lasers made by deep proton bombardment, and that a potentially useful lightwave pulse regenerator can be made by taking advantage of their unusual behavior.

ACKNOWLEDGMENT

We would like to thank A. E. Bakanowski, H. E. Elder, and A. J. Schorr for supplying the devices used.

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Low Threshold Be Implanted (GaAl)As Laser On Semi-Insulating Substrate

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***Abstract*—Be implanted stripe geometry double heterostructure lasers have been fabricated on a semi-insulating GaAs substrate, with threshold currents as low as 15 mA for a cavity length of 100 μm. The laser has been monolithically integrated with a metal-semiconductor field-effect transistor.**

THE integration of semiconductor based optical and electronic devices has gained much interest recently. The most important step in such devices is the fabrication of low-threshold injection lasers on semi-insulating (SI) substrates, such as GaAs. Lasers, which have been fabricated on SI GaAs substrates, include the crowding effect laser [1], the *T*-laser [2], and the transverse-junction-stripe (TJS) laser [3]. The latter has been successfully operated continuously at temperatures above 100°C [4].

We have recently demonstrated monolithic integration of GaAs lasers with several electronic devices. These include a Gunn oscillator [5] and metal-semiconductor field-effect transistor [2]. Recently, an integrated optical repeater [6] consisting of a detector, an electronic amplifier, and a laser was developed.

In all these experiments, the laser used was of the crowding effect type which, although lending itself readily to integration, possesses relatively high (>100 mA) currents. In this paper, we report on the fabrication of a low-threshold new type of double-heterostructure (GaAl)As laser on an Si GaAs substrate using Be ion implantation. This laser is a lateral version of the Be implanted laser on a conductive substrate [7]. The laser has been monolithically integrated with a MESFET, giving rise to a direct modulation of the laser light.

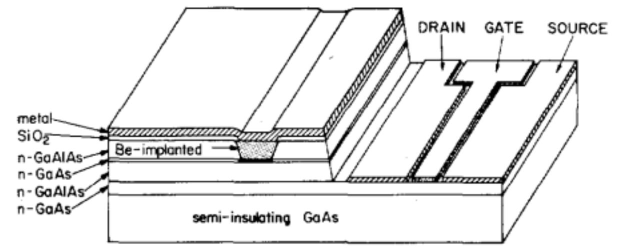

Fig. 1. The Be implanted laser with the integrated MESFET on semi-insulating GaAs.

The structure of the device is shown in Fig. 1. Fabrication of the device starts with the growth of four n-type layers on Cr doped GaAs substrate by liquid phase epitaxy. The bottom GaAs layer is doped to $\sim 10^{16}$ cm^{-3} and its thickness is 0.8 μm. The other three layers form a typical double heterostructure with thicknesses of 3 μm for the lower $Ga_{0.6}Al_{0.4}As$, 0.25 μm for the GaAs active layer, and 1 μm for the upper $Ga_{0.6}Al_{0.4}As$. The wafer is covered with 2500 Å of SiO_2 and a layer of photoresist in which stripes with width of 4 μm are opened. A 100-keV Be implantation is then performed at room temperature with a dose of 3×10^{15} cm^{-2}, followed by a 40 min anneal at 800°C. This results in diffusion of the implanted stripe down to the GaAs active region. The Be region has a minimal lateral diffusion under the SiO_2 layer and in most cases the p-n junction is located within the GaAs active region. This follows from the different diffusion coefficients of Be in GaAs and GaAlAs [7]. After a shallow Zn diffusion into the stripe side, an evaporation of Au-Zn is performed and alloyed for the p-

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Manuscript received December 13, 1979. This work was supported in part by the Office of Naval Research and the National Science Foundation.

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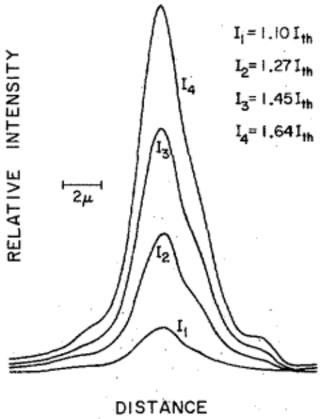

Fig. 2. The near field pattern of the Be implanted laser.

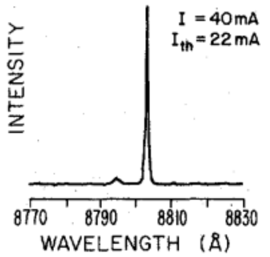

Fig. 3. Emission spectrum of the Be implanted laser.

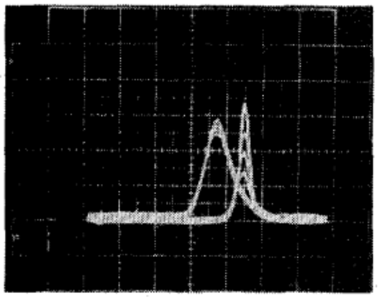

Fig. 4. Laser current (left scale 10 mA/div) and light output (right scale, arbitrary units) for several gate voltages (0.5 V/step). Horizontal scale is 20 ns/div.

contact. Then a mesa is formed by etching down to the n-GaAs layer with 1:8:8 (H_2SO_4:H_2O_2:H_2O), followed by a shadow evaporation of Au-Ge and Au. The Schottky gate is formed using a self-aligned process and a lift-off technique. After alloying the Au-Ge contacts, the substrate is thinned and the wafer is cleaved into individual devices.

Typical pulsed threshold currents for lasers with a 4-μm stripe width and cavity lengths of 250 and 125 μm were 35 and 20 mA, respectively. The lowest pulsed threshold current found was 15 mA for a cavity length of 100 μm. The stable near-field pattern of the laser is shown in Fig. 2. The light versus current characteristics were linear and kink free up to 10 mW output power. The measured differential quantum efficiency was 50 percent, approximately. The spectrum of the laser is shown in Fig. 3. It shows essentially single-mode operation.

In the stripe geometry used, the p-n junction is formed in a closed, current confined structure, which prevents current spreading around the stripe. This limits the gain region to the stripe width and to minority carrier diffusion tails on either side of the stripe, thus giving rise to an effective confinement of the lasing filament at all current levels. The gate length was 8 μm and transconductance ranged from 5 to 10 mmho. The effect of the gate voltage on the light output is shown in Fig. 4. The left and right curves correspond to the current through the laser and light output, respectively. When the laser and the MESFET are operated in series with voltage applied between the laser anode and the FET source, the laser light output is varied by applying a negative voltage to the gate.

In conclusion, we have fabricated (GaAl)As double-heterostructure lasers on semi-insulating substrates using Be ion implantation. The CW operation of these lasers and the ease of integration with electronic devices make these attractive devices for optoelectronic systems. This was demonstrated by integration of the laser with a metal-semiconductor field-effect transistor.

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