Monolithic GaAs/AlGaAs optical transmitter circuit using a single growth step

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Indexing terms: Integrated circuits, MESFETs, Semiconductor lasers

A strained GaAs/AlGaAs/InGaAs MQW laser has been monolithically integrated with GaAs MESFETs in a differential pair configuration to form a transmitter circuit. The structure used a single epitaxial growth step in which the laser was grown on top of the MESFET. The circuits operate with bandwidths as high as 3.4GHz.

Introduction: Substantial progress in the fabrication of optoelectronic integrated circuits (OEICs) has recently been made and there have been many reports in the literature which document greatly improved perfomance of photoreceivers [1, 2], integrated laser/modulators [3, 4] and wavelength division multiplexers [5]. However, there have been comparatively few reports of integrated lasers and driver circuits. Approaches to this problem have included selective area growth [6] and adaptation of the structure so that the laser and transistor may use the same layer structure [7]. For ease of fabrication and potentially greater reliability it is desirable to accomplish the integration with a single growth on a planar substrate.

The InP system is well suited to long-haul communications applications because of the availability of low-loss fibres at long wavelengths, and the laser-driver integrations which have been reported have concentrated in the 1.3 – 1.55μm range [8, 9]. However, for short haul applications, such as LANs, it may be desirable to employ GaAs-based circuits for improvement in high-temperature operation. In this Letter we present results on a GaAs/AlGaAs/InGaAs laser integrated with GaAs MESFETs in a differential pair configuration. The circuit was realised with a single growth step and was successfully operated at frequencies as high as 3.4GHz.

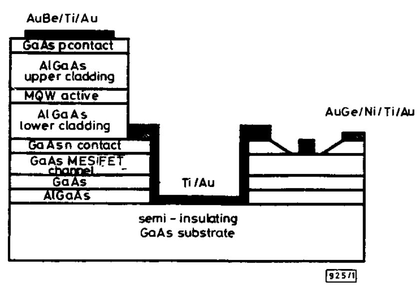

Fig. 1 *Schematic diagram of integrated optical transmitter circuit*

Experiment: The layer structure was grown via metal organic chemical vapour deposition (MOCVD) and is pictured in the device schematic diagram shown in Fig. 1*a*. The structure consisted of 1000Å of unintentionally doped GaAs, 1000Å of unintentionally doped $Al_{0.4}Ga_{0.6}As$, an *n*-type channel layer consisting of 2300Å of GaAs with a concentration of $6 \times 10^{17}cm^{-3}$ and a 600Å GaAs *n*-contact layer doped to $5 \times 1018cm^{-3}$. This contact layer served as the ohmic contact layer for both the laser and the MESFET. These layers were followed by the laser structure, which consisted of a 1.5μm *n*-type $Al_{0.6}Ga_{0.4}As$ lower cladding layer doped to $10^{18}cm^{-3}$, a 600Å undoped $Al_{0.2}Ga_{0.8}As$ inner cladding, an undoped multiquantum-well active region consisting of 400Å of GaAs, three 80Å InGaAs quantum wells sandwiched between 200Å GaAs barriers and 400Å of GaAs, another 600Å undoped $Al_{0.2}Ga_{0.8}As$ inner cladding, a 1.5μm *p*-type $Al_{0.6}Ga_{0.4}As$ upper cladding layer doped to $10^{18}cm^{-3}$ and a 1000Å GaAs p^+ ohmic contact layer doped to $10^{19}cm^{-3}$.

The ridge for the laser was 4μm wide and was defined via reactive ion etching. The *n*-contact layer for both the laser and the MESFET was realised via wet chemical etching. To stop on such a thin contact layer, it was necessary to employ a selective etch of $HF:H_2O$ at a ratio of 1:5. Isolation mesas were then formed around the lasers and MESFETs by etching down to the semi-insulating substrate. Depositions of the *p*-type and *n*-type ohmic contacts, the gates and the interconnect metal were accomplished via standard photolithographic techniques. The devices were then thinned down to a thickness of 150μm and cleaved into 810μm-long bars for testing.

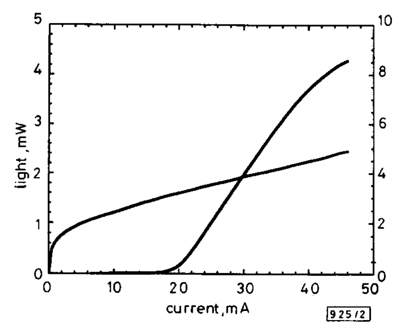

Fig. 2 *Light/current and voltage/current characteristics for laser diode alone*

Results: The DC characteristics of the MESFETs were measured from isolated devices on the same processed wafer as the integrated optical transmitters. The devices exhibited transconductances as high as 138mS/mm with current densities I_{ds} of up to 455mA/mm. Similarly, the DC characteristics of isolated laser diodes were also measured. A typical light/current and voltage/current characteristic of the lasers is shown in Fig. 2. The lasers had threshold currents of 24mA, which corresponds to a threshold current density of 700A/cm², and exhibited output powers of around 5mW.

After DC testing, the RF characteristics of the MESFETs and laser diodes were measured using an HP network analyser and wide bandwidth coplanar waveguide probes. The MESFETs were characterised between 100MHz and 40GHz. By measuring the microwave characteristics of the pads alone, it was possible to isolate the device characteristics from the parasitics due to the pads by subtracting the *y*-parameters of the pads from the *y*-parameters of the device and pads. The FETs were biased for maximum transconductance. The FETs were found to have cutoff frequencies as high as f_t = 6.3GHz and f_{max} = 8.5GHz. The modulation characteristics of the lasers were measured between 130MHz and 20GHz. The lasers exhibited 3dB rolloff frequencies of several gigahertz.

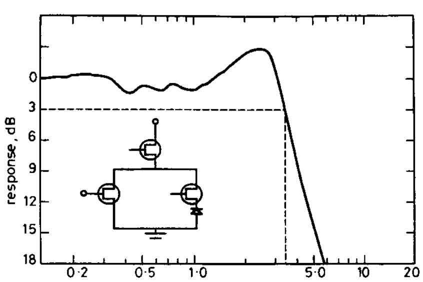

Fig. 3 *Frequency response characteristic of integrated optical transmitter circuit with circuit diagram inset*

The high-frequency characteristics of the transmitter circuits were evaluated using an HP 8703A optical component analyser with a measurement capability between 130MHz and 20GHz. The circuit is shown in the inset of Fig. 3. The laser is turned on by applying a gate voltage sufficient to pinch off the MESFET in the branch of the circuit without the laser diode, typically about −5V. The light output of the laser may be modulated by superimposing an RF signal on to this gate bias through a high-frequency bias network. A frequency response characteristic of the circuit is shown in Fig. 3. The circuits exhibited bandwidths as high as 3.5GHz, believed to be limited by the frequency response of the lasers. This limitation is indicated by the presence in the response of the resonance peak of the laser, which would not be present if the response were limited by the MESFETs or circuit parasitics. An eye diagram of the circuit was measured at 2Gbit/s and is shown in Fig. 4. A clear open eye suggests that these circuits should be suitable for transmission at a bit rate of 2Gbit/s.

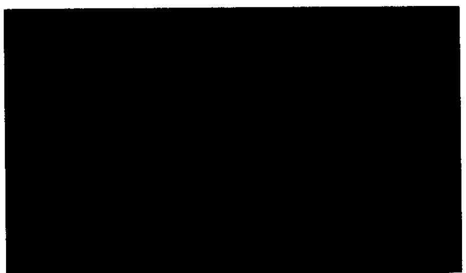

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Fig. 4 *Eye diagram of transmitter circuit at 2Gbit/s*

Summary: Integrated laser transmitter circuits have been fabricated in which GaAs/AlGaAs/InGaAs multiquantum well lasers were integrated with GaAs MESFETs in a differential pair configuration. The circuits exhibited 3dB bandwidths as high as 3.4GHz, and a clear open eye diagram was demonstrated at 2Gbit/s.

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3.4ps wide compressed optical pulses from electrically gain-switched vertical cavity surface emitting laser

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Indexing terms: Vertical cavity surface emitting lasers, High-speed optical techniques, Optical dispersion

The authors show that by using singlemode fibre it is possible to achieve significant compression in optical pulses generated by electrical gain-switching in a vertical cavity surface emitting laser (VCSEL). A pulse width of 3.4ps was achieved, which is, to the authors' best knowledge, the lowest obtained by electrical gain switching in VCSELs. The measured timing jitter of the compressed pulses is 6.6ps and is almost identical to the timing jitter before compression.

Gain-switched lasers are a convenient source of triggerable, short optical pulses which can be used in a variety of applications such as electro-optic sampling, optical communication and soliton transmission [1]. Previously, 4ps wide pulses were obtained using optical gain switching in vertical cavity surface emitting lasers (VCSELs) [2], and 13.5ps using electrical gain-switching [3]. Recently, 15ps compressed pulses were reported in [4] and the design tradeoffs were discussed. In this Letter we report 3.4ps wide optical pulses obtained from electrically gain-switched VCSELs after temporal compression in a 500m long conventional singlemode fibre. The timing jitter of the compressed pulses (6.6ps) is found to be almost unchanged from the uncompressed pulses.

The optimum fibre length for maximum pulse compression, assuming a Gaussian pulse shape, can be calculated as in [5]. We note that the chirp varies from pulse to pulse [6], so that optimum compression can be achieved only on average. The amount of chirp is related to the timing jitter of the gain-switched pulses in that pulses that appear later than the average turn-on time tend to chirp more. In other words, the effectiveness of pulse compression schemes for gain-switched pulses is intrinsically related to their timing jitter characteristics.

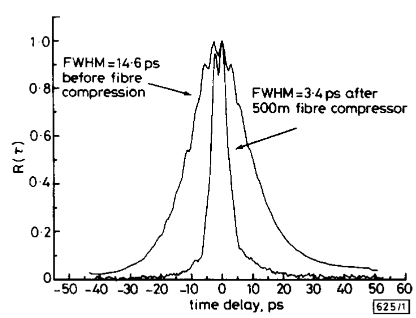

Fig. 1 *Autocorellation traces of original pulse and compressed pulse after 500m of fibre*

The bias current was I_b = 0mA, and the pulse amplitude at the laser input was 16V. An FHWM pulse width of 3.4ps after compression and 14.6ps before compression was calculated assuming $sech^2$ pulses