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Picosecond Response of GaAs/AlGaAs Planar Schottky Barrier Photodiode

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A high-speed high-sensitivity planar GaAs/$Al_{0.3}Ga_{0.7}As$ heterostructure Schottky barrier photodiode has been developed. An n^+-$Al_{0.3}Ga_{0.7}As$ buffer layer is used to reduce the series resistance and the undesired diffusion tailing. Furthermore, surface passivation and antireflection coating with a Si_3N_4 film are applied to improve the sensitivity of the photodiode. The measured external quantum efficiency and responsivity are 60% to 77% and 0.47 A/W to 0.6 A/W, respectively, for the wavelength range of 0.5 μm to 0.84 μm. A risetime of 8.5 ps and a 3-dB cutoff frequency of 50 GHz were measured by sampling/correlation method.

I. Introduction

With the recent development of femtosecond-pulsed lasers and the modulation of light in the several tens of gigahertz, wide band photodetectors with high response speed and high sensitivity are required for use in microwave and millimeter-wave modulated lightwave communication systems [1,2]. Various types of photodetectors have been developed, for example, Schottky barrier [3], p-i-n [4] photoconductor [5], and APD's [6] for such applications.

A planar Schottky barrier GaAs photodiode is very attractive both for integrated optoelectronic applications and for short optical links in which the maximum data rate is not limited by the dispersion of optical fibers but by the photodetectors, lasers, and electronic circuitry. In this paper, a high-speed high-sensitivity GaAs/AlGaAs heterostructure planar Schottky barrier photodiode capable of operating beyond 50 GHz has been designed, fabricated, and characterized.

II. Analysis and Design

The main considerations in the design of a photodetector are the response-speed, quantum efficiency, dark current, and noise. The response-speed of the Schottky barrier photodiode can be determined primarily by three parameters [7]; the transit time (t_{tr}) across the depletion region, the diffusion time (t_{diff}) in the quasi-neutral reqion, and the RC time constant (t_{RC}) of the junction capacitance and the internal and external resistances. For high-speed operation, the Schottky barrier photodiode requires a narrow depletion region for a short transit time, and a wide depletion region and a small area for a low junction capacitance. Therefore, the geometry and dimension of a photodiode as well as the dopant density of the epilayer should be optimized for high-speed and high-sensitivity operation.

The cross section and top views of the designed $GaAs/Al_{0.3}Ga_{0.7}As$ planar Schottky barrier photodiode are shown in Fig.1. This planar geometry on the semi-insulating GaAs substrate can reduce the parasitic capacitance significantly; it is also suitable for integrated optoelectronic circuits. To reduce the series resistance, a thin (0.3 μm) heavily doped (1×10^{18} cm^{-3}) n^+- buffer layer is used. Furthermore, to eliminate the undesirable absorption in this layer, which results in a long diffusion time, an $Al_{0.3}Ga_{0.7}As$ layer, transparent to the wavelength of interest, can be used to replace the n^+-GaAs buffer layer. The undoped (5×10^{15} cm^{-3}) n-GaAs layer (1 μm) is used as the absorption layer. The illumination window is formed by a thin (100 Å) transparent Au film with a diameter of 6 μm. The small window area and the n^+-$Al_{0.3}Ga_{0.7}As$ buffer layer can significantly reduce the RC time constant and the diffusion time, resulting in improvement of the response speed of the photodiode.

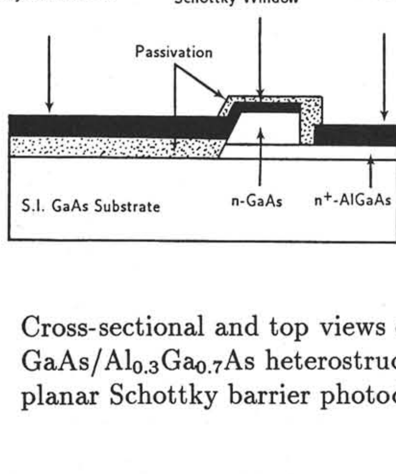

Figure 1 Cross-sectional and top views of the $GaAs/Al_{0.3}Ga_{0.7}As$ heterostructure planar Schottky barrier photodiode.

To improve the sensitivity of a photodiode, the dark current and reflection loss should be minimized. It is known, however, that a GaAs surface exposed to air will form a thin native oxide and a fraction of a monolayer of free As which increases the surface leakage current [8]. Hence, surface passivation is necessary to reduce the reverse-bias dark current. In addition, an antireflection coating with the quarter-wavelength design rule [9] is highly desirable to reduce the reflection loss.

III. Fabrication

A high-speed planar Schottky barrier photodiode has been fabricated on the LPE grown n^--$GaAs/n^+$-$Al_{0.3}Ga_{0.7}As$ epilayers on semi-insulating GaAs substrate. The n^--GaAs and n^+-$Al_{0.3}Ga_{0.7}As$ epilayers have thicknesses of 1.5 μm and 0.3 μm, and dopant densities of 5.0×10^{15} cm^{-3} and 2.0×10^{18} cm^{-3}, respectively. Both Schottky barrier and ohmic contacts were formed by using a standard lift-off process. The ohmic contact was first formed by deposition of a Au-Ge/Ni alloy metal and by subsequent annealing. A 100 Å Au film for the transparent Schottky barrier contact and a Cr/Au film for the bonding pad were deposited. For the surface passivation and antireflection coating, a 1100 Si_3N_4 film was deposited by plasma-assisted rf sputtering.

IV. Results and Discussion

Current-voltage (I-V) characteristics of the fabricated Schottky barrier photodiodes were measured by using an HP 4140B pA Meter/DC Voltage Source, and the results are shown in Fig.2.

The reverse-bias dark current density was 1.3×10^{-7} A/cm^2 at $V_R = -5$ V, and the breakdown voltage was found to be around -30 V at 10 μA of dark current. The ideality factor, determined from the slope of the forward-bias I-V characteristics, was found to variy between 1.11 and 1.21. Capacitance-voltage (C-V) characteristics were measured by using HP 4280A C-Meter/C-V Plotter. The total (junction and parasitic) capacitance of the photodiode with an area of 9.8×10^{-5} cm^2 was less than 10 fF at $V_R = -5$ V.

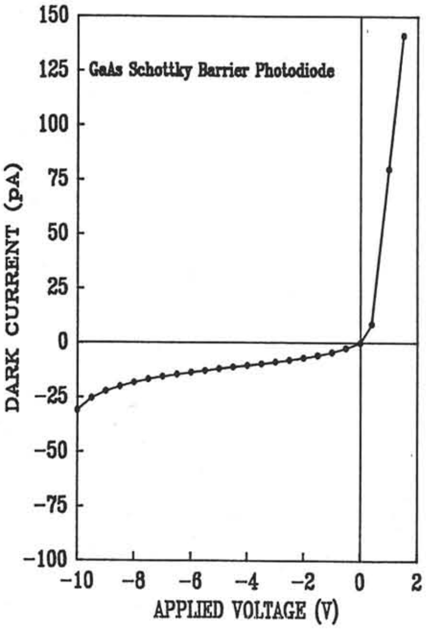

Figure 2 The current-voltage characteristics of the photodiode passivated with Si_3N_4.

The spectral response of the photodiode was measured by using a Jarrell-Ash Quarter-Meter Monochromator and an Optics Technology Optical Power Meter. As shown Fig.3, the measured external quantum efficiency and responsivity of the Si_3N_4 coated photodiode were 60% to 77% and 0.47 A/W to 0.6 A/W, respectively, for the wavelength range of 0.5 μm to 0.84 μm.

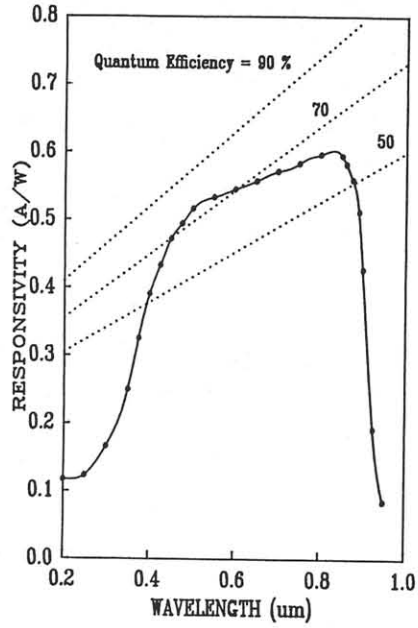

Figure 3 The external quantum efficiency and responsivity of the photodiode.

The response speed was measured in time domain by a sampling/correlation method [10]. To measure the response speed, the photodiode was mounted on a coplanar waveguide (CPW) transmission line fabricated on a semi-insulating GaAs substrate. A 10 μm gap located between the center line and the sampler line exposed the GaAs substrate to form the optoelectronic sampling gate (Auston switch) [11]. The response time of this sampling gap was approximately 2.3 ps. A dispersion-compensated colliding-pulse mode locked ring dye laser (FWHM of 80 fs, wavelength of 620 nm, and repetition rate of 125 MHz) was used for photoexcitation of the photodiode and of the sampler photoconductive circuit element (PCE). Data acquisition was done by averaging at the rate of 50 points per second (see Ref.12 for a detailed description of the measurement system).

Figure 4 shows the measured response speed of the photodiode. A risetime of 8.5 ps and a FWHM of 16 ps were measured. This value corresponds to a 3-dB cutoff frequency of 50 GHz.

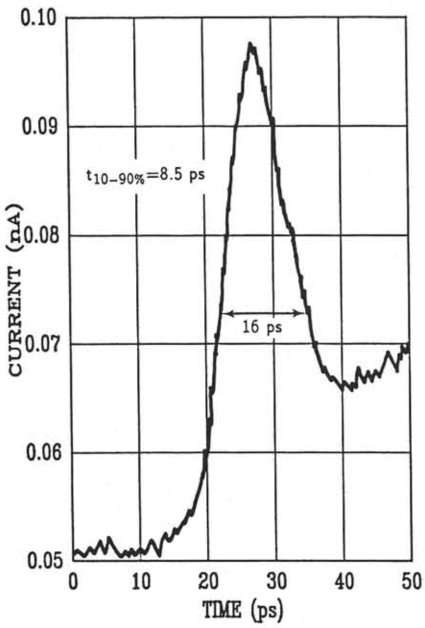

Figure 4 The response speed of the photodiode measured by the sampling/correlation method.

V. Conclusion

A high-speed and high-sensitivity planar GaAs/AlGaAs heterostructure Schottky barrier photodiode has been designed, fabricated, and characterized. A highly doped $Al_{0.3}Ga_{0.7}As$ buffer layer is used to reduce the series resistance and the undesired diffusion tailing. Furthermore, surface passivation and antireflection coating using a Si_3N_4 film are performed to reduce the reverse-bias dark current and the reflection loss, thereby significantly improving the sensitivity of the photodiode. The measured external quantum efficiency and responsivity are 60% to 77% and 0.47 A/W to 0.6 A/W, respectively, for the wavelength range of 0.5 μm to 0.84 μm. The sampling/correlation measurements show that the risetime of the photodiode is 8.5 ps, corresponding to a 3-dB cutoff frequency of 50 GHz.

Acknowledgement

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