Integration of an injection laser with a Gunn oscillator on a semi-insulating GaAs substrate[a]

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The integration of an injection semiconductor laser with an active electronic device (Gunn oscillator) in a *single* epitaxial crystal device is demonstrated.

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Integration of a variety of optical and electronic components monolithically on a single chip of substrate is the goal of integrated optics. During the past few years a lot of effort has been put into the development of individual optical devices such as low-threshold single-mode GaAs lasers, waveguides, modulators, etc.[1] On the other hand, a great amount of progress has also been made on the high-speed GaAs electronic devices such as FET's,[2] Gunn oscillators,[3] etc. However, the integration of these two kinds of devices has not been achieved. Recently, we succeeded, for the first time, in fabricating GaAs heterostructure lasers on semi-insulating substrates.[4,5] Because of the nonconductive substrate, the electrical integration can be performed on epilayers, and hence becomes much easier. In this paper we report, for the first time, the integration of a GaAs-GaAlAs injection laser with an electronic device—Gunn oscillator—on the same chip of substrate.

The structure of the device is shown in Fig. 1. The laser has structure similar to our crowding effect laser[4] except that the n-type layers are below the p-type layers. Current injected through the n-type contact flows through the n-GaAs layer into the mesa region. Due to the sheet resistance of the n-GaAs and n-GaAlAs layers, the voltage 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. When lasing, the near-field pattern (Fig. 2) shows that the laser light comes from a region only about 5 μm wide. The Gunn device was fabricated on the first n-GaAs layer. As the voltage drop across the Gunn electrodes is higher than some critical value, a high-field dipole domain is formed and drifts from the cathode to the anode. The frequency of oscillation depends on the distance between the electrodes and is higher as the distance is smaller. In our experiment the electrode on the left side of the Gunn device was not used, and the voltage was applied between the electrode to the right and the p-type contact on top of the laser mesa. The Gunn current thus flowed through the laser. If this current oscillation range is higher than the threshold of the laser, the laser light will be modulated. If the lasing threshold is between the upper limit and the lower limit of the current oscillation, 100% depth of laser light modulation can be achieved.

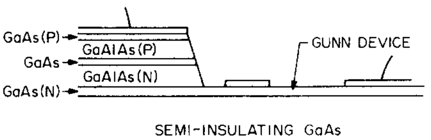

FIG. 1. The structure of the integrated Gunn-laser device. The voltage was applied between the cathode of the Gunn oscillator and the p-type contact on top of the laser mesa.

The device consists of five epitaxial layers grown on a semi-insulating substrate. The first n-GaAs layer is used for fabricating the Gunn device and for providing the voltage drop for the crowding effect. The doping concentration of this layer was chosen to be ~ 10^{16} cm^{-3} in order to get a proper Gunn oscillation. The active layer of GaAs is not intentionally doped. The confining $Ga_{1-x}Al_xAs$ layers have $x \sim 0.4$ and are doped with Ge and Sn for p-type and n-type doping, respectively. The typical thicknesses of the layers, starting from the bottom, are 3, 2, 0.3, 2, and 1 μm. The step etching was performed after the p-type contact (Au-Zn) was evaporated on the wafer. The etching has to be deep enough to reach the first n-GaAs layer. Following the etching step, the n-type contact (Au-Ge) was evaporated. Using the step of the mesa as the self-aligned mask, we were able to evaporate Au-Ge on the n-GaAs layer

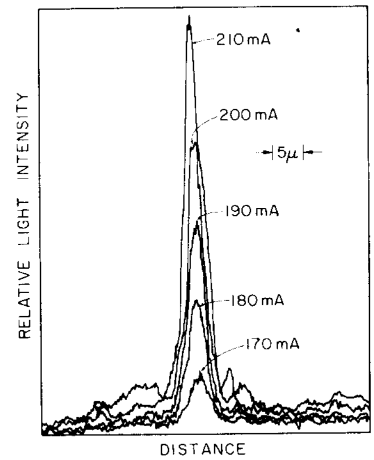

FIG. 2. The recorded traces of the near-field patterns of the laser at different currents. The threshold is 170 mA.

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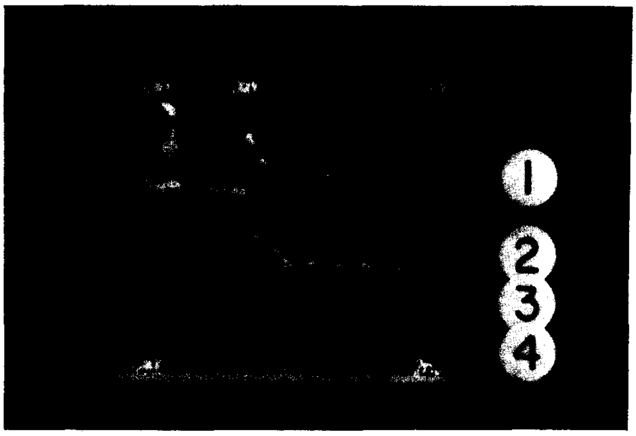

FIG. 3. A four-trace oscillogram of the current and the light pulses. Trace 1 is the light pulse and trace 2 is the current pulse. Traces 3 and 4 are the expanded traces of 1 and 2, respectively. The time scale is 100 nsec/div for 1 and 2 and 2 nsec/div for 3 and 4.

with a separation between the contact and the step edge. A distance of 200 μm to the right of the step edge, a 140-μm-wide stripe window was opened in the Au-Ge contact using photolithographic methods. The GaAs(n) under the window serves as the drift region of the Gunn oscillator. The cross section of the final structure is shown in Fig. 1. As a two-terminal device, the voltage was applied across the p-type contact on the mesa top and the n-type contact on the far right. The laser (the laser is one of the Gunn oscillator electrodes) and the Gunn device are thus integrated in series. The oscillating current pulses coming from the Gunn device form the injection current of the diode laser and modulate the laser light. The frequency of oscillation can be adjusted by changing the distance between the electrodes of the Gunn device. Direct current modulation of the light output at frequencies up to 1 GHz has been achieved. Figure 3, for example, is a four-trace oscillogram of the current pulse and the light pulse. Trace 1 is the light pulse and trace 2 is the current pulse. Oscillation can be seen on top of both pulses. In this case even the minima of the current exceed the threshold value (170 mA) and the laser is not turned off. Because of the threshold nonlinear behavior of lasers, the modulation depth of the laser output (70%) is much larger than that of the current (15%). Traces 3 and 4 are expanded traces of the light and the current, respectively. The frequency of oscillation is about 0.75 GHz.

For three-terminal operation it is possible to put a Schottky gate on the Gunn device and use the gate to trigger the Gunn oscillation. In this way a single short laser pulse can be achieved.

In conclusion, we have demonstrated the integration of an active electronic device, a Gunn oscillator in this case, with a GaAs laser on the same piece of semi-insulating GaAs substrate. Direct current modulation on the light output has been achieved at frequencies up to 1 GHz. Further integration of the GaAs laser with other devices is in progress.

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Low-resistivity ZnCdS films for use as windows in heterojunction solar cells[a)]

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Low-resistivity Zn$_x$Cd$_{1-x}$S films have been obtained by a multisource evaporation method. The films have been doped with In during the deposition. The resistivity of such films varies from 2×10^{-3} Ωcm for $x=0$ up to 2 Ωcm for $x=0.3$ and rises up to 10^{12} Ωcm for $x=1$. For energies lower than the energy gap, the transparency of these films, when corrected for the reflection loss, can reach a value of almost 100%. In the range of an x variation between 0 and 0.4 these films, because of their low resistivity and their high transparency, can be used as windows in heterojunction solar cells.

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In heterojunction solar cells, the part of the cell which serves as a window should have the highest forbidden gap possible and at the same time should have a very low resistivity. In some heterojunction solar cells,[1-3] CdS has been successfully used as a window. This is due to the fact that CdS has both an high gap of 2.4 eV and a very low resistivity up to 10^{-2} Ωcm or less in the form of films.[4-6] Zn$_x$Cd$_{1-x}$S films, if made

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