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OEIC Transmitter Fabricated by Planar Integration Process

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An AlGaAs/GaAs OEIC transmitter has been fabricated by our newly developed planar integration process, in which MBE grown GRIN-SCH SQW laser was planarily embedded in semi-insulating GaAs substrate by using ion-beam etching. This planar OEIC process has improved controllability in lithography, especially in the laser stripe formation. The fabricated OEIC transmitter has achieved a low threshold current (10 mA) of the integrated laser and stable gigabit operation of the overall circuit.

INTRODUCTION

OEIC transmitters and receivers, that have input/output signal levels matching with those of available LSI families of multi-function and are packaged for convenient treatment in both optical and electrical connections, are attractive and very useful for flexible and systematic construction of optical communication networks as well as for compact components of new functional machines. The integrated structure and fabrication technology of basic OEICs such as transmitters and receivers, however, have not matured yet and the fabrication cost is too high for practical use, mainly due to the low fabrication yield. One of effective approaches to improve the yield is an introduction of a planar integration process to the fabrication of OEIC, because a main bottleneck of the low fabrication yield is unstable processes caused by uneven-surface of conventional integrated structure.

In this paper, we present a planar integration process to bury an MBE grown AlGaAs/GaAs GRIN-SCH SQW laser flat into semi-insulating GaAs substrate and characteristics of an OEIC transmitter fabricated by applying this planar integration process.

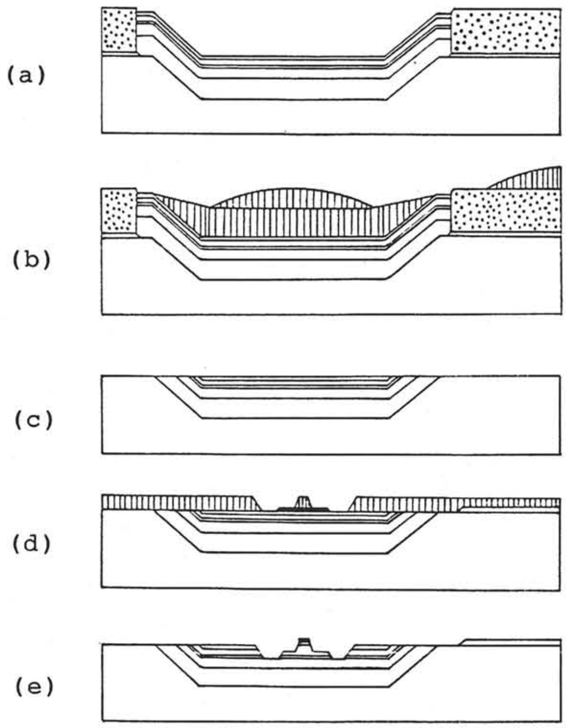


Fig.1 Planar integration process with ridge waveguide formation. (a) MBE growth of GRIN-SCH SQW laser layers on grooved semi-insulating substrate. (b) Formation of photoresist layers for planarization and protection of both laser and FET regions. (c) Planar laser embedded by Ar ion-beam etching and removal of poly-crystal on SiO_2 film. (d) MBE growth of FET layer and formation of Au/Zn/Au contact and photoresist mask for ridge waveguide. (e) Ridge waveguide together with p-n isolation groove formed by Ar ion-beam etching.

PLANAR INTEGRATION PROCESS

Figure 1 shows a planar integration process. First, GRIN-SCH SQW laser layers were grown on a grooved semi-insulating GaAs substrate by molecular beam epitaxy (MBE). Second, a photoresist mask (AZ4620) for planarization was formed. The thickness of a triangle-cross-sectional photoresist layer on the slope of laser layers was determined so that a total equivalent thickness of laser epi and photoresist layers is kept constant on the slope, taking account of ion-beam etching-rate ratio between the laser epi and the photoresist. The overlay photoresist mask protects both laser and FET regions. By Ar ion-beam etching with oblique incident beam on a rotating stage,[1] laser layers were embedded flat in semi-insulating GaAs substrate as shown in Fig.1 (c). After MBE growth of FET layer and formation of Au/Zn/Au contact, a photoresist mask for 3 µm-wide ridge waveguide was formed. Then, again by Ar ion-beam etching, the ridge waveguide together with p-n isolation grooves was formed as shown in Fig.1 (e). Due to stable and fine-line lithography on the flat surface brought by this planar integration process as shown in Fig.1 (d), reproducible control of cross-sectional shape of the ridge waveguide has been achieved without trenching and shadowing effects in the Ar ion-beam etching.

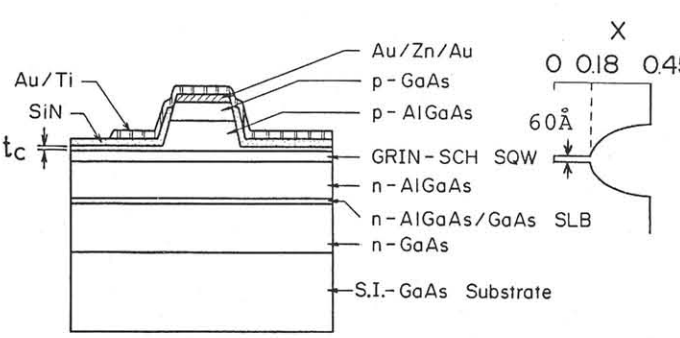
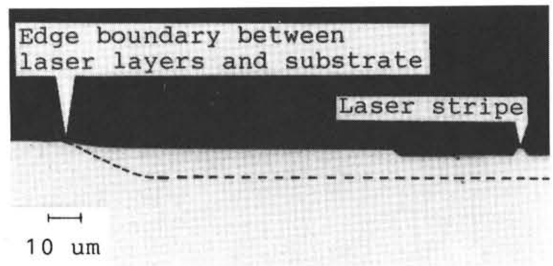
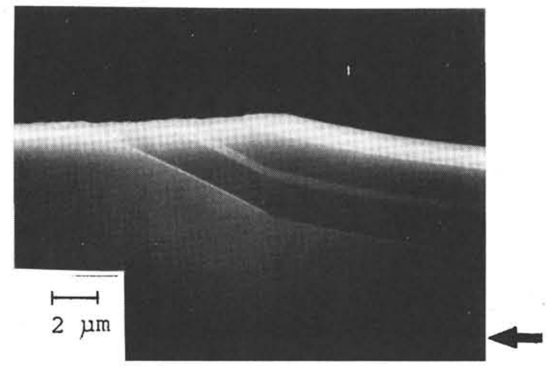


Fig.2 Schematic cross-section of ridge waveguide GRIN-SCH SQW laser together with Al fraction in active layer. t_c indicates the thickness of p-AlGaAs cladding layer at the ridge shoulder.



(a)



(b)

Fig.3 (a) Cross-sectional photomicrograph of planar embedded GRIN-SCH SQW laser with ridge waveguide. (b) Magnified view at edge boundary shown in (a). The position of boundary line between 3.8 µm-thick n-GaAs layer and a semi-insulating GaAs substrate is marked by an arrow.

Figure 2 shows a schematic cross-section of the ridge waveguide GRIN-SCH SQW laser structure, which corresponds to a magnified view of the center part of Fig.1 (e). The quantum well thickness is 60 Å and the detailed data about MBE grown layers have been reported elsewhere.[2] In order to obtain a low threshold current and a high differential quantum efficiency of the ridge waveguide laser, it is important that the thickness of p-AlGaAs cladding layer at the ridge shoulder, t_c as shown in Fig.2, is controlled to be an optimum thickness, 0.05-0.1 µm.[3] Therefore, the above-mentioned planar integration process has been very useful to improve both performance and fabrication reproducibilities of integrated GRIN-SCH SQW lasers.

Figure 3 shows a cross-sectional photomicrograph and a scanning electron micrograph of the planar embedded GRIN-SCH SQW laser. Laser layers with the total

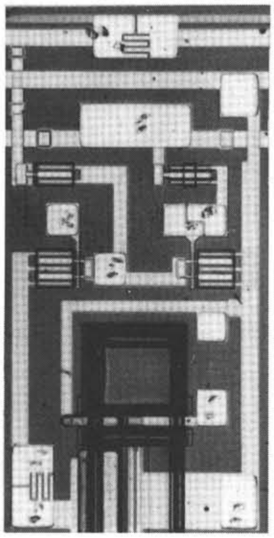


Fig.4 Photomicrograph of completed OEIC transmitter chip, including an MCF laser, a power-monitor photodiode, three FETs and an impedance-matching resistor. The chip is 2 x 1 mm square.

thickness of 8.5 μm were buried flat and smoothly. Au/AuGe (n-type) contact was formed in a small rectangular hole, where the n-GaAs layer was exposed. This technique was used because we found that Si-doped (amphoteric dopant) AlGaAs and GaAs MBE layers on the slope of grooved GaAs substrate was p-type when the slope angle was larger than 30 degree.[4] The n-contact holes with sufficiently gentle slopes showed no harmful effects on the following processes. If the bottom AlGaAs/ GaAs layers of the laser are Be-doped (p-type) and the top layers at the ridge waveguide are Si-doped, p-contact of the bottom layer would be formed on the flat surface at the edge boundary region, which is shown in Fig.3 (a).

Figure 4 shows a completed OEIC transmitter chip. A GRIN-SCH SQW laser with a micro-cleaved facet,[5] a power-monitor photodiode and a driving circuit consisting of three FETs (2 μm-long gate) and an impedance matching resistor (50 ohm) are monolithically integrated on a 2x1 mm square chip. Layout and dimensions of components are same as ever reported.[2]

OEIC CHARACTERISTICS

Light output-current characteristic and emission spectrum of an integrated GRIN-SCH SQW laser is shown in Fig.5. The threshold current and differential quantum efficiency are 10 mA and 45 %/facet, respectively, under CW operation. The laser has a micro-cleaved facet coated with a Si_3N_4 ECR-plasma CVD film and a conventionally cleaved facet coated with an Al_2O_3 sputtered film. The thickness of the coating films is a quarter of the lasing wavelength. The light output and spectrum were measured on the facet conventionally cleaved. At the injection current of 13 mA, the longitudinal mode was nearly single and the lasing wavelength was 834 nm, being consistent with the quantum well thickness of 60 Å. The obtained high performance is due to the optimum control of the thickness t_c as mentioned in the previous section (Fig.2). The power-monitor photodiode, which faced the micro-cleaved facet of the laser at a 60 μm-seperation, had a sensitivity of 3 μA/mW at the reverse bias voltage of 6 V.

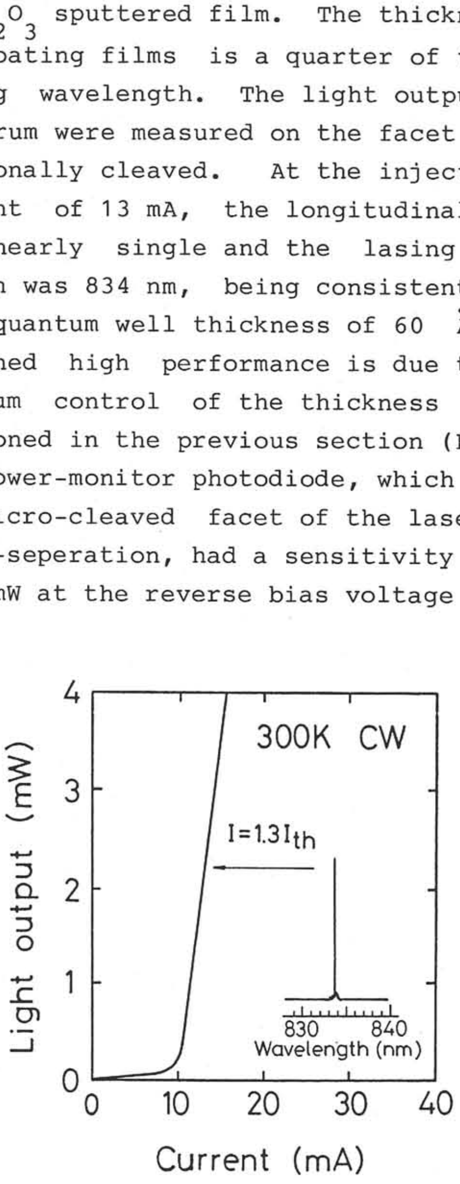
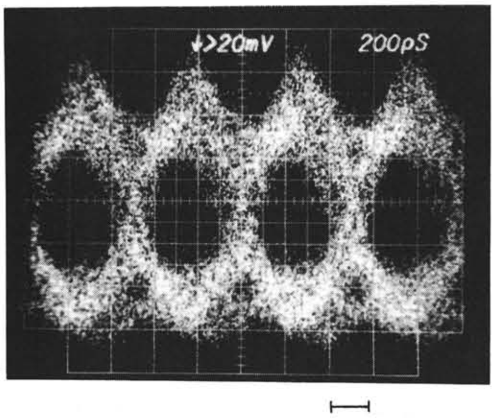


Fig.5 Light output-current characteristic of integrated GRIN-SCH SQW laser, which has a micro-cleaved facet coated with Si_3N_4 ECR-plasma CVD film and a conventionally cleaved facet coated with Al_2O_3 sputtered film. Light output and spectrum were measured at conventionally cleaved facet.

(a)



(b)

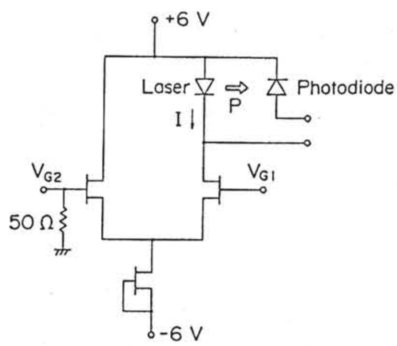


Fig.6 (a) Eye diagram of transmitter light output obtained when 2 Gb/s random pulses were fed into input-FET gate V_{G2}. (b) OEIC transmitter circuit.

The OEIC transmitter chip, which incorporated 50 ohm impedance matching resistor monolithically, was mounted in a chip carrier together with supply bypass capacitors for high-speed operation. Figure 6 (a) shows an eye diaram of transmitter light output obtained when 2 Gb/s random pulses were fed into the input-FET gate V_{G2}, which is shown in OEIC transmitter circuit (b). This result confirms gigabit modulation ability of this transmitter chip. The maximum operating speed of the transmitter was found to be limited by relaxation frequency of the integrated GRIN-SCH SQW laser, since the operating speed of the driving circuit exceeded 2 Gb/s in our separate experiment.

CONCLUSION

An AlGaAs/GaAs OEIC transmitter has been fabricated by our newly developed planar integration process. Due to improved controllability in lithography, high performance of the OEIC transmitter has been demonstrated. The presented planar integration process to embed MBE grown lasers flat in a semi-insulating substrate is one of the most attractive approaches to surface-flat OEIC with larger integration scale.

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