Be-implanted (GaAl)As stripe geometry lasers

N. Bar-Chaim, M. Lanir,[a] S. Margalit, I. Ury, D. Wilt, M. Yust, and A. Yariv
California Institute of Technology, Pasadena, California 91125

(Received 27 September 1979; accepted for publication 28 November 1979)

(GaAl)As double-heterostructure stripe geometry lasers have been fabricated using Be ion implantation. Pulsed threshold currents as low as 21 mA have been found. The light-vs-current characteristics were kink-free up to 10 mW output power and the measured differential quantum efficiency was 45%.

PACS numbers: 42.55.Px, 42.80.Sa, 61.70.Tm

Ion implantation has gained much attention recently as a fabrication technique for GaAs optoelectronic devices. Barnoski *et al.*[1] fabricated GaAs homostructure injection lasers by ion implantation of Zn. Hunsperger *et al.*[2] produced *p*-type layers in GaAs by implanting Be at an energy of 40 keV. More recent investigations have reported on the electrical properties of GaAs implanted with Be at energy up to 400 keV.[3-5] Planar *p-n* junctions were fabricated with low leakage currents and abrupt breakdown characteristics.[6] No information has yet been reported on Be implantation in GaAlAs.

In this letter we describe a (GaAl)As double-heterostructure laser fabricated using Be ion implantation. The stripe geometry used differs from previously reported stripe lasers in that the *p-n* junction is formed in a closed, current confined structure. Conventional stripe lasers with extended *p-n* junctions, even those with small stripe widths, have considerable current spreading to the sides of the stripe, giving gain profiles often much wider than the stripe. The gain profile also changes with injection level, causing the lasing filament to move, resulting in kinks in the light-vs-current characteristics. The new closed structure prevents current spreading around the stripe, limiting the gain region to the stripe width and to small minority-carrier diffusion tails on either side of the stripe. The result is an effective confinement of the lasing filament at all current levels.

A great deal of work has appeared on the stabilization of lateral modes in double-heterostructure lasers.[7-14] The closed stripe structure presented here represents a simple alternative method of achieving this aim.

The structure of the laser is shown in Fig. 1. Fabrication of the device starts with the growth of three *n*-type layers on n^+ GaAs substrate by liquid phase epitaxy to form a double heterostructure. Typical layer thicknesses are 3 μm for the lower $Ga_{0.55}Al_{0.45}As$, 0.25 μm for the GaAs active layer, and 1 μm for the upper $Ga_{0.55}Al_{0.45}As$. After the deposition of 2500 Å of SiO_2 on the wafer, it is coated with photoresist (Shipley AZ-1350J), which serves as a mask for the Be implantation. Stripes are opened in the photoresist with widths ranging from 2 to 10 μm, and the SiO_2 in these openings is etched. Due to undercutting, the openings in the SiO_2 are typically 1 μm wider than the openings in the photoresist. A 100-keV Be implantation is then performed at room temperature with a dose of 3×10^{15} cm^{-2}. The LSS theory gives a projected range of 0.35 μm for Be ions in $Ga_{0.55}Al_{0.45}As$ at this energy.[15] After removal of the photoresist mask, the wafer is annealed for 40 min at 800 °C. This results in diffusion of the implanted stripe down to the GaAs active region. These conditions were chosen based on our finding that junction depth depends most strongly upon implanted dose and Al content of the material. With these implanting and annealing conditions, we find a junction depth of 0.8 μm in GaAs and 1.4 μm in $Ga_{0.55}Al_{0.45}As$. Changing the annealing conditions to 40 min at 850 °C resulted in only a 10% change in junction depths. Tests with differing Al content in $Ga_{1-x}Al_xAs$ showed the junction depth to rise monotonically with Al content at least up to $x = 0.65$. These results are consistent with the reported concentration dependence of Be diffusion,[3] and enabled us to control with great precision the location of the junction in the device. Our data are summarized in Table I. In most cases, the junction was locat-

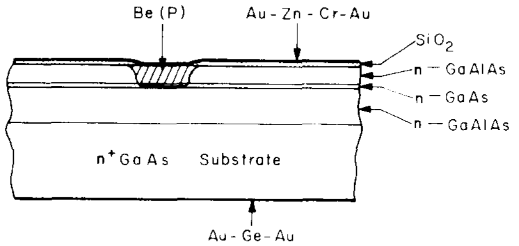

FIG. 1. Schematic cross section of the Be implanted laser.

TABLE I. Be diffusion data for $Ga_{1-x}Al_xAs$ (dose = 3×10^{15} cm^{-2}, energy = 100 keV).

	Anneal		Junction	Sheet
x	Temperature (°C)	Time (min)	depth (μm)	resistance (Ω/□)
0.00	800	40	0.8	100
	850	40	0.9	...
0.45	800	40	1.4	370
	850	40	1.6	...
0.65	800	40	1.9	1000
	850	40	2.1	...

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[a] Present address: Rockwell International Science Center, Thousand Oaks, CA 91360.

0003-6951/80/040233-03$00.50

FIG. 2. SEM photomicrograph of the cross section of the Be implanted laser.

ed within the GaAs active region. An SEM photomicrograph showing the cross section of a finished device is shown in Fig. 2. As can be seen in this figure, the Be region has minimal lateral diffusion under the SiO_2 layer. This is due to the use of the photoresist as an implanting mask above the SiO_2 layer, which is also made thin to reduce stress during annealing.

In order to form a good Ohmic contact to the *p*-GaAlAs layer, a shallow Zn diffusion is performed, followed by plating of Au-Zn, evaporation of Cr and Au, and alloying at 460 °C. The substrate is then lapped and the *n*-type substrate contact is made by evaporation of AuGe and Au and alloying at 380 °C. The resulting series resistance of the laser diodes is typically 10 Ω.

Due to the simple, self-aligned technique, the device yield is very high. Typical pulsed threshold currents for a 7.5-μm stripe width and cavity lengths of 250 and 125 μm were 55 and 30 mA, respectively. For a 3.5-μm stripe width the threshold currents were 40 and 25 mA for the same cavity lengths. The lowest pulsed threshold current found was 21 mA. cw operation was achieved with threshold currents 30% higher than in pulsed operation. The stable near field pattern of the Be implanted laser is shown in Fig. 3. The light-vs-current characteristics were linear and kink-free up to 10 mW output power. The measured external differential quantum efficiency was 45%.

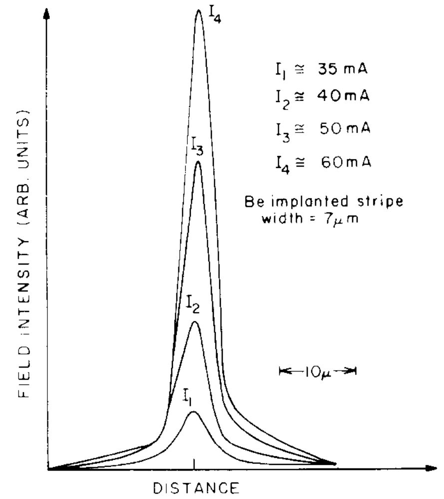

FIG. 3. The near-field pattern of the Be implanted laser.

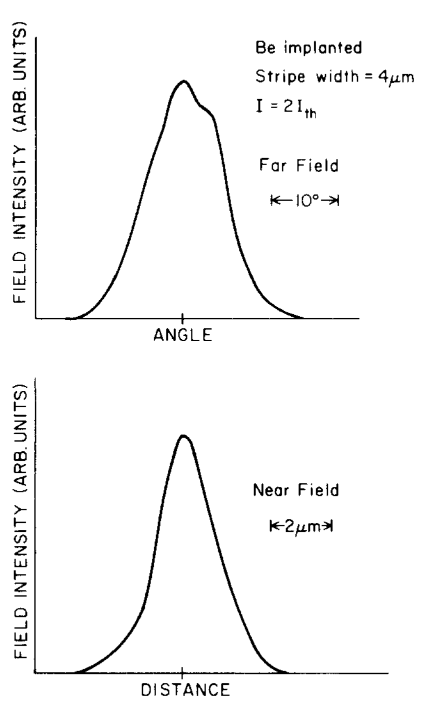

FIG. 4. Comparison of the near- and far-field patterns of the Be implanted laser.

In order to determine if the lateral mode in these devices is gain or index guided, the near field and the far field of a device were measured and compared. The results are shown in Fig. 4. The half-power widths were 2.3 μm for near field and 14° for far field. On the basis of this measurement we believe these devices to be gain guided.

The doping in the active layer was $\sim 10^{17}$ for these devices. Higher active region doping (up to 10^{18} cm^{-3}) gave the same or higher threshold current and the same well-controlled lateral mode behavior.

In conclusion, we have fabricated (GaAl)As double–heterostructure lasers using Be ion implantation to form a stripe geometry. Linear light-current characteristics, low threshold current, and ease of fabrication make this an attractive device for optoelectronic systems.

The authors would like to thank Pat Koen of the California Institute of Technology for the SEM photomicrograph.

This work was supported by the Office of Naval Research and the National Science Foundation.

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A cw x-ray preionizer for high-repetition-rate gas lasers

Tsunenori Arai, Minoru Obara, and Tomoo Fujioka
Department of Electrical Engineering, Keio University, 3-14-1, Hiyoshi, Kohoku-ku, Yokohama-shi, Japan, 223

(Received 22 October 1979; accepted for publication 5 December 1979)

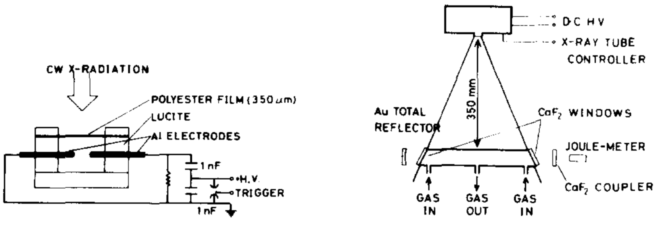
Continuous-wave x-ray exposure was first used as a preionizer on a pulsed-discharge HF laser. We investigated experimentally the preionization effect of this cw x-ray preionizer on a pulsed HF laser. Although the cw x-ray preionizer resulted in a characteristic performance similar to that of the flash x-ray preionizer, the cw x-ray generator has a much larger dose than a flash x-ray generator. Applicability of a cw x-ray preionizer to a high-repetition-rate pulsed laser was discussed.

PACS numbers: 42.60.By, 52.80.Pi, 42.55.Ks

In the field of high-power pulsed-discharge laser application, high-repetition-rate (HRR) pulsed lasers,[1,2] which quickly repeat laser operation to increase average power, have become necessary for cutting, welding, laser induced chemistry, laser isotope separation,[3] and laser fusion.[4] There are many technical problems in developing HRR lasers, one of which is gas contamination due to the preionizer. The material of the uv preionizer easily vaporizes to stain the laser medium. In order to solve this problem, a flash x-ray preionizer[5] was developed, which can be spatially separated from the laser chamber. However, due to its extremely high current density on the anode, the flash x-ray preionizer is not durable (up to about 10^3 shots[6]) enough to adapt it for the HRR lasers. Since the cw x-ray generator has a long lifetime, we thus attempted to examine the cw x-ray generator to find out whether it satisfies the requirements for a preionizer.

In this letter, we report on the first demonstration of cw x radiation used as a preionization source for a pulsed-discharge HF (H_2/SF_6) laser. The use of any cw preionization source such as a cw x-ray preionizer for a pulsed-discharge laser has never been reported before. One advantage of this preionization scheme is the elimination of the optimization of the time delay between flash preionization and main discharge. In order to measure the initial electron number density produced by the cw x-ray preionizer, an ion chamber study was performed. Our experiments show that the cw x-ray generator has the ability to precondition a pulsed-laser discharge. We also discuss the applicability of a cw x-ray preionizer for HRR pulsed lasers.

An industrial cw x-ray tube (Hitachi SIO-100-5/Be), 5 cm in diameter and 22 cm long, was used as the cw x-ray source in these experiments. This tube has a $1 \times 1\text{-mm}^2$ W anode and a 1-mm-thick Be exit window, which allows transmission of soft x-ray photons to provide high cw x-ray dose. Using a Victreen 660-3 chamber, an x-ray dose rate of 125 R/min was measured at 30 cm away from the cw x-ray exit window under conditions where the cw x-ray tube voltage and current were 50 kV and 2 mA, respectively. Since this x-ray chamber could not detect photons under 10 kV due to the transmission characteristics of its incident window material, practical dose rate is larger than the measured value. The x radiation generated from the cw x-ray tube was spread out with a half-angle of about 20°. The cw x-ray tube was immersed in high-voltage transformer oil for high-voltage insulation and cooling. We employed a Tanaka x-ray System (NDI-105) as the x-ray tube controller. The laser



(a) (b)

FIG. 1. Schematic drawings showing (a) cross-sectional view of the laser chamber, (b) arrangement of the laser chamber and cw x-ray preionizer.

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