10 GHz bandwidth monolithic *p-i-n* modulation-doped field effect transistor photoreceiver

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A photoreceiver circuit using an InGaAs *p-i-n* photodiode and InGaAs/InAlAs pseudomorphic modulation-doped field effect transistor (MODFET) based preamplifier has been fabricated. The 18 μm diam photodiode has a bandwidth of 29 GHz and the f_t and f_{max} of the MODFET are 26 and 30 GHz, respectively. The photoreceiver circuits have bandwidths of 10 GHz and 17 dB gain. The sensitivity at 2.5 Gb/s is -26.4 dBm.

Optoelectronic integrated circuits (OEICs) are important for the next generation optical data transmission and switching systems. Among the important OEIC technologies are the photoreceiver and phototransmitter fabrication technology. Several different types of photoreceivers based on OEICs have been previously reported.[1-9] These devices use either *p-i-n* photodiodes or MSM (metal-semiconductor-metal) photodiodes for the conversion of incident photons to electrons followed by HBT or FET-based amplifiers circuits. Recently we fabricated an integrated receiver circuit using an InGaAs *p-i-n* photodiode and an InGaAs/InAlAs based modulation-doped field effect transistor (MODFET) preamplifier. This device has a 3-db bandwidth of $\sim$1 GHz and has receiver sensitivity comparable to that for hybrid receivers.[9] This letter reports the fabrication and performance characteristics of a *p-i-n* MODFET receiver with a 3-dB bandwidth of 10 GHz.

The schematic of the device structure is shown in Fig. 1. The *p-i-n* photodiode is grown by MBE first. The *p-i-n* photodiode consisted of a superlattice (SL) buffer, a 0.4 μm n^+-$In_{0.52}Al_{0.48}As$ lower contact layer, a 0.75 μm i-$In_{0.53}Ga_{0.47}As$ active region with 300 Å i-$In_{0.52}Al_{0.48}As$ setback layers above and below to minimize impurity interdiffusion, a 0.4 μm p^+-$In_{0.52}Al_{0.48}As$ upper contact layer, and a 200 Å p^+-$In_{0.53}Ga_{0.47}As$ cap layer. A heterojunction photodiode reduces the dark current created by generation and recombination of carriers in the higher band-gap material, and the upper contact acts as an optical window. The epilayer is then coated with SiO_2 using plasma enhanced chemical vapor deposition (PECVD). The wafer is then patterned photolithographically and mesas are formed in the *p-i-n* material by chemically removing the surrounding material down to the InP substrate. The wafer is cleaned and reinserted into the MBE for regrowth of the MODFET. The MODFET structure is comprised of a SL buffer, a i-$In_{0.52}Al_{0.48}As$ buffer, a 400 Å i-$In_{0.53}Ga_{0.47}As$ layer, a 100 Å strained i-$In_{0.65}Ga_{0.35}As$ channel layer, a 50 Å i-$In_{0.52}Al_{0.48}As$ spacer, a 150 Å n^+-$In_{0.52}Al_{0.48}As$ donor layer (5×10^{18} cm^{-3}), a 400 Å i-$In_{0.52}Al_{0.48}As$ layer to reduce gate leakage, and a 200 Å n^+-$In_{0.53}Ga_{0.47}As$ cap layer. Polycrystalline material grows on top of the SiO_2 mask, and single-crystal material beside the *p-i-n* mesa. The wafer is again patterned and the polycrystalline material and SiO_2 is selectively removed by wet etching.

The wafer is processed to produce the *p-i-n* MODFET circuits. The MODFETs employ a Π gate configuration to reduce the gate resistance. The gate lengths are 1.0 μm, produced using contact lithography, and the gate widths are varied. The circuits are a combination of two sizes (18 and 50 μm diam) photodiodes and three gate widths (40, 75, and 100 μm). The processed wafer also has isolated photodiodes and MODFETs.

The dc characteristics of the MODFETs are measured from isolated devices on the same wafers as the OEICs. The extrinsic transconductance (g_m) of the MODFETs are as high as 512 mS/mm at a source to drain voltage of 1.6 V. The typical current densities are 140–150 mA/mm. The transistor figures of merit f_t and f_{max} are measured from 100 MHz to 40 GHz using a vector network analyzer and coplanar waveguide probes. The parasitic effects of the pads are removed by subtracting the Y parameters of the pads without a device from a device with pads. The MODFETs have f_t and f_{max} values of 26 and 30 GHz, respectively.

The responsivity of the *p-i-n* photodiodes are $\sim$0.55–0.60 A/W at $\lambda\sim1.3$ μm. The typical dark currents are in the 30–50 mA range at 5 V and breakdown voltages are $\sim$18–20 V.

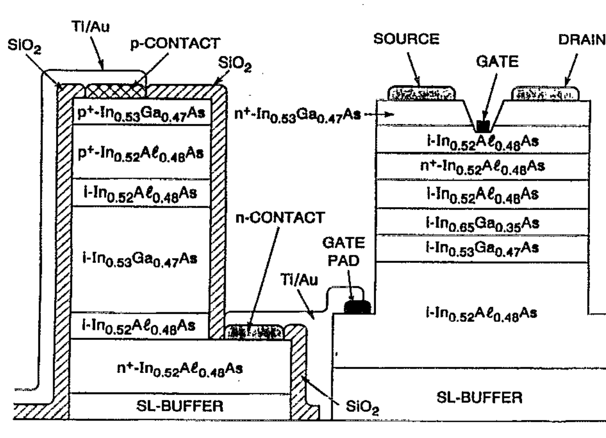

FIG. 1. Schematic of a *p-i-n* MODFET photoreceiver epitaxial layer structure and design.

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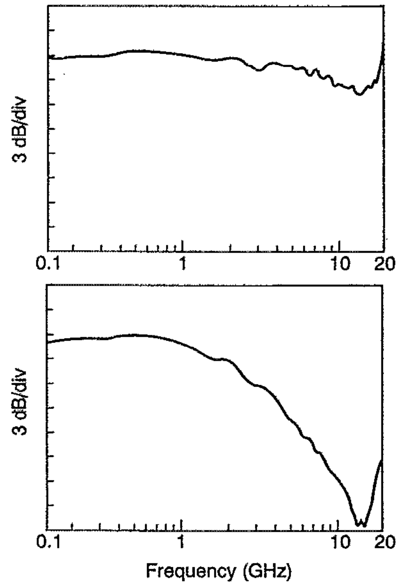

FIG. 2. The modulation response of a *p-i-n* MODFET circuit. The top and bottom curves are for circuits with 18 and 50 μm diam photodiode, respectively.

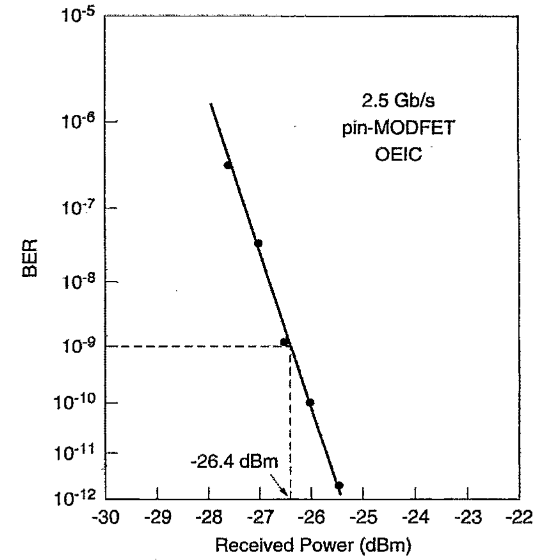

FIG. 3. Measured bit-error-rate (BER) as a function of received power at 2.5 Gb/s.

The modulation response of the circuit is measured using a lightwave component analyzer which had a modulated 1.55 μm laser source. The modulation frequency is varied from 130 MHz to 20 GHz. The circuits were probed on a wafer with a microwave probe station and the photodiode was illuminated with the modulated laser light using a lensed single mode fiber. The circuit is biased with V_{ds} $=1.5$ V and the photodiode reverse biased at -5 V using biased $-T_s$. The modulation response of two circuits with 18 and 50 μm diam photodiodes are shown in Fig. 2. The 3 dB bandwidth of the circuit with the smaller photodiode is 10 GHz and that for the larger photodiode is 2.3 GHz. The MODFETs for the above circuits have 2×40 μm wide gates. The isolated *p-i-n* photodiodes are also measured in a similar manner. The 18 and 50 μm diam photodiodes exhibited 3 dB bandwidths of 29 and 3.5 GHz, respectively. The 3 dB bandwidth of 18 μm diam photodiode is extrapolated from the measured 1.5 dB bandwidth of 20 GHz.

Another parameter of interest is the circuit gain. The gain is defined as the response of the circuit minus the response of the isolated photodiodes on the same wafer. As expected, the devices with larger gate width have higher transconductance and therefore they have higher gain than that for devices with smaller gate width. The maximum flatband gain for devices with 100, 75, and 40 μm gate widths are 21.0, 19.2, and 17 dB, respectively.

The bit-error-rate (BER) characteristics of the circuit were measured. The data are shown in Fig. 3. The source used was a distributed feedback laser emitting near 1.55 μm and modulated at 2.5 Gb/s. The measured sensitivity at 10^{-9} BER is -26.4 dBm.

In summary, a *p-i-n* MODFET photoreceiver circuit has been fabricated using InGaAs *p-i-n* photodiodes and InGaAs/InAlAs MODFET preamplifier. The 18 μm diam *p-i-n* photodiodes have bandwidths of 29 GHz. The photoreceiver circuits utilizing these photodiodes have bandwidths of 10 GHz and 17 dB gain.

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