Planar, Linear GaAs Detector–Amplifier Array with an Insulating AlGaAs Spacing Layer Between the Detector and Transistor Layers

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Abstract—**Monolithic, high-speed, planar, linear, parallel channel, ten-element GaAs detector-amplifier arrays with a 70-μm detector center-to-center spacing have been fabricated using a GaAs/AlGaAs/GaAs epitaxial structure grown on semi-insulating GaAs. The AlGaAs layer provided excellent electrical isolation between the transistor and n^- photoconductor epitaxial layers. Rise and fall times of integrated detector-amplifier array channels of 650 ps and 1.1 ns, respectively, were measured at 0.84-μm wavelength. The sensitivity of single, discrete, detector-amplifier channels was better than −34 dBm.**

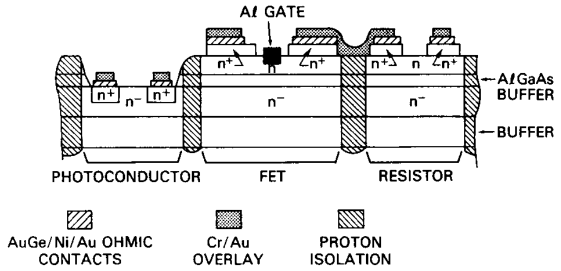

Fig. 1. Cross section of detector-amplifier array components showing MBE buffer, detector, isolating AlGaAs, FET, and n^+ contact layers. Layers (doping concentrations and thickness values given in text) grown on semi-insulating substrate. Not to scale.

MONOLITHIC GaAs detector-amplifier circuits and arrays using planar photoconductors may be useful in optoelectronic applications such as spectrum analysis and communications in the 820–890-nm wavelength range [1]–[8]. In addition, planar GaAs photoconductors are attractive candidates for optoelectronic circuits because their response characteristics may be changed during fabrication [1]; because they provide the potential for large bandwidths, photoconductive gain at the focal plane, and high quantum efficiency [1]–[10]; and because they may be easily integrated with field-effect transistor (FET) amplifier circuits [1]–[3], [5]–[8]. To obtain low detector dark current and high quantum efficiency, it is desirable to use a low doped, thick active material for the detectors. This material need is not consistent with the material requirements for the FET's, however. High-speed, planar, linear, parallel channel, ten-element, GaAs detector-amplifier arrays, in which the active detector layer and FET layer with the desired material characteristics were electrically isolated by an insulating layer of AlGaAs, are described in this paper. The photodetectors were planar, linear photoconductors with a center-to-center spacing of 70 μm. The arrays described in this paper are the first linear, parallel channel GaAs detector-amplifier arrays reported and have more detector elements and a shorter detector center-to-center spacing than other reported GaAs detector-amplifier circuits. Faster GaAs detector-amplifier chips having more than one photodetector previously have been reported [11]; however, the arrays reported in this paper are the fastest reported linear, parallel channel detector-amplifier arrays designed for acousto-optical (AO) spectrum analysis.

The detector-amplifier arrays were fabricated in a multilayered molecular beam epitaxial (MBE) GaAs/AlGaAs/GaAs materials system on semi-insulating GaAs substrates (Fig. 1) [3]. The GaAs buffer layer was ≈ 1 μm thick and had a carrier concentration $< 1 \times 10^{14}/\text{cm}^3$. The n^- GaAs detector layer was ≈ 1 μm thick and had a silicon doping density of $5 \times 10^{14}/\text{cm}^3$. The insulating layer between the detector and FET layers was undoped AlGaAs and was 100 nm thick. The FET layer, in which the resistors were also fabricated, was n-type GaAs with a thickness of 300 nm and a silicon doping density of $1.1 \times 10^{17}/\text{cm}^3$. A 50-nm-thick n^+ GaAs layer with a silicon doping density of $7.0 \times 10^{18}/\text{cm}^3$ was used below the AuGe/Ni/Au ohmic metal to obtain reduced ohmic contact resistance to the FET layer. Lateral isolation of the circuit components was obtained by proton bombardment.

The insulating AlGaAs layer between the FET and detector layers (Fig. 1) was very effective in providing electrical isolation between the two active layers. Resistance values between adjacent ohmic contacts, one in the FET layer and one in the detector layer separated by 15 μm in the lateral direction, were in the range of 40–120 MΩ for the detector layers with silicon doping concentrations of either $5 \times 10^{14}/\text{cm}^3$ or $3 \times 10^{15}/\text{cm}^3$.

A hybrid circuit was used for the dynamic measurements of

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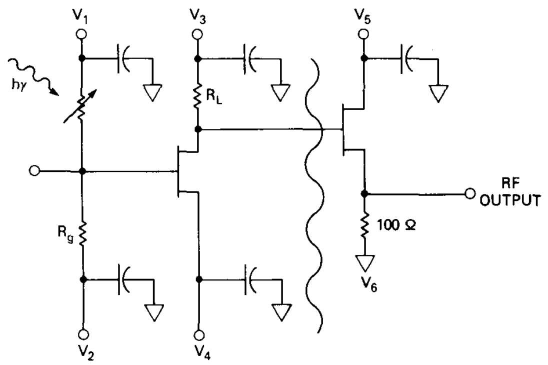

Fig. 2. Hybrid detector-amplifier circuit of single channel of detector-amplifier array. Portion to left of vertical curved line on ten-element GaAs array chip. Portion to right of vertical curved line is off-chip source-follower output stage. Bypass capacitors shown added to bias leads.

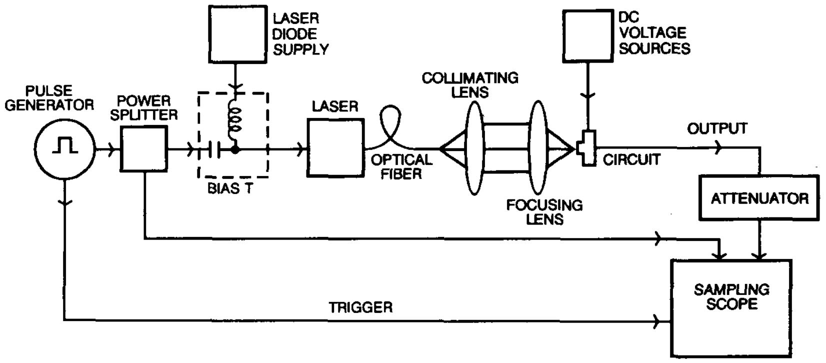

Fig. 3. Detector-amplifier test system.

the ten-element array characteristics. Each array chip was mounted on a 2-in square, 0.010-in-thick alumina substrate with 0.002 inches of chrome-gold metallization on each side. Avantek model AT8251 FET's, one for each array channel, were also mounted on the alumina substrate in source-follower configurations. The hybrid detector-amplifier circuit for a single channel is shown in Fig. 2. The source-follower output stages were impedance transformers allowing matching of the high ($> 1000\ \Omega$) output impedance of the detector-amplifier on-chip amplifier stages to the 50-Ω instrumentation input impedance. Bypass capacitors were added to the bias leads (Fig. 2) to maintain stable bias values and to minimize ringing.

The test system is shown in Fig. 3. The optical source was an 0.84-μm wavelength laser (Ortel SL320-SMF) with a single-mode fiber pigtail. A Colby PG 1000A pulse generator was used to excite the laser. The peak power at the focal plane was ≈200 μW except when the laser output was attenuated. A 50-Ω sampling oscilloscope with a 25-ps rise time (t_r) and signal averaging techniques were used to analyze the output signals. Infrared achromatic objectives were used as the collimating and focusing lenses except when the fiber was positioned very close to the focal plane. With these lenses the focal plane spot size was 6 μm in diameter 3 dB below the laser peak power and 16 μm in diameter 30 dB below the laser peak power.

The dc characteristics of FET's, photoconductors, and resistors of single-channel detector-amplifier circuits fabricated on the same substrates with the arrays were measured. In addition, the dc characteristics of the FET's and resistors in the arrays were measured. Typically, the FET's, which had aluminum gates, had I_{dss} values of ≈5 mA, pinch-off voltage values between -1.5 and -4.8 V, and transconductance values between 30 and 80 mS/mm at 0-V gate bias. The values of the transform resistors R_g and load resistors R_L (Fig. 2) were ≈5100 and ≈1200 Ω, respectively. Discrete photoconductors had t_r and fall time t_f values in the ranges 0.5–4 and 0.5–16 ns, respectively, when the optical excitation was at 0.84-μm wavelength and had a full width at half maximum (FWHM) in the range 2–10 ns. The t_r and t_f values are defined as the elapsed times between 10 and 90 percent and between 90 and 10 percent, respectively, of the the response maximum.

The t_r and t_f values of channels of the detector-amplifier arrays were as short as 650 ps and 1.1 ns, respectively, when the optical excitation was at 0.84-μm wavelength and had a FWHM between 2 and 6 ns and a repetition rate between 20 and 100 MHz. Representative results for an array channel are shown in Fig. 4. The upper trace is the pulse generator output to the laser, and the lower trace is the output of the hybrid circuit attenuated by a factor of 10 showing t_r and t_f values of 1.1 ns. This measurement was made without the infrared

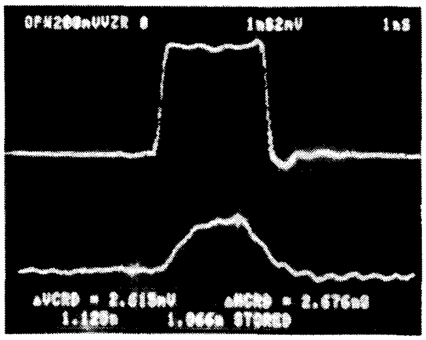

Fig. 4. Detector-amplifier array channel response, channel 4, chip no. DA10AJ13. Upper trace: pulse generator output to laser (t_r 225 ps, t_f 201 ps, FWHM 2.7 ns, pulse repetition rate 100 MHz, pulse height 567 mV); lower trace: attenuated hybrid circuit output (t_r and t_f 1.1 ns, pulse height 2.7 mV). Bias values V_1, V_2, V_3, V_4, V_5, and V_6 were 9.0 V, −1.0 V, 5.0 V, 0.0 V, 3.0 V, and ground, respectively.

achromatic objectives and with the end of the optical fiber positioned ≈30 μm from the focal plane.

The response times of discrete detector–amplifier channels fabricated on the array wafers were longer when the light was attenuated by factors of 10 to 10^3 using absorbing neutral density filters. For example, the t_r of a single channel was 7 ns when the optical excitation had a peak power of 176 μW and a FWHM of 20 ns. The channel had a t_r of 702 ns and a signal-to-noise ratio of 30, however, when the optical excitation had a peak power of 1.24 μW (−29 dBm), a t_r of 127 ns, a FWHM of 3.5 μs, and a repetition rate of 22 kHz. The sensitivity of this device was better than −34 dBm for a signal-to-noise ratio greater than one as determined when an additional neutral density filter was used.

In conclusion, monolithic, high-speed, planar, linear, parallel channel, ten-element GaAs detector-amplifier arrays have been operated with an undoped AlGaAs MBE layer which provided excellent vertical electrical isolation between the detector and FET layers. The active photodetectors were planar photoconductors. Rise and fall time values of 650 ps and 1.1 ns, respectively, were observed for detector–amplifier array channels. These are the shortest response times reported to date for detector arrays designed primarily for AO spectrum analysis. The arrays had more detector elements and a shorter detector center-to-center spacing than other GaAs detector–amplifier circuits reported to date and are the first linear, parallel channel GaAs detector–amplifier arrays reported. Similar arrays with a larger number of detector elements may be very useful in applications such as communications and AO signal processing.

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