High Bandwidth-Efficiency GaAs Schottky Photodiodes for 840 nm Operation Wavelength

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I. INTRODUCTION

The bandwidth capabilities of optical-fiber telecommunication systems are still not fulfilled with present performance of optoelectronic devices, and high speed photodetectors have been an active research area for the past two decades [1]. It has been shown that a Schottky photodiode, with 3-dB operating bandwidth exceeding 200 GHz, is one of the best candidates for high-speed photodetection [2]-[5]. However, like p-i-n photodiode, Schottky photodiode also suffers from bandwidth-efficiency trade off. A recent family of photodetectors, resonant cavity enhanced (RCE), has the potential to overcome this trade-off as compared to conventional photodetectors [6]-[12]. The RCE detector operation is principally the same as the conventional one, with the main difference being an increased internal optical field by virtue of a Fabry-Perot resonant cavity. The higher field enables high efficiencies with thinner absorbing layers, resulting in high quantum efficiency with low photo-carrier transit times. The Schottky photodiode has its advantages in its simplicity, compatibility with monolithic integration processes and use of thin Schottky metal as the top mirror of the resonant cavity. However, high-speed RCE photodetector research has mainly concentrated on p-i-n type photodiodes, where near 100% quantum efficiencies along with a 3-dB bandwidth of 17 GHz have been reported [13]. There are only a few reports on RCE Schottky photodiodes [14]-[15]. We briefly report our work on design, fabrication, and testing of high- speed RCE Schottky photodiodes for operation at 840 nm.

II. DESIGN AND FABRICATION

We have fabricated two different structures, S1 and S2, which are optimized for top illumination. The details of the epitaxial structures are given in the Tables 1 and 2. The bottom Bragg mirrors are consist of quarter-wave stacks ($Al_{0.20}Ga_{0.80}As/AlAs$) designed for high reflectivity at 840 nm center wavelength.

Material	Doping (cm^{-3})	Thickness (nm)
$Al_{0.15}Ga_{0.85}As$	10^{17}	80
$Al_{0.15}Ga_{0.85}As$ to GaAs	10^{17}	30
GaAs	10^{17}	120
GaAs to $Al_{0.20}Ga_{0.80}As$	10^{17}	30
$Al_{0.20}Ga_{0.80}As$	10^{17}	160
$Al_{0.20}Ga_{0.80}As$	n^+	400
$Al_{0.20}Ga_{0.80}As$	undoped	230
Bragg Mirror (18.5 pairs)		
S.I. GaAs		

Table 1: Structure of sample S1

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Material	Doping (cm^{-3})	Thickness (nm)
GaAs	10^{17}	350
GaAs to $Al_{0.20}Ga_{0.80}As$	10^{18}	50
$Al_{0.20}Ga_{0.80}As$	$n^+=10^{18}$	500
$Al_{0.20}Ga_{0.80}As$	undoped	260
Bragg Mirror (14.5 pairs)		
S.I. GaAs		

Table 2: Structure of sample S2

Both structures were grown by solid-source MBE on semi-insulating (SI) buffered GaAs substrates. Both samples have low carrier trapping due to graded interfaces of the absorbing layer. The thicker cap layer of sample S2 has the advantage of wavelength tuning by etching the top layer. Prior to the fabrication process, sample S2 was wavelength tuned, according to its reflection spectrum (see Figure 1). About 40 nm recess etch of the top layer resulted in approximately 30 nm shift in resonance wavelength.

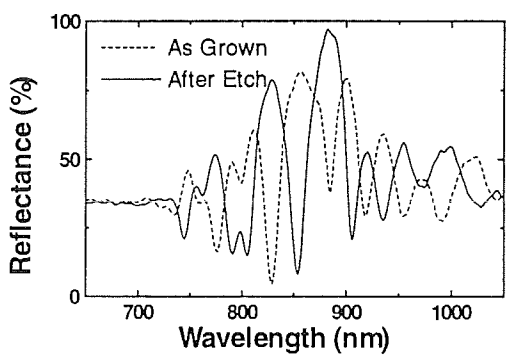

Figure 1: Reflectance tuning by wet etching, for sample S2.

The samples were fabricated using a microwave-compatible monolithic micro-fabrication process. Figure 2 shows the schematics of the fabricated devices. Fabrication started with formation of ohmic contacts to n^+ layers, followed by a recess etch through the top layers (approximately 0.6 μm), a self aligned Ge-Au-Ni-Au lift-off, and a rapid thermal anneal.

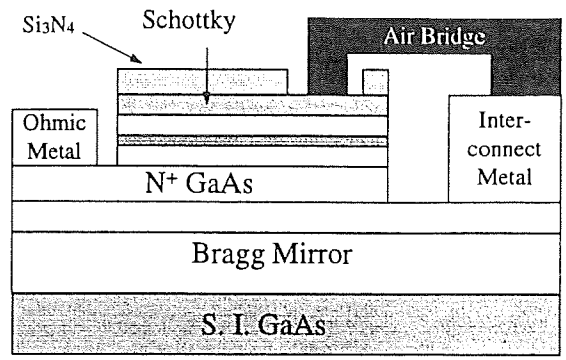

Figure 2: Schematic cross section of a fabricated Schottky RCE photodiode.

Mesa isolation was achieved by etching away all the epilayers except active areas. Then Ti-Au interconnect metallization, which formed coplanar waveguide (CPW) transmission lines, was defined by lift-off. A thin (10 nm) Au Schottky contact was deposited, followed by a 210 nm thick silicon nitride layer. This silicon nitride besides protecting the surfaces also served as a dielectric for bias capacitors. Finally a thick (~1.0 μm) Ti-Au layer was deposited to form an air bridge connection between the center conductor of CPW and the Schottky metal [15].

III. MEASUREMENTS

Photoresponse measurements were carried out in the 700-900 nm wavelength range, by using a tungsten-halogen projection lamp as the light source and a single pass monochromator. Output of the monochromator was coupled to a multimode fiber. The monochromatic light was delivered to the devices by a light-wave fiber probe, and the electrical characterization was carried out on a probe station. The incident power spectrum was measured by a calibrated optical powermeter.

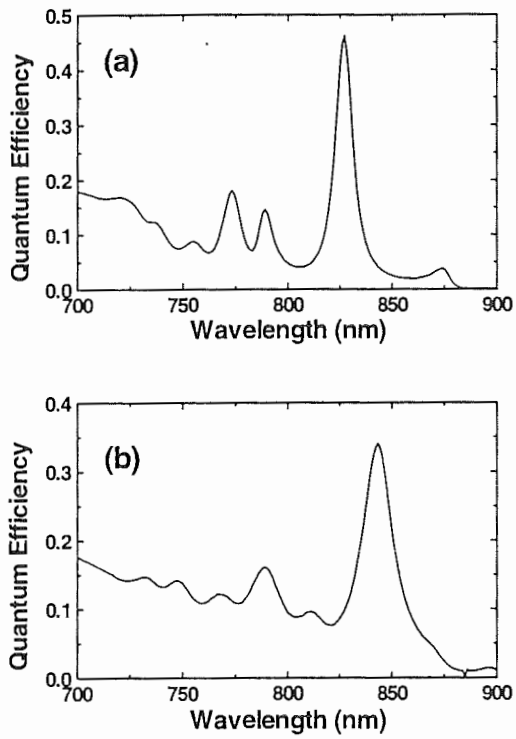

Figure 3: Photoresponse of samples (a) S1 and (b) S2.

For the spectral measurement large area photodiodes were chosen (60x60 to 400x400 μm^2) to ensure all of the optical power is incident on the active area. Silicon nitride layers on top of each sample were separately etched in small steps, by using HF:DI Water (1:1600) solution, in order to obtain maximum quantum efficiency. The peak wavelength shift was very small (less than 1 nm) whereas peak efficiency varied by about 10%. The maximum quantum efficiencies for samples S1 and S2, were obtained at silicon nitride thicknesses of 150 and 130 nm, respectively. Photoresponses of the devices, after silicon nitride layers were etched down to optimum thicknesses, are given in Figure 3. Sample S1 has a higher quantum efficiency (46% at 827 nm), as compared to that (34% at 843 nm) of the sample S2.

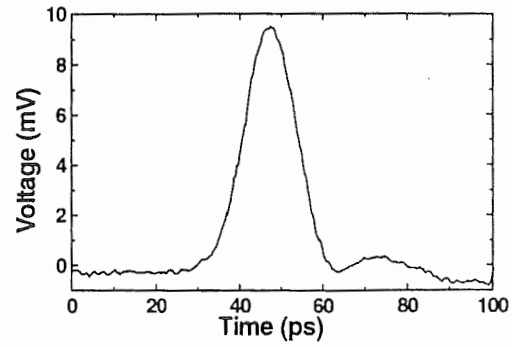

Figure 4: Pulse response of sample S2.

When compared to single pass structures, approximate enhancement factors are 15 and 6 for S1 and S2, respectively. The higher off-resonance photoresponse (hence lower enhancement) of device S2 is a result of thicker absorption layer as compared to S1. The full-width at half maximum (FWHM) is 10 nm for S1, and 9.5 nm for S2. These data were taken without any bias. A -1.5 V bias increased the efficiencies about 3% for both devices. However, at around –2 V the quantum efficiencies started to increase drastically. We believe that this increase is caused by an internal gain mechanism, mainly the beginning of an avalanche breakdown.

High-speed measurements were made with 1 ps FWHM optical pulses obtained from a Ti-Sapphire laser operating at 840 nm. Figure 4 shows the temporal response of a small area photodiode (from sample S2) measured by a 50 GHz sampling scope. The measured photodiode output has a 14 ps FWHM, and a fall time of 9.5 ps. The Fourier transform of the data has a 3-dB bandwidth of 35 GHz. However, since the rise time is very close to the fall time, we conclude that the measurement was limited by the experimental setup.

IV. CONCLUSION

Two different RCE Schottky photodiode structures for ~840 nm operation have been demonstrated. Structure S1 had 10 nm FWHM with an enhancement of a factor of 15, whereas structure S2 had 9.5 nm FWHM with an enhancement factor of 6. The temporal response of S2 (which was limited by the experimental set up) was 14 ps, which corresponds to a 3-dB bandwidth of 35 GHz. To our knowledge, our results correspond to the fastest RCE photodetectors in 800-850 nm wavelength region published in scientific literature.

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