8·2 GHz BANDWIDTH MONOLITHIC INTEGRATED OPTOELECTRONIC RECEIVER USING MSM PHOTODIODE AND 0·5 μm RECESSED-GATE AlGaAs/GaAs HEMTs

Indexing terms: Optoelectronics, Receivers, Optical communication

An 8·2 GHz bandwidth monolithic optoelectronic receiver consisting of an MSM photodiode, a transimpedance amplifier, and a 50 Ω output buffer has been fabricated using an enhancement/depletion 0·5 μm recessed-gate AlGaAs/GaAs HEMT process. Successful operation at data rates up to 10 Gbit/s has been demonstrated.

Introduction: Optoelectronic components for light of 0·85 μm wavelength are currently being integrated with electric circuits to enhance the performance of the combined circuits. Several research groups have reported on the technology of monolithic integration of MESFETs on GaAs with photodetectors.[1,2] We report on a high-speed monolithic integrated optoelectronic receiver consisting of a metal–semiconductor–metal (MSM) photodiode, a transimpedance amplifier, and a 50 Ω output buffer. This is the first integrated receiver which is based on 0·5 μm recessed-gate enhancement and depletion type AlGaAs/GaAs HEMTs.

Design and fabrication: The optoelectronic receiver was fabricated using our established process for high-speed analogue and digital circuits.[3–5] This process is based on double delta-doped quantum well AlGaAs/GaAs HEMTs. It enables fabrication of enhancement and depletion transistors, diodes, NiCr thin film resistors, metal–insulator–metal (MIM) capacitors, and airbridge inductors. The interconnection between different devices is achieved through two levels of metallisation. Airbridges can be manufactured during deposition of the second metal. Now this standard process includes MSM photodiodes.

Fig. 1 shows a cross-section of an MSM photodiode integrated with enhancement and depletion type transistors. The

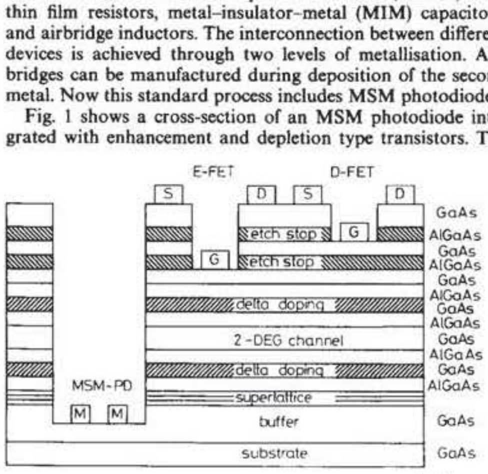

Fig. 1 *Schematic cross-section of MSM photodiode integrated with enhancement and depletion HEMTs*

vertical structure was grown on the semi-insulating GaAs substrate by molecular beam epitaxy in the following order: a 3000 Å GaAs buffer with an AlGaAs/GaAs superlattice, a 2000 Å AlGaAs spacer, 17 Å $2.5 \times 10^{12}\,cm^{-2}$ Si-delta-doped GaAs, a 50 Å AlGaAs spacer, a 150 Å 2-DEG quantum well channel, a 33 Å AlGaAs spacer, 17 Å $4 \times 10^{12}\,cm^{-2}$ Si-delta-doped GaAs, 33 Å AlGaAs, 60 Å GaAs, a 30 Å $2 \times 10^{17}\,cm^{-3}$ Si-doped AlGaAs etch stop, 75 Å $2 \times 10^{17}\,cm^{-3}$ Si-doped GaAs, a 30 Å $2 \times 10^{17}\,cm^{-3}$ Si-doped AlGaAs etch stop, and a 300 Å $3 \times 10^{18}\,cm^{-3}$ Si-doped GaAs cap layer.[3] The Al mole fraction of the AlGaAs layers was 0·3. By means of the etch stops and a selective reactive ion etch process an exact control of the threshold voltages for the enhancement and the depletion transistors was obtained.[4,5] Transistors with 0·5 μm long gates patterned by direct-write electron-beam lithography showed a typical standard deviation of 25 mV across a 2" wafer. For the best wafers the standard deviation was less than 10 mV. A deep wet etch was used to fabricate the recess for the interdigitated MSM photodiode deposited on the undoped GaAs buffer layer. The photodiode fingers were defined by electron-beam lithography[6] and formed by evaporation and subsequent liftoff of Ti/Pt/Au Schottky metal.

As shown in Fig. 2 the receiver consists of an MSM photodiode, a transimpedance amplifier, and a 50 Ω output buffer.

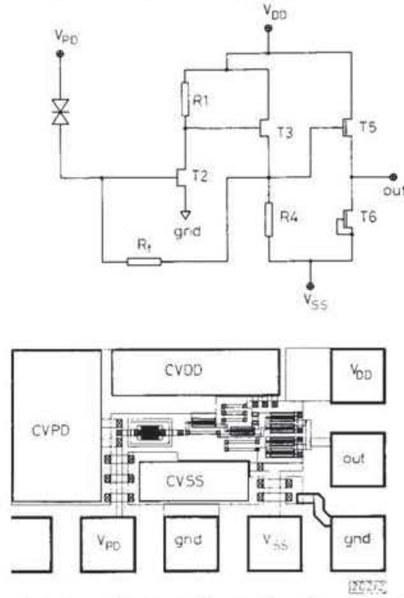

Fig. 2 *Circuit diagram and layout of optoelectronic receiver*
Pad size = 100 × 100 μm²

The photodiode has 1 μm wide fingers with 1·5 μm wide spacing and an active area of 25 × 25 μm². Airbridges connect the photodiode to the electric circuit. The transimpedance stage itself is composed of two enhancement transistors $T2$ and $T3$ (gate widths 40 μm), two 1 kΩ NiCr thin film resistors $R1$ and $R4$, and a 500 Ω NiCr feedback resistor R_f. The output buffer stage is a source follower with a constant current load (depletion transistors $T5$ and $T6$, gate widths 80 μm). The layout includes also three blocking capacitors for the supply voltages V_{PD}, V_{DD} and V_{SS}.

Device and circuit performance: The following mean values for the enhancement and depletion AlGaAs/GaAs parameters, respectively, have been obtained: threshold voltage = 0·1 and −0·5 V, transconductance = 500 and 390 mS/mm, source resistance = 0·7 and 0·6 Ω mm, transit frequency = 35 and 30 GHz. The DC responsivities of MSM photodiodes to light of 0·84 μm wavelength were 0·25 A/W for 4 V and 0·35 A/W for 10 V bias voltage, respectively. The dark current at 4 V was less than 2 nA.

All high frequency measurements on the integrated optoelectronic receivers were performed on-wafer using Cascade probes. The photodiode was irradiated by 0·84 μm light from a high speed Ortel laser diode via a singlemode fibre. The current driving the laser diode was modulated to obtain up to 0·8 mW peak-to-peak modulated optical signals. The photodiode bias voltage was $V_{PD} = 10\,V$, the circuit supply voltages were $V_{DD} = 3\,V$ and $V_{SS} = -1\,V$ (Fig. 2). The relative response against frequency, measured at the output of the optoelectronic receiver for sinusoidal modulated incident light, is shown in Fig. 3. This curve shows that the −3 dB bandwidth lies at 8·2 GHz.

The circuit response to a non-return-to-zero (NRZ) optical signal at a data rate of 10 Gbit/s is depicted in Fig. 4. The eye diagram of the output voltage demonstrates that the optoelectronic receiver operates successfully for a 10 Gbit/s NRZ pseudorandom data stream of length $2^7 - 1$ bits.

Conclusions: We have designed, built and tested the first monolithic integrated optoelectronic receiver consisting of an

MSM photodiode and a transimpedance amplifier based on recessed-gate quantum well AlGaAs/GaAs HEMTs with two

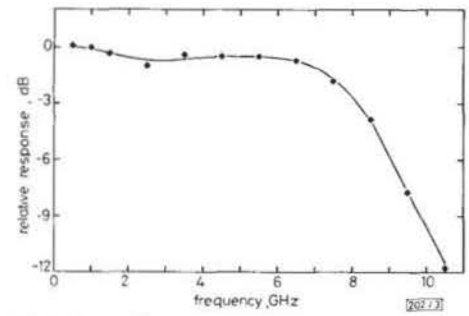

Fig. 3 *Measured frequency response of photoreceiver*
−3 dB bandwidth lies at 8·2 GHz

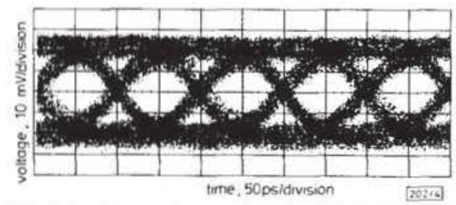

Fig. 4 *Eye diagram of output voltage for 10 Gbit/s NRZ pseudorandom optical pulse input*

delta-doped carrier supply layers. The detector circuit has a bandwidth of 8·2 GHz and operates at data rates up to 10 Gbit/s.

Our results show that it is possible to make monolithic receivers for extremely high-speed optical signals using our established 0·5 μm gate length process.

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