energy ion bombardment with minimal sputtering or degradation in mask smoothness during etching. The low flowrates

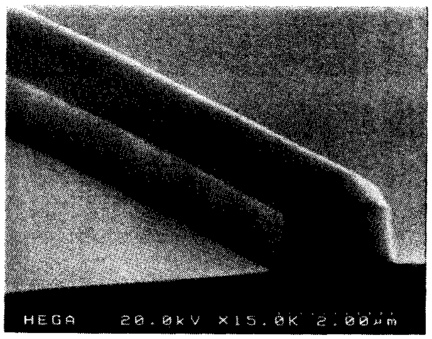

Fig. 3 *Losses for wet and dry etched waveguides*

○ wet
● dry

and pressures used result in low etch rates, improving process control.

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H. E. G. Arnot, H. P. Zappe, J. E. Epler, B. Graf, R. Widmer and H. W. Lehmann (*Paul Scherrer Institute Zürich, Badenerstrasse 569, CH-8048 Zürich, Switzerland*)

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MONOLITHIC GaAs/AlGaAs *pin* MESFET PHOTORECEIVER USING A SINGLE MOLECULAR BEAM EPITAXY GROWTH STEP

D. Nichols, N. K. Dutta, P. R. Berger, P. R. Smith, D. Sivco and A. Y. Cho

Indexing terms: Optoelectronics, Optical receivers, Field-effect transistors, Epitaxy and epitaxial growth

A monolithic *pin*/MESFET photoreceiver in the GaAs/AlGaAs system was investigated. The structure used a single epitaxial growth step in which the *pin* photodiode was grown on top of the MESFET. The photoreceivers exhibited flat-band gains as high as 17dB and bandwidths as high as 2·0GHz.

Introduction: The monolithic integration of optical and electronic components on the same substrate allows for higher speed and more stable operation of the systems which they comprise. Optoelectronic integrated circuits (OEICs) are the objects of intense research and many improvements in their performance have been reported in the literature in both the InP [1–6] and GaAs [7–9] systems. Of particular interest has been the monolithic photoreceiver in which a photoreceiver and transistor amplifier are integrated on the same chip. Approaches to the realisation of these circuits have included vertical integration, single growths on patterned substrates and regrowth of the transistor layers after the detectors. For ease of fabrication and potentially higher device performance, it is desirable to realise the integration with a single growth on a planar substrate.

Long-wavelength InP-based circuits are well suited to long-haul communications applications because of the availability of low-loss fibres at long wavelengths. However, for short-haul applications, such as LANs, it may be desirable to employ GaAs-based circuits for high-temperature operation. We present results on a *pin*/MESFET monolithic photoreceiver realised with a single molecular beam epitaxy growth step. We demonstrate successful operation of the circuit at 1 Gbit/s using a very simple amplifier configuration.

Experiment: The structure, pictured in Fig. 1, was grown via molecular beam epitaxy (MBE) on semi-insulating GaAs and

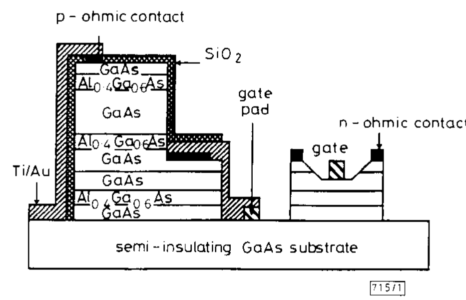

Fig. 1 *Schematic diagram of pin/MESFET circuit*

consisted of a 1000 Å layer of GaAs which was unintentionally doped, 1000 Å of $Al_{0.4}Ga_{0.6}As$, also unintentionally doped, an *n*-type channel layer consisting of 2300 Å of GaAs with a concentration of $4 \times 10^{17} cm^{-3}$ and a 3000 Å GaAs *n*-conrtact layer doped to $2 \times 10^{18} cm^{-3}$. This contact layer served as the ohmic contact layer for both the MESFET and the *pin* diode. These layers were followed by the *pin* structure which consisted of 2000 Å of $Al_{0.4}Ga_{0.6}As$ doped *n*-type to $2 \times 10^{18} cm^{-3}$, a 6000 Å GaAs absorption layer which was unintentionally doped, 2000 Å of $Al_{0.4}Ga_{0.6}As$ doped *p*-type to $2 \times 10^{18} cm^{-3}$ and the GaAs *p*-contact layer doped to $5 \times 10^{18} cm^{-3}$. The *pin* layers were then removed selectively via wet chemical etching in order to define the MESFET areas on the wafers and isolation mesas were formed around both the *pins* and MESFETs by etching down to the semi-insulating substrates. Standard photolithographic techniques were then employed to define the ohmic contacts, gates, Ti resistors and interconnect metal. Isolated MESFETs and *pin* photodiodes were included in the mask for diagnostic purposes. The MESFETs employed a π-gate configuration in order to reduce the gate resistance. The gate lengths were 1·0 μm and the gates were defined using optical lithography. The gate widths were varied (2 × 40, 2 × 75 and 2 × 100 μm wide.)

Results: The DC characteristics of the MESFETs were measured from isolated devices on the same processed wafer as the integrated photoreceivers. The devices exhibited transconductances as high as 341 mS/mm with current densities I_{ds} of up to 537 mA/mm. Similarly, the DC characteristics of the isolated *pin* photodiodes were also measured. The diodes had reverse breakdown voltages between 15 and 20 V and reverse leakage currents smaller than 10 nA when biased at −5 V.

After DC testing, the RF characteristics of the MESFETs and photodiodes were measured using an HP 8510 network analyser and wide bandwidth coplanar waveguide probes. The devices were characterised between 100 MHz and 40 GHz. 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 and typical high-frequency characteristics are shown in Fig. 2. The devices

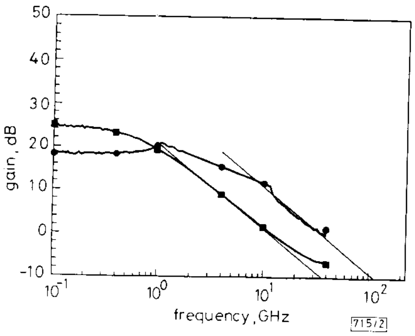

Fig. 2 *Variation of the short-circuit current gain (H_{21}) and maximum available gain with frequency for an isolated MESFET using a $2 \times (1 \times 75)\,\mu m$ gate*

■ H_{21}
● MAG

were found to have cutoff frequencies as high as $f_t = 11{\cdot}3$ GHz and $f_{max} = 35{\cdot}1$ GHz. The reflection coefficient of the photodiode was measured as a function of frequency in order to derive an equivalent circuit. From these characteristics, we can deduce that the diode has a resistance of 30 Ω and a capacitance of 0·04 pF, indicating that these diodes should be capable of operation well into the gigahertz range.

High-speed characterisation of the photodiodes and photoreceiver circuits was carried out using a lightwave component analyser with a measurement capability between 130 MHz and 20 GHz. A GaAs/AlGaAs laser diode with a measured bandwidth of 2·6 GHz was modulated by the lightwave analyser and its output was coupled to the photoreceivers via an optical fibre. The responses of the individual diodes and circuits were then measured. The diodes had diameters of 18 and 50 μm and were biased at −5 V. The smaller diodes had bandwidths which were limited by the response of the laser. The response of the photodiode of each receiver was used to calibrate the gain of the amplifier section. Typical characteristics of the receivers as shown in Fig. 3. The photoreceiver

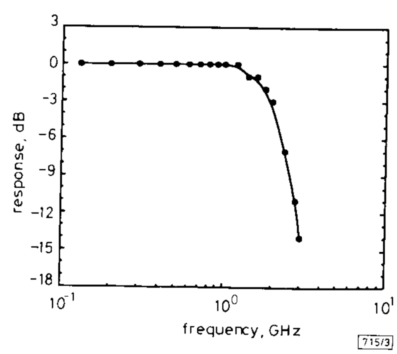

Fig. 3 *Typical rolloff characteristic of pin/MESFET circuit*

circuits exhibited 3 dB bandwidths as high as 2·0 GHz and flatband gains as high as 17 dB. The receiver sensitivity was measured at 1 Gbit/s using a $PRBS = 2^{15} - 1$ NRZ signal. The receiver sensitivity was measured to be −15 dBm at a BER of 10^{-9}, probably limited by the noise characteristics of the transistors. Thus, the sensitivity can be improved through optimisation of the structure. The eye diagram of the circuit at 1 Gbit/s was measured and is shown in Fig. 4. The successful operation of the receiver circuit at 1 Gbit/s is evidenced by a clear open eye pattern.

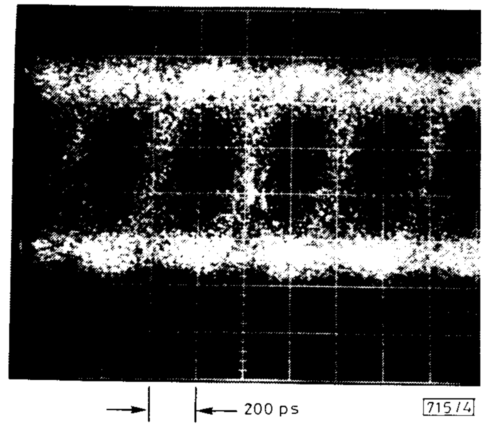

Fig. 4 *Eye diagram of pin/MESFET circuit using a $2 \times (1 \times 75)\,\mu m$ at a data rate of 1 Gbit/s*

Summary: A *pin*/MESFET photoreceiver was fabricated and tested using a single epitaxial growth step. The photoreceivers were successfully operated at 1 Gbit/s, exhibiting flatband gains as high as 17 dB using only a single transistor amplifier configuration.

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D. Nichols, N. K. Dutta, P. R. Berger,* P. R. Smith, D. Sivco and A. Y. Cho (*AT&T Bell Laboratories, 600 Mountain Avenue, Murray Hill, New Jersey 07974, USA*)

* Present Address: University of Delaware, Newark, Delaware 10716, USA

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