prospect of a GaAs-based integrated optics technology[1,2] envisages a variety of electronic and electro-optic components such as lasers, modulators, detectors, FET transistors, etc., incorporated monolithically on a single-crystalline chip of GaAs. The electrical insulation of the individual components can be achieved by using a semi-insulating substrate. In this paper we report, the first GaAs-GaAlAs double-heterostructure (DHS) laser fabricated on a semi-insulating substrate. The lasers possess a narrow and confined active region along the junction plane. The threshold current is low and is comparable to the conventional stripe-geometry lasers. The transverse carrier and optical confinement are due to the carrier crowding effect.[3]

The structure of our crowding effect laser (CEL) is shown in Fig. 1. Current injected through the Au-Zn p-type contact flows through the p-GaAs layer into the mesa region. Due to the sheet resistance of the p-GaAs and p-GaAlAs layers the potential drop across the p-n junction decreases with distance from the edge of the mesa. This causes the injected current to cross the p-n junction in a narrow stripe adjacent to the edge of the mesa. This current crowding yields a narrow effective gain region near the mesa edge. It also results in a laser structure in which both current contacts are applied from the same direction and so can be interconnected with other monolithic components.

The crowding effect lasers consist of five epitaxial layers grown on a semi-insulating GaAs substrate. The LPE growth starts with the p-type layers and ends with the n-type GaAs layer. The structure is similar to the conventional DHS laser but in reverse order. The active layer of GaAs is not intentionally doped. The layers neighboring it are n- and p-$Ga_{1-x}Al_xAs$ ($x \sim 0.4$) doped with Sn and Ge, respectively. The first layer, p-GaAs, and the top layer, n-GaAs, are prepared for providing good Ohmic contact with the metals. The typical thickness of the layers, starting from the bottom in Fig. 1, is 3, 2, 0.3, 2, and 1 μm. After the growth Au-Ge-Ni was first evaporated all over the wafer. A part of this layer was removed photolithographically. The remaining metal served as the mask for the selective etching of the layers. The etching results in a steplike structure with edge parallel to the $\langle 110 \rangle$ direction. The etching must be deep enough to reach the p-GaAs layer since Ohmic contacting to p-GaAlAs is poor. The etchants used are $H_2SO_4(4):H_2O_2(1):H_2O(1)$ and HF. The first solution etched the layers down to the p-GaAlAs region and the second solution removed the remaining p-GaAlAs selectively without attacking the p-GaAs layer. After etching, a second evaporation was performed. Au-Zn was used for the p-type contact. In the evaporation system the sample was tilted at an angle to the metal source so that the edge of the step provided a shadow to the evaporation and the metal contacts on the first layer and on top of the mesa were separated. The cross section of the final structure is shown in Fig. 1. The laser chip was mounted on a Cu heat sink with two contact leads up. Since the size of the active region is not determined by the area of the contact, one can cut a wide chip and use a broad top contact for the purpose of smaller resistance and easy handling.

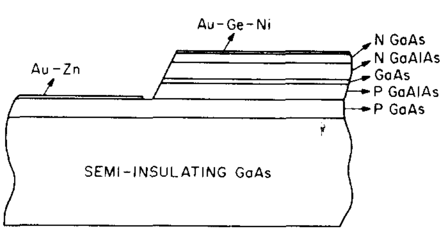

FIG. 1. The cross section of a CEL laser diode.

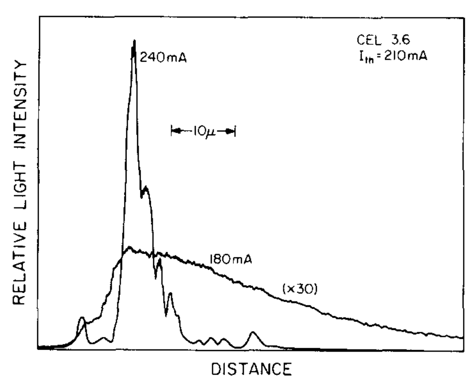

FIG. 2. Recorder traces of the mirror illumination parallel to the junction plane below and above lasing threshold.

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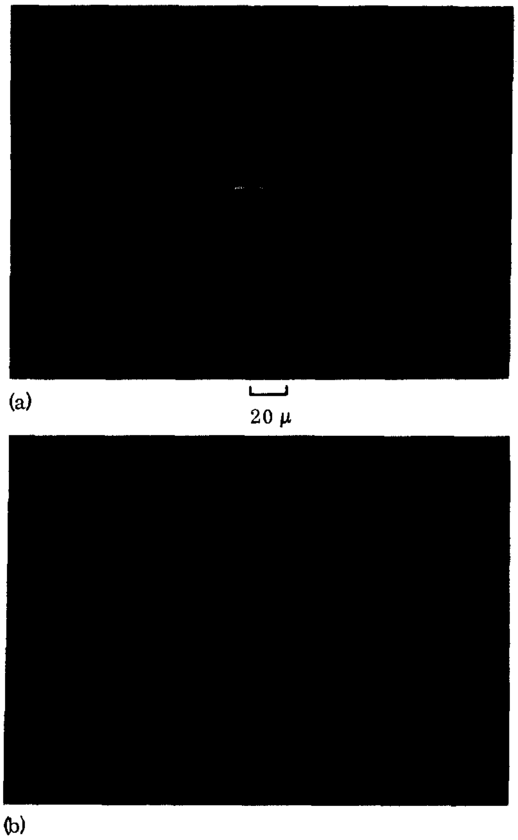

FIG. 3. The near field radiation pattern of a CEL with current (a) 10 mA, and (b) 250 mA. The threshold current of this laser is 240 mA.

The distribution of injected carriers as a function of distance from the mesa edge is obtained from data such as shown in Fig. 2 which consists of a recorder trace of the optical intensity along the mirror. The 180-mA trace is taken below threshold and is thus a reliable replica of the spontaneous-emission intensity and the carrier density under the mesa. The 240-mA trace is above threshold and its narrowness is due to the transverse confinement of the laser modes. This confinement is due to the monotonic decrease of the gain as a function of distance from the mesa edge. It is thus similar in kind to that obtained in stripe contact[4] and TJS lasers.[5] A solution of the electromagnetic mode problem of this structure has been accomplished and will be discussed in detail elsewhere. The laser intensity distribution of Fig. 2 (the 240-mA trace) corresponds to a superposition of a number of transverse modes.

The laser threshold current at room temperature in a typical CEL with a length ~350 μm is about 200 mA. The external quantum efficiency is about 25%. The photographs of the near-field pattern of a CEL diode at different currents are shown in Fig. 3. The pictures

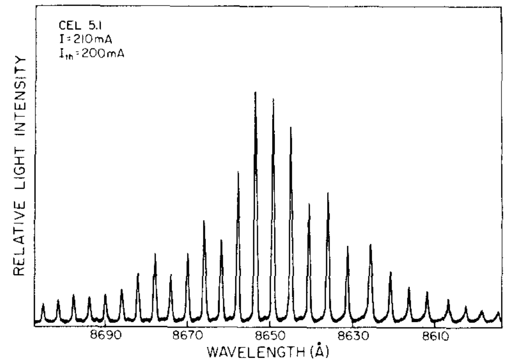

FIG. 4. Lasing spectrum of a CEL.

give direct evidence of the crowding effect. Figure 3(a), with a current 10 mA, way below threshold, shows a light distribution extending a long distance (~100 μm) under the mesa. Figure 3(b), with current above threshold, shows much narrower light distribution. Most of the laser light is due to a region some 10—15 μm wide near the edge of the mesa. Figure 4 is a spectrum of a typical CEL laser. The lasing output is TE polarized as that of regular DHS lasers.

Since the crowding effect depends on the sheet resistance of the first two layers, it is possible to control the width of the injection region (the active region) by varying the thickness and the doping concentration of these layers. We have used a carrier concentration of $\sim 2\times10^{18}/\text{cm}^3$ in the first layer with a thickness ~3 μm. The second p-GaAlAs layer is more lightly doped. The crowding effect in our case is thus controlled by the first layer.

In conclusion we have fabricated GaAs-GaAlAs DHS lasers on semi-insulating substrates. The active region is effectively confined due to the crowding effect. The threshold current is comparable to conventional stripe-geometry lasers. Because the lasers are fabricated on semi-insulating GaAs and operated at low current, it is possible that integration with other devices such as GaAs Schottky FET can be achieved.

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