Monolithic integration of an injection laser and a metal semiconductor field effect transistor[a]

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(Received 4 December 1978; accepted for publication 22 January 1979)

A new laser structure, the "T-laser", has been monolithically integrated with a MESFET on a semi-insulating GaAs substrate. Integration is achieved by means of a compatible structure in which the optically active layer of the laser also serves as the electrically active layer of the MESFET. Direct modulation of the laser by means of the transistor is demonstrated.

PACS numbers: 42.82. + n, 42.55.Px, 85.30.Tv

High-speed optical communication systems, based on semiconductor lasers and detectors coupled to low-loss optical fibers, are currently the subject of great interest. It is to be noted, however, that in these "optical" systems, it is high-speed *electronic* devices which actually perform such functions as laser modulation and detected signal amplification. By *monolithically integrating* optical and electronic components to form transmitters, receivers, and repeaters, increased system performance in terms of speed and reliability, along with greatly reduced size and cost, can be expected.

Monolithic integration is greatly facilitated by the availability of electrically nonconductive substrates to isolate the various devices on the chip. Lasers grown on semi-insulating GaAs substrates have already been demonstrated by ourselves and by others.[1-3] Recently, we have reported on the integration of a laser with a Gunn diode on a semi-insulating substrate.[4] We now report on the successful integration of a new laser structure on semi-insulating GaAs with a MESFET[5] (metal semiconductor field effect transistor).

The laser structure which we have used in the present work is a planar version of the low mesa stripe laser,[6] employing lateral rather than vertical contacts. The structure of the "T-laser" with an integrated MESFET is shown in Fig. 1. Lasing action in the T-laser occurs along the stripe which runs parallel to the drain of the MESFET.

Fabrication of the device begins with a four-layer LPE growth. The mesa, which forms both the laser stripe and the p-side contact region, is defined by a two-step etch to the n-type active layer. In the first step, the top p-GaAs contact layer is etched away in the region surrounding the mesa. In the second step, the sample is etched in HF to selectively remove the p-$Ga_{1-x}Al_xAs$ ($x \sim 0.4$) layer. Following the mesa etch, Au-Ge and Au are deposited on the active layer to one side of the T structure. The n-type active layer of the laser, which also forms the active layer of the MESFET, is doped nominally to a carrier concentration of $\sim 10^{17}$ cm^{-3} and has a thickness of 0.2–0.3 μ. The bottom $Ga_{1-x}Al_xAs$ ($x \sim 0.4$) cladding layer is either not intentionally doped or else very lightly doped with Ge to compensate for residual donors. This cladding layer, which forms part of the double heterostructure, also doubles as a high-resistivity buffer layer for the transistor.

The MESFET is fabricated using a novel self-aligned process. After coating the wafer with Shipley type 1350J photoresist, a window is opened in the photoresist to define the gate region. The source and drain are formed by etching away the metallization in the gate region with a solution of $KI + I_2$. The etchant is allowed to slightly undercut the photoresist mask to effect a separation between the source, drain, and gate regions. Aluminum is next evaporated onto the sample with the photoresist still in place. The gate is then formed by means of the lift-off technique.

The T-laser operates in the following manner. Under forward bias, holes are injected by the p-GaAlAs layer chiefly into the lasing region of the active layer. Electrons are injected into the active layer as majority carriers at the drain contact and drift toward the lasing region where they recombine with the injected holes. The bottom GaAlAs layer keeps the injected carriers confined to the active layer, but unlike a cladding layer of a conventional double heterostructure, the bottom GaAlAs layer passes no current. The optical mode is confined to the region of the active layer under the mesa stripe by the lower effective index of refraction outside the mesa. Leakage currents associated with the large-area p-n junction which resides under the contact pad and connecting

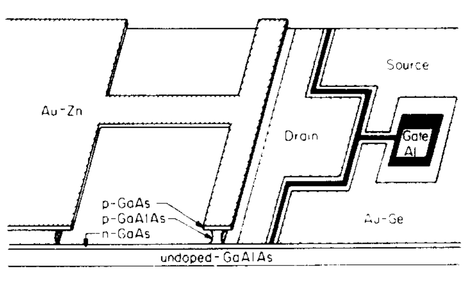

FIG. 1. A T-laser with an integrated MESFET.

[a]Research supported by the Office of Naval Research and the National Science Foundation.

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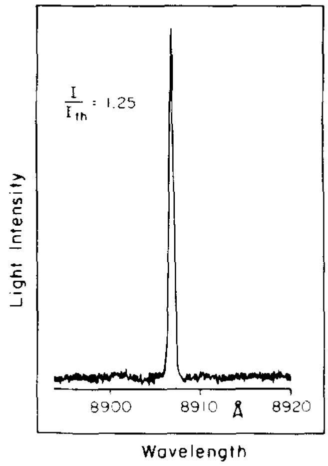

FIG. 2. Emission spectrum of a T-laser with a 5-μ-wide stripe, for current (pulsed) 25% above threshold.

stripe to the T are kept down by the sheet resistance of the active layer, which is on the order of several hundred $\Omega/\Box$. The series resistance which is thus introduced creates voltage drops which effectively cut off current to the parasitic diode.

Laser threshold currents as low as 87 mA were obtained under pulsed operation at room temperature for a 5-μ-wide 300-μ-long stripe. The lasers were found to be free of kinks in their light-vs-current curves. The laser emission was generally confined to a single longitudinal mode for currents up to 25% above threshold, as shown in Fig. 2. For higher levels of excitation, two longitudinal modes were characteristically observed.

Modulation of the laser current by the MESFET can be achieved by operating the pair in series, with the transistor source grounded. With a positive voltage applied to the laser anode, the laser current can be modulated by applying a negative voltage to the gate. The effect of gate voltage on laser current for one of our devices can be seen in the upper oscilloscope trace in Fig. 3. The double curve is obtained by pulsing the anode voltage, with gate voltage as a parameter. The curve with the higher peak value of current corresponds to zero gate voltage, while the curve with lower current corresponds to a gate voltage of -5 V. The length of this device was 450 μ between mirror facets. A serpentine gate structure was employed whose dimensions were 10 μ by 5 mm. The relatively small observed change in current with gate voltage is explained by the fact that the pinch-off voltage of the active layer exceeded the Schottky gate breakdown voltage for this particular growth. This necessitated operating the transistor in the linear low-gain region of the drain-current–vs–voltage curve. The height of the applied voltage pulse was chosen to limit the peak value of the current to just below the threshold current value of 110 mA while a negative dc bias of -5 V was applied to the gate. The approximately 20-mA increase in peak current which resulted from applying zero gate voltage was sufficient to drive the laser across threshold, as is evidenced in the second trace in Fig. 3 by the superlinear dependence of light on current.

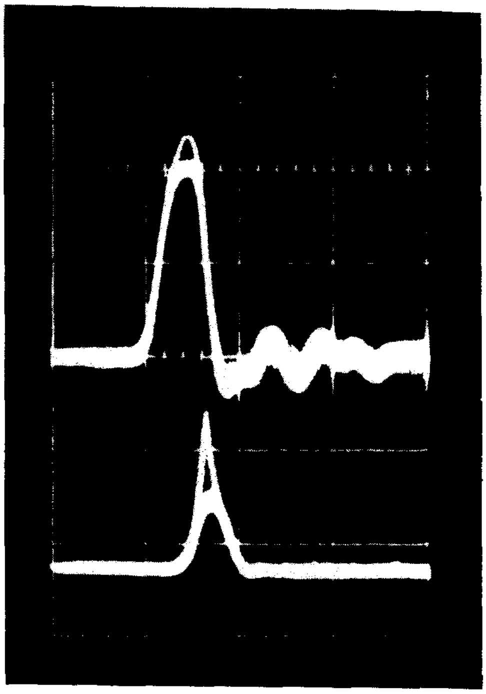

FIG. 3. Laser current (upper trace, 50 mA/div) and light output (lower trace, arbitrary units) for two values of gate voltage, with a voltage pulse applied between laser anode and transistor source. In each trace, the larger peak corresponds to zero gate-to-source voltage, and the smaller peak corresponds to a gate-to-source voltage of -5 V. Horizontal scale is 1 μs/div.

In conclusion, a new laser structure on semi-insulating GaAs, the "T-laser", has been developed, and its monolithic integration with a MESFET has been demonstrated. When connected in a common source configuration, the MESFET has been used to dc-modulate the laser. High-speed modulation characteristics of the MESFET-driven T-laser are currently being investigated.

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