Large optical cavity AlGaAs injection lasers with multiple active regions

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A new type of AlGaAs injection laser is described. The structure consists of alternating *p*- and *n*-type layers of GaAs and $Al_x Ga_{1-x}As$. The electrical mode of operation of the device is that of a Shockley diode (SCR). Optically the device operates as a large optical cavity. Single transverse mode operation was observed with optical cavities larger than 4 μm.

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The combined operation of AlGaAs *pnpn* Shockley diodes (SCR) as injection lasers[1,2] and the operation of a homostructure multilayer GaAs device[3] have been demonstrated. However, no analysis was given of the multilayer device. The main attractiveness of these devices is in the pulsed mode of operation, where the bistable characteristics of the SCR are exploited.

We report here a new type of related device. The basic structure consists of alternating *p*- and *n*-type layers of GaAs and $Al_x Ga_{1-x}As$, with the GaAs layers serving as the active regions of the device.

The basic rationale for the device is the desire to increase the active mode volume, hence the power, of a laser by having a number of otherwise independent lasers coupled together via their evanescent mode fields. This goal can also be achieved by conventional large optical cavity lasers.[4] However, splitting the active region volume into several separated layers may give more degrees of freedom in designing the optical and electrical properties of the device. The proper way of regarding the resulting electromagnetic field is as the mode of a layered strucutre in which a number (four in our case) of high index GaAs layers are separated from each other by lower index $Ga_{1-x}Al_xAs$ layers.[5]

The electrical design is such that the high index GaAs layers become the active regions where gain takes place.

By extension of the two-transistor model or by direct solution of the diffusion equation of the entire structure, it can be shown that when forward biased, such a device possesses at most two stable states: a blocking state and an "ON" state. The difference in structure—as compared to that of a simple SCR—leads to different switching conditions. In particular it is found that the device must have more current gain per basic transistor cell for switching, and that switching occurs at higher voltages. For example, if all the transistors in the model of the device were equal, then in the common *pnpn* structure the switching condition is that the common base current gain (α) of each transistor equal $\frac{1}{2}$. However, if the basic *pn* cell is repeated *m* times, the swtiching condition is $\alpha = 1 - 1/m$.

Consideration of optical gain distribution must also be taken into account in the design of the device. For example, to achieve equal gain in all the active regions, one should, as a first-order approximation, make the recombination currents in these regions as equal to each other as possible. This can be achieved by tailoring the widths and the aluminum contents of the various layers. Detailed solution of the electrical properties of multiple *pn* structures will be published elsewhere.[6]

The characteristics of one typical device investigated are described below. The layered structure was grown by liquid phase epitaxy at 800 °C and subsequently etched to a 100 μm width and cleaved to about 300 μm in length. It is shown in Fig. 1(a), with the details of the various layers given in Table I. The extended transistor-model is shown in Fig. 1(b). The calculated electrical characteristics in the ON state are given in Fig. 2. Fig. 2(a) shows the distribution of the excess minority carriers across the device, which peaks in the active regions. The fraction of the total current recombined in each layer of the device is shown in Fig. 2(b). We see that most of the current ($\sim 82\%$) recombines in the active regions, and the level of recombination currents in the different active regions is uniform to within 10%. The measured *I*-*V* curve is shown in Fig. 3. The breakover voltage (V_{Bo}) of the device is ~ 9 V. Devices with breakover voltages of more than 35 V were also observed. The value of V_{Bo} in each particular device also depends on the amount of leaking due to imperfections. The holding current density is about 1.5 A/cm^2. The calculated optical properties are shown in Fig. 4. The real index profile is shown in Fig. 4(a). The value of

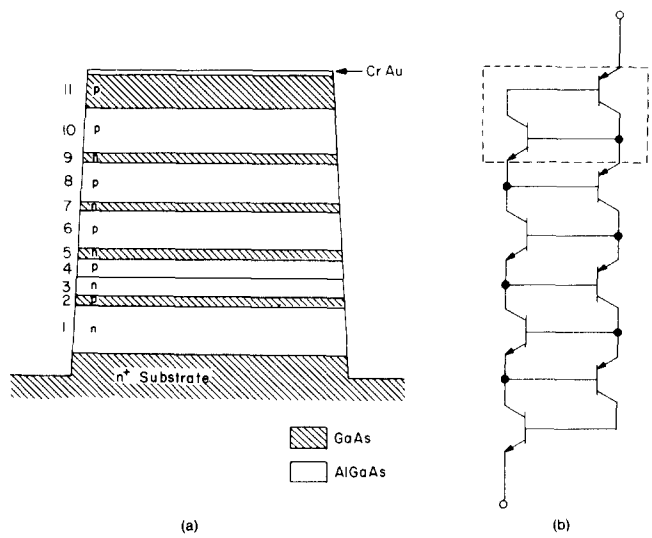

FIG. 1. (a) Structure of the device and (b) extended transistor model of the device.

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TABLE I. Detailed description of the layers of the structure.

Layer No.	Type	Al contents (x)	Doping Type	Concentration (cm^{-3})	Width (μm)	Remarks
1	n	0.4	Sn	10^{17}	1.5	
2	p	0.0	Ge	3.10^{18}	0.25	active region
3	n	0.1	Sn	10^{17}	0.5	
4	p	0.1	Ge	10^{17}	0.5	
5	n	0.0	Te	3.10^{18}	0.25	active region
6	p	0.1	Ge	10^{17}	1.0	
7	n	0.0	Te	3.10^{18}	0.25	active region
8	p	0.1	Ge	10^{17}	1.0	
9	n	0.0	Te	3.10^{18}	0.25	active region
10	p	0.4	Ge	10^{18}	1.5	
11	p^+	0.0	Ge	$\sim 10^{19}$	1.0	capping layer

the imaginary part of the index of refraction assumed for the calculation is shown in Fig. 4(b) and corresponds to a gain of about 45 cm^{-1}. The calculated results of the near field and far field patterns are not sensitive to varying this parameter since the magnitude of the imaginary part of the index of refraction is only a small fraction of the magnitude of the total index of refraction. The calculated near and far field patterns of the lowest order mode (the one with the smallest phase velocity) are plotted in Figs. 4(c) and 4(d). The measured optical near and far field distributions are shown in Fig. 5. The inability to fully resolve the two extreme weak side lobes of the mode (Fig. 5b) is due to the nonuniform and filamentary lasing in the direction of the junction plane. It is expected that reducing the transverse width of the active region from 100 to $\sim 10\,\mu$ will enable the device to oscillate also in a single transverse mode, in the same way it is done in conventional stripe injection lasers. The fact that the far field pattern is broader than the calculated value is probably due to spontaneous emission. Generally there is good agreement between calculated and measured results. Typical threshold current densities for the devices are about 13 kA/cm^2 and

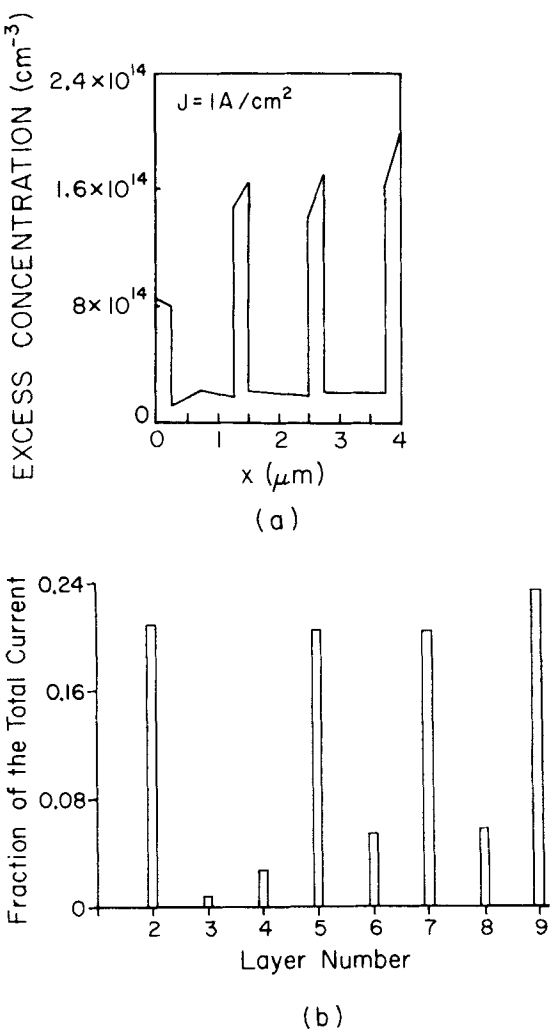


FIG. 2. Calculated electrical characteristics of the device in the "ON" state. (a) Excess minority carrier distribution and (b) recombination current distribution in the various regions.

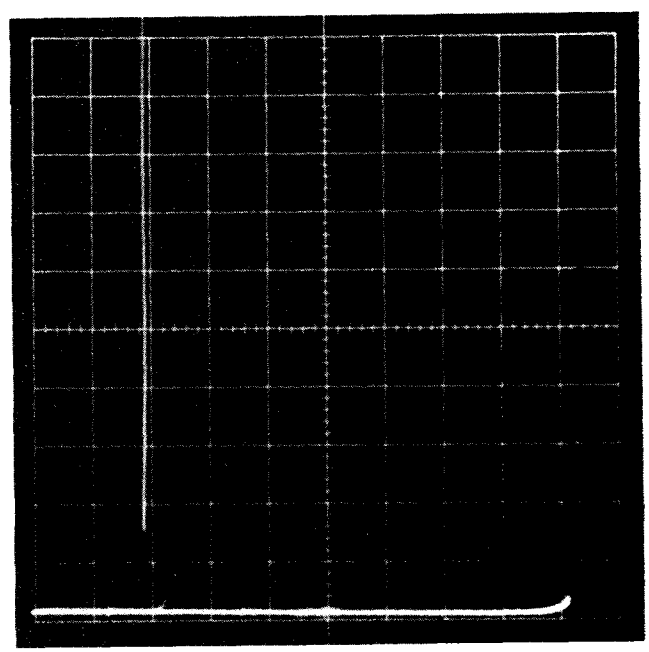


FIG. 3. I-V curve of the device (horizontal scale: 1 V/div; vertical scale; 0.1 mA/div).

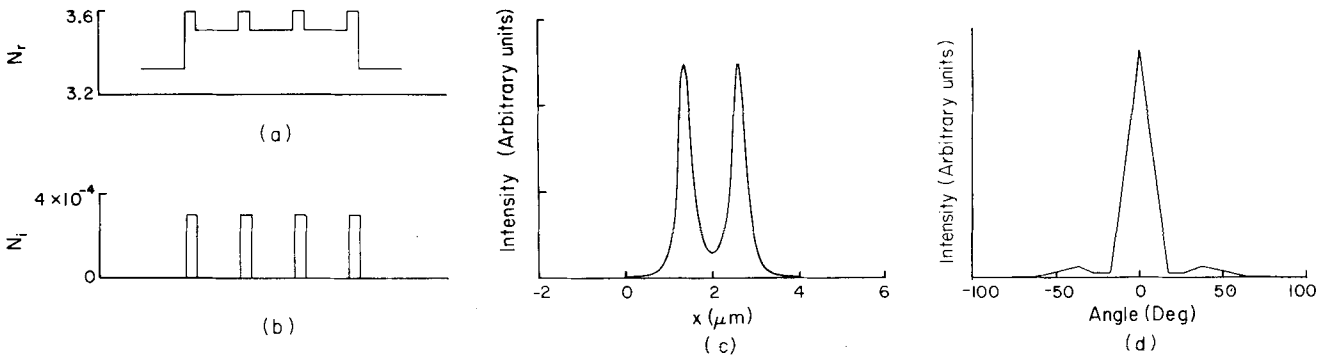
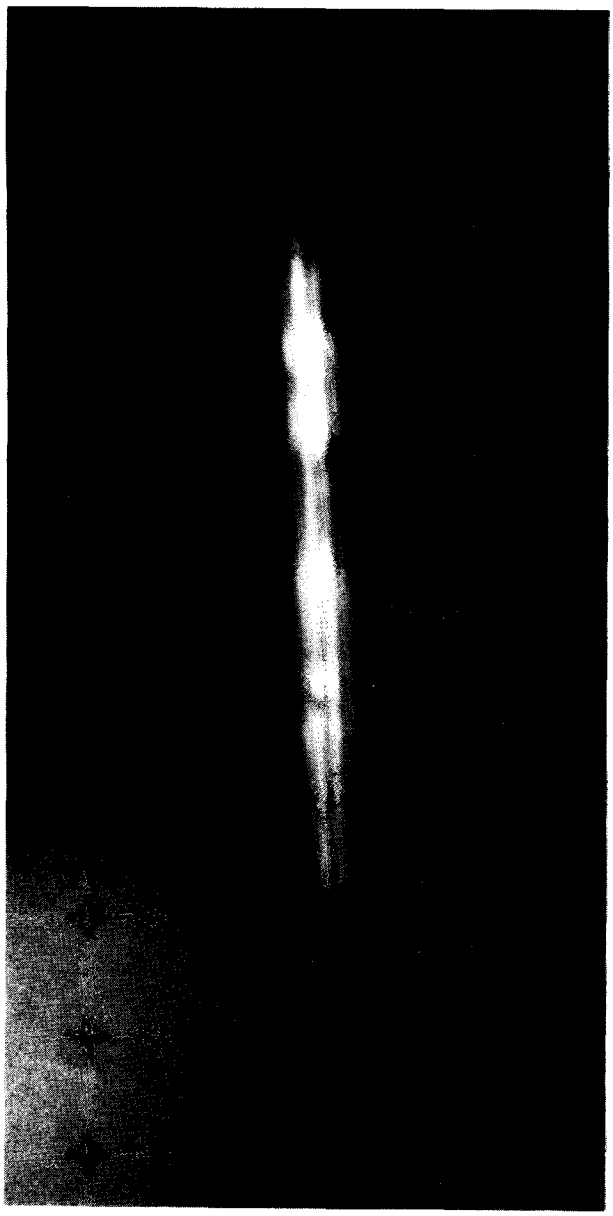
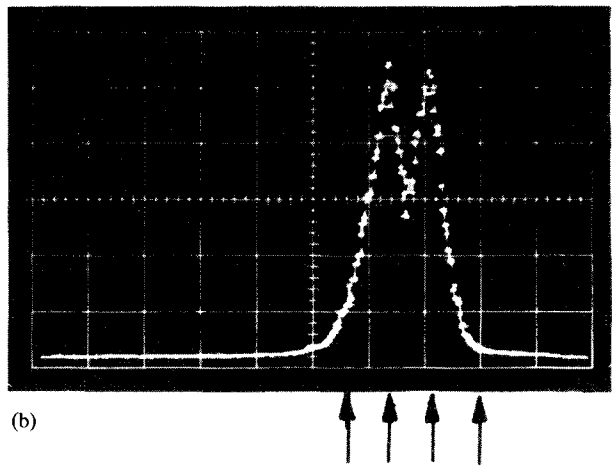


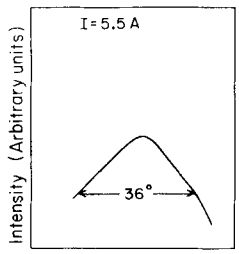
FIG. 4. Calculated optical properties of the device: (a) real part of the index of refraction, (b) imaginary part of the index of refraction, (c) near field pattern, and (d) far field pattern.



(a)



(b)



(c)

FIG. 5. Measured optical properties of the device ($I \simeq 1.2 I_{th}$): (a) photograph of the near field pattern ($\sim 1000X$ magnification), (b) measured near field pattern, and (c) far field pattern.

the differential quantum efficiency is about 40%. Since the devices were tested without heat sinks, they were operated in a pulsed mode with a low duty cycle and typical output peak powers were several hundred mW per facet.

In conclusion, we have demonstrated the operation of a large optical cavity multiple-active-region AlGaAs injection laser. The electrical mode of operation was found to be that of a bistable device (SCR) and not of a simple *PN* junction. Optically, the device oscillates in a "supermode" made up of a coherent superposition of single waveguide modes. Possible applications include pulsed mode operation of injection lasers and a defacto power combining of the output of many individual lasers.

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