14GHz BANDWIDTH MSM PHOTODIODE AlGaAs/GaAs HEMT MONOLITHIC INTEGRATED OPTOELECTRONIC RECEIVER

V. Hurm, M. Ludwig, J. Rosenzweig, W. Benz,
M. Berroth, R. Bosch, W. Bronner, A. Hülsmann,
K. Köhler, B. Raynor and J. Schneider

Indexing terms: Integrated optoelectronics, Optical receivers

A monolithic optoelectronic receiver consisting of an MSM photodiode and a two-stage amplifier has been fabricated using an enhancement/depletion 0.3 μm recessed-gate AlGaAs/GaAs HEMT process. The bandwidth of 14.3 GHz implies suitability for transmission rates of up to 20 Gbit/s. The transimpedance is 670 Ω (into 50 Ω) and the projected sensitivity is -16.4 dBm ($\text{BER} = 10^{-9}$).

Introduction: Fibre optical links with extremely high data rates ($> 1 \text{ Gbit/s}$) are required in long haul telecommunication systems as well as in computer local area networks, and board-to-board and chip-to-chip interconnections. Short distance interconnections can operate at 0.85 μm wavelength which allows the use of fully integrated GaAs transmitter and receiver circuits.

In a previous paper [1] we reported the first 10 Gbit/s monolithic integrated optoelectronic receiver which was based on a GaAs metal-semiconductor-metal (MSM) photodiode and on enhancement/depletion 0.5 μm recessed-gate AlGaAs/GaAs HEMTs. A bandwidth of 8.2 GHz was demonstrated. In this Letter a receiver with a two-stage amplifier based on 0.3 μm HEMTs is described together with its ultrahigh-speed low-noise characteristics. To our knowledge this is the fastest monolithic integrated optoelectronic receiver to date [2, 3].

Design and fabrication: The receiver was fabricated using our standard process for double delta-doped quantum well AlGaAs/GaAs HEMTs with gate lengths of 0.3 μm [4, 5]. This process enables the fabrication of enhancement and depletion transistors, diodes, MSM photodiodes, NiCr thin film resistors, MIM capacitors, and airbridge inductors. The interconnection between different devices is achieved by two levels of metallisation. The following mean values for the enhancement and depletion HEMT parameters, respectively, have been obtained: threshold voltage: 0.09 and -0.41 V ,

transconductance: 565 and 360 mS/mm, source resistance: 0.7 and 0.6 Ωmm , transit frequency: 50 and 42 GHz.

For the receiver we used an MSM photodiode with 1 μm wide fingers, 1.5 μm wide finger spacing, an active area of $25 \times 25 \mu\text{m}^2$, and no antireflection coating. The DC responsivities to light of 0.84 μm wavelength are 0.25 A/W for 4 V and 0.27 A/W for 10 V bias voltage, respectively. The corresponding external quantum efficiencies are 37% at 4 V and 40% at 10 V. The dark currents are 2 nA at 4 V and 110 nA at 10 V.

The circuit diagram of the receiver is shown in Fig. 1. The receiver consists of an MSM photodiode, a transimpedance

Fig. 1 Circuit diagram of photoreceiver

amplifier with a 500 Ω feedback resistor, a second-stage amplifier, and an output buffer. In the transimpedance stage we used enhancement HEMTs with gate widths of 20 μm . The values of the NiCr thin film resistors depicted are in Ohms. The same circuit parameters as in the transimpedance stage were applied to the second-stage amplifier. The output buffer includes four depletion transistors with gate widths of 40 and 80 μm . Fig. 2 is a photograph of the fabricated receiver. The depicted chip area measures $500 \times 350 \mu\text{m}^2$. Airbridges connect the MSM photodiode to the amplifier circuit. The receiver also includes blocking capacitors for the supply voltages.

Fig. 2 Photograph of fabricated photoreceiver
MSM photodiode has $25 \times 25 \mu\text{m}^2$ active area

Circuit performance: All receiver measurements 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 measured transimpedance of the receiver is 1.29 k Ω unloaded and 670 Ω when loaded to 50 Ω . The voltage gain achieved by the second-stage amplifier is ~ 3.5 and the power dissipation of the receiver is 115 mW.

For high-frequency measurements the current driving the laser diode was directly modulated. The frequency response of the laser diode was determined using a calibrated GEC Marconi photodiode and an HP 8510 network analyser. Fig. 3 shows the small signal frequency response of the receiver itself. The -3 dB bandwidth is 14.3 GHz. The flat frequency response and the ultrahigh bandwidth indicate that the receiver is suitable for transmission rates of up to 20 Gbit/s (NRZ). Eye diagrams of the receiver output voltage were measured at data rates up to 10 Gbit/s (the upper limit of our Anritsu pulse pattern generator). The eye diagrams of the present 20 Gbit/s

receiver are of the same quality as our 10 Gbit/s receiver demonstrated previously [1]; they are determined mainly by the laser performance.

Fig. 4 shows the output noise power spectrum of the receiver. It was measured with a 26.5 GHz setup consisting of an

Fig. 3 Measured frequency response of photoreceiver
-3 dB bandwidth lies at 14.3 GHz

Fig. 4 Measured output noise power spectrum
Equivalent input noise current density is $8.7 \text{ pA}/(\text{Hz})^{1/2}$

HP 70620B low-noise preamplifier and an HP 71209A spectrum analyser. The total output noise power is $9.7 \times 10^{-9} \text{ W}$ (into 50Ω). Taking into account the transimpedance of 670Ω and the bandwidth of 14.3 GHz this implies an averaged equivalent input noise current density $(\langle i^2 \rangle_c)^{1/2}$ of $8.7 \text{ pA}/(\text{Hz})^{1/2}$. From the theory of Smith and Personick, eqn. (4-108) [6] the sensitivity can be calculated to be -16.4 dBm for a bit-error-rate (BER) of 10^{-9} .

Conclusions: A 20 Gbit/s monolithic integrated optoelectronic receiver for light of $0.85 \mu\text{m}$ wavelength has been designed, built, and tested. The bandwidth is 14.3 GHz, the transimpedance is 670Ω (into 50Ω), and the sensitivity is -16.4 dBm ($\text{BER} = 10^{-9}$).

Using AlGaAs/GaAs HBTs and a *pin* photodiode, Pedrotti *et al.* [2] produced a receiver with a bandwidth of 13 GHz, a transimpedance of 250Ω , and a sensitivity of -12 dBm ($\text{BER} = 10^{-9}$). Ketterson *et al.* [3] used pseudomorphic GaAs/InGaAs/AlGaAs MODFETs and an MSM photodiode in the design of a 10 GHz bandwidth receiver with a transimpedance of 300Ω . Including a variable active feedback resistor, a gain-peaked response with a bandwidth of 14 GHz was measured at a lower transimpedance of 90Ω .

Our results are thus the highest yet reported. This demonstrates the ability of our standard enhancement/depletion $0.3 \mu\text{m}$ recessed-gate AlGaAs/GaAs HEMT process to provide monolithic integrated receivers with ultrahigh-bandwidth low-noise characteristics.

Acknowledgments: The authors are extremely grateful to the entire technology department managed by T. Jakobus. Special

thanks go to H. S. Rupprecht for his continuous encouragement, and to the members of the devices and circuits department.

19th October 1992

V. Hurm, M. Ludwig, J. Rosenzweig, W. Benz, M. Berroth, R. Bosch, W. Bronner, A. Hülsmann, K. Köhler, B. Raynor and J. Schneider (Fraunhofer-Institut für Angewandte Festkörperphysik, D-7800 Freiburg, Germany)

References

1. HURM, V., ROSENZWEIG, J., LUDWIG, M., BENZ, W., BERROTH, M., HÜLSMANN, A., KAUFEL, G., KÖHLER, K., RAYNOR, B., and SCHNEIDER, J.: '8.2 GHz bandwidth monolithic integrated optoelectronic receiver using MSM photodiode and $0.5 \mu\text{m}$ recessed-gate AlGaAs/GaAs HEMTs', *Electron. Lett.*, 1991, 27, (9), pp. 734-735
2. PEDROTTI, K. D., SHENG, N. H., PIERSON, R. L., JR., FARLEY, C. W., ROSKER, M. J., and CHANG, M. F.: 'Monolithic ultrahigh-speed GaAs HBT optical integrated receivers', Tech. Dig. 13th GaAs IC Symp., Monterey, CA, USA, 1991, pp. 205-208
3. KETTERSON, A., SEO, J.-W., TONG, M., NUMMILA, K., BALLEGEER, D., KANG, S.-M., CHENG, K. Y., and ADESIDA, I.: 'A 10 GHz bandwidth pseudomorphic GaAs/InGaAs/AlGaAs MODFET-based OEIC receiver', Dig. 50th Device Research Conf. Cambridge, MA, USA, 1992, paper VIB-5
4. KÖHLER, K., GANSER, P., BACHEM, K. H., MAIER, M., HORNUNG, J., and HÜLSMANN, A.: 'Advanced high electron concentration GaAs/AlGaAs pulse-doped double heterostructure for device application', Proc. 17th Int. Symp. on gallium arsenide and related compounds, Jersey, UK, Inst. Phys. Conf. Ser., 1990, No. 112, pp. 521-526
5. HÜLSMANN, A., KAUFEL, G., KÖHLER, K., RAYNOR, B., SCHNEIDER, J., and JAKOBUS, T.: 'E-beam direct-write in a dry-etched recess gate HEMT process for GaAs/AlGaAs circuits', *Jpn. J. Appl. Phys.*, 1990, 29, (10), pp. 2317-2320
6. SMITH, R. G., and PERSONICK, S. D.: 'Receiver design for optical fiber communication systems', in KRESSEL, H. (Ed.): 'Topics in applied physics' (Springer, 1982), Vol. 39, pp. 89-160