9:00am - 9:15am
TuB2

Ultrafast Resonant Cavity Enhanced Schottky Photodiodes

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Schottky photodiodes (PD) are very attractive for high-speed photodetection, because of their simple material structure and fabrication process. This enables easy integration with III-V discrete devices and integrated circuits [1]. With the increasing demand for higher bandwidth detectors, the optimized structure of a Schottky PD typically requires a thin absorption region. However, a thin absorption region results in a reduction in quantum efficiency. Although high performance photodetectors with semi-transparent metal contacts have been successfully fabricated [1,2], the bandwidth-efficiency product is limited.

Over the past several years a new family of optoelectronic devices has emerged whose performance is enhanced by placing the active device structure inside a Fabry-Perot resonant microcavity [3]. In such resonant cavity structures, the device functions largely as before, but is subject to the effects of the cavity. As a result, the bandwidth-efficiency product is drastically improved [4]. The resonant cavity enhanced (RCE) detection scheme is particularly attractive for Schottky type photodetectors, since the semi-transparent Schottky contact can also function as the top reflector. RCE detectors with single layer top mirrors (as opposed to utilizing distributed Bragg reflectors(DBR)) also benefit from post-growth adjustment of the resonant wavelength by simply recessing the top layer [3,5]. Recently, we fabricated RCE Schottky photodiodes with a 3-dB bandwidth of 100 GHz. In this paper, we present theoretical and experimental results on spectral and high-speed properties of RCE Schottky photodiodes with semi-transparent top metal contacts.

We studied RCE Schottky diodes in the GaAs/InGaAs material system operating at 900 nm wavelength. Similar principles may be applied to other III-V materials and different wavelength regions. The layer structure was grown on a GaAs substrate by molecular beam epitaxy. The InGaAs absorption layer has an In mole fraction less than 10% and a thickness of 130 nm to eliminate the standing wave effect [3] in the cavity. The position of the absorption layer in the depletion region is optimized to yield minimum transit time for electrons and holes [3]. The resonant cavity is formed by a GaAs/AlAs DBR bottom reflector and the semi-transparent Au contact on top. On top of the Schottky metal, an anti-reflection layer (Si_3N_4) is deposited to increase detector responsivity.

For RCE Schottky PDs, the top mirror reflectivity increases with metal thickness, enhancing the quantum efficiency. However the increasing losses in the semi-transparent metal layer lead to a reduction of the quantum efficiency for top illuminated devices. We analyzed the dependence of responsivity on the thicknesses of the metal contact and the dielectric coating . Via simulations, we demonstrated that these thicknesses can be optimized to yield nearly 75% quantum efficiency at resonance for the thin(130 nm) absorption region. Figure 1 illustrates the results of these simulations showing the variation of peak resonant quantum efficiency with the metal thickness. To emphasize the advantage of RCE detection, in Fig. 1, we also plot the quantum efficiencies of an optimized RCE Schottky PD and a conventional (one-pass) detector with identical absorption layer and metal thickness. The RCE detector displays a 10 fold improvement in quantum efficiency.

The Schottky PDs designed for 900 nm operation were fabricated with 200 Å Schottky Au and 1250 Å Si_3N_4 anti-reflection layer using the optimum values obtained from the simulation results. The photodiodes of various sizes were fabricated by standard photolithography with mesa isolation and a Au airbridge connecting the top contact to a co-planar transmission line. The resulting devices showed breakdown voltages larger than 12 V. Large mesa devices were used in spectral response measurements using a monochromatic light source. The resonant peak is observed at 895 nm with a 6 fold resonant enhancement(See Fig. 2). The measured peak quantum efficiency was about 20% which is significantly less than the theoretical value. The discrepancy is due to the red shift in the center wavelength of the bottom DBR mirror resulting in a

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~60% bottom reflectivity. Since the spectral range of the pulsed laser source is limited to 900 nm we were unable to study devices fabricated to operate at the peak of the bottom DBR reflectivity. Optimized device structure is expected to yield ~70% quantum efficiency.

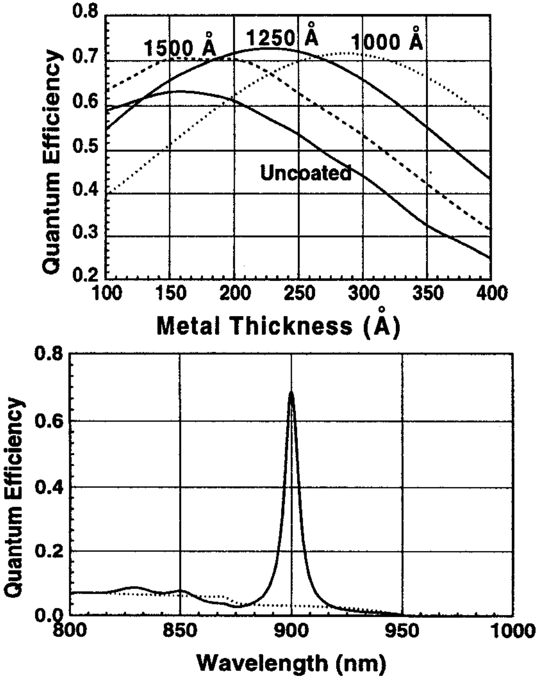

Fig. 1. Top: Simulated quantum efficiencies of RCE Schottky photodiodes as a function of Au thickness, with no anti-reflection (bottom solid), 1000 Å(dotted), 1250 Å(top solid), 1500 Å(dashed) Si_3N_4 coatings. Bottom: Theoretical comparison of the quantum efficiency of an optimized RCE Schottky PD and a conventional Schottky PD with a thin absorber (dotted line).

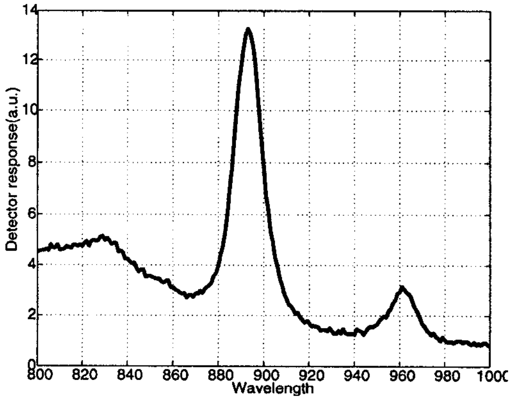

Fig. 2. Experimental spectral response of RCE Schottky photodiodes.

High-speed measurements were demonstrated using a picosecond mode-locked Ti/Sapphire laser tuned to 895 nm. The devices were illuminated using a single mode fiber on a microwave probe station and the resulting pulses were observed with a 50 GHz sampling scope. Figure 3 shows the pulse response of a $10 \times 10 \mu m$ RCE Schottky PD at zero bias. The full-width-at-half-maximum (FWHM) was measured 10 ps. Considering a 9 ps FWHM for the 50 GHz scope [6], and the laser pulse width(1.5 ps), the device speed was estimated to be 4.3 ps corresponding to a 100 GHz 3-dB bandwidth. This is a conservative estimate since the microwave components and laser timing jitter also contribute to the measured pulse width.

The devices with mesa sizes less than $20 \times 30 \mu m$ were not capacitance limited. A $18 \times 28 \mu m$ detector was studied for the excitation wavelength dependence of the impulse response. We measured 10 ps FWHM and 13 ps FWHM pulses on the scope respectively, corresponding to impulse response times of 4.3 ps at 895 nm and 9.2 ps at 845 nm. This demonstrates a bandwidth enhancement more than twice with the RCE detection scheme. The longer response time of the devices at 845 nm is due to the carriers absorbed in GaAs. Together with the ~4 fold increase in the efficiency (See Fig. 2), the bandwidth-efficiency product of the devices is improved by a factor of 8 at resonance.

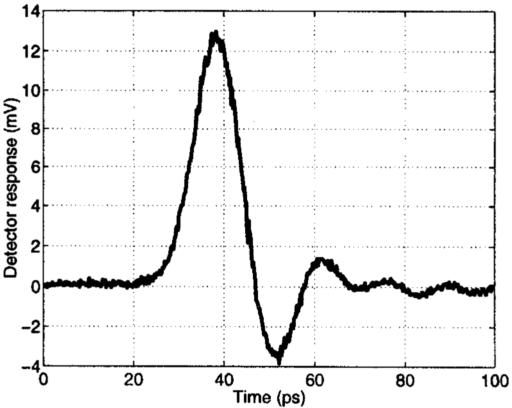

Fig. 3. Measured pulse response of the RCE Schottky PD.

In conclusion, we have demonstrated a high-speed top illuminated RCE Schottky PD with semi-transparent Au contact. The 10 ps FWHM pulses measured on the scope are estimated to represent 4.3 ps FWHM impulse response, corresponding to a 3-dB bandwidth of 100 GHz. The optimized structure is expected to yield a bandwidth-efficiency product larger than 70 GHz.

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