Ultra-high bandwidth (570GHz) Metal-Semiconductor-Metal Traveling-Wave-Photodetectors

Jin-Wei Shi[1], Kian-Giap Gan[2], Yi-Jen Chiu[2], Yen-Hung Chen[1], Chi-Kuang Sun[1,3,*], Ying-Jay Yang[3], and John E. Bowers[2]
[1]Graduate Institute of Electro-Optical Engineering
National Taiwan University
Taipei 10617, TAIWAN
Email: sun@cc.ee.ntu.edu.tw

[2]Department of Electrical and Computer Engineering
University of California Santa Barbara
CA, 93106, USA

[3]Department of Electrical Engineering
National Taiwan University
Taipei 10617, TAIWAN

We demonstrate a novel type of ultra-high speed traveling wave photodetector: "metal-semiconductor-metal traveling wave photodetecor" (MSM TWPD), and characterized it's ultrahigh electrical bandwidth by E-O sampling technique. The device was fabricated using low-temperature grown GaAs (LTG-GaAs). In order to achieve high internal quantum efficiency, the narrow spacing between electrodes was fabricated by self-aligned process without e-beam lithography. E-O sampling measurement results at different optical pumping level are reported. Ultra-high bandwidth (0.8 ps, 570GHz transform bandwidth) performance was observed even under high optical power illumination (~2.2 mW) with 8.1% net quantum efficiency. Compared with LTG-GaAs based p-i-n TWPD and vertically illuminated MSM photodetector (PD), this novel TWPD has higher output saturation current with near THz electrical bandwidth, better quantum efficiency, and can be easily fabricated and integrated with other microwave devices. By utilizing the ultra-high speed performance of this device, we also studied the micowave propagation effect of its generated subpicosecond electrical pulse on integrated CPW line. The measurement results also reveals some microwave behavior of CPW line in near THz frequency regime, which are quit important due to high speed data linking or transmission.

[*] Corresponding author

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High speed and high-sensitivity photodetectors have been studied extensively in the past ten years [1], owing to their application in broadband optical communication network and optical generation of high power microwave/millimeter waves [2]. Metal-semiconductor-metal (MSM) photodetectors [3] and photoconductive switches merit special attentions due to their high electrical bandwidth and ability of generating ultra-short electrical pulses [4]. In this paper we demonstrate a novel ultra-high speed photodetector: MSM traveling wave photodetector (MSM-TWPD). By utilizing LTG-GaAs as the photo-absorption layer, and the traveling wave type electrodes structure. The fabricated devices exhibit high-speed performance, which have a 0.8ps impulse response FWHM (full-width-half-maximum) and 570GHz transformed electrical bandwidth. By properly designing the edge couple structure and utilizing self-align process to shorten the spacing between electrodes to hundreds of nm, 8.1 % net quantum efficiency (including coupling loss) is achieved, which is much higher than most LTG-GaAs based photoconductive switch [4] or vertically-illuminated MSM PDs [3], and is similar to the reported value of LTG-GaAs based p-i-n TWPD [5]. The MSM structure also promises the superior microwave properties than p-i-n structure, especially in the long absorption length for high output saturation current case [6].

The cross sectional schematic of an MSM-TWPD is shown in Figure1 (a). The structures of epi-layers are composed by a thin LTG-GaAs layer (500nm) for photo-absorption and two AlGaAs layers with thickness of 1 μm and 3 μm for optical wave guiding purpose respectively. The optical waveguiding in the x-direction is achieved by the etched-mesa ridge structure. Three metal stripes are electrodes for collecting photo-generated carriers in LTG-GaAs layer. The structure of three metal stripes acts as a co-planar waveguide (CPW), which support a photexcited microwave guiding mode. The ground plane (with width w_s) is naturally separated with center stripe (with width w_c) with the under-cut profile of etched mesa (so called self-aligned process). By utilizing the self-aligned process, the gap between metal stripes can be shorten to 200~300nm without E-beam lithography. There are some advantages for the narrow gap width of CPW line. Because the narrow spacing between metal stripes, the carrier drift-time is shorten and the electric field strength is increased, with enhanced internal quantum efficiency. Narrow gap width can also reduce the dominant microwave radiation loss, when operating in the ultra-high frequency regime (several hundreds of GHz) [7]. The top view of device is shown as figure 1(b), which integrates with a CPW line for EO sampling measurement and D. C. bias purpose.

We employed a mode-locked Ti: sapphire laser as the light source for I-V and EO sampling measurements. For D.C. photocurrent measurement the laser wavelength was tuned to 780nm. The measured average photocurrent was found to linearly increased with increased bias voltage. From the slope of a linear fitting line, which obtains from output photocurrent and optical pumping power at 15 V bias, we can get net quantum efficiency about 8.1 % (including coupling loss). This value is also similar to that of the reported quantum efficiency of LTG-GaAs based p-i-n TWPD [5].

We used EO sampling technique to perform transient current measurement. Figure 2 shows the measured EO traces at a fix 5V bias with different optical input powers. When the average optical input power was below 2.2mW, there was no significant response broadening and the FWHM of impulse response was about 0.8 ps. At even high bias, this device can endure more intense optical illumination and deliver even higher output saturation current without bandwidth degradation. Compared with LTG-GaAs p-i-n based TWPD, MSM TWPD has higher output saturation current due to its wider waveguide width and larger photo-absorption volume. By utilizing the impulse response trace in figure 2 (at 1mW), we obtained its corresponding Fourier transform trace shown in the inset of Figure 2, which has an electrical 3dB bandwidth of 570GHz. The resonance in frequency domain (200GHz and 400GHz) of transformed trace is originated from the negative tail in the time domain trace. In order to avoid the microwave propagation effect (dispersion) on the integrated CPW line during the EO sampling measurement, we perform it as close as possible to the photo-absorption region (the nearest distance is limiting by pump-probe interference). One possible origin of the negative tail is the substrate high order radiation mode from the CPW line structure [7] of the photo-absorption region. The time interval between the peaks of signal and negative tail is 3.6ps, in agreement with the run-trip time of oblique incidence echo signal due to substrate radiation mode with a substrate thickness of 100μm. The microwave propagation effect of this subpicosecond electrical pulse on the integrated CPW line is also shown as trace (A) ,(B), (C) and (D) in figure 3. The probe distance between each trace is about 100μm, and we can clearly see that microwave loss is quit serious on the integrated CPW line in near THz frequency regime due to the significant decrease in the positive peak of signal. Each trace composes by a positive and negative part, the negative part is originated from the dispersion effect of CPW line as discussed before. The broadening in FWHM of positive signal, and the increase in magnitude of negative tail also implies the microwave dispersion effect from substrate radiation effect. More power and bias dependent behaviors of this novel device will be given in the conference. This work is sponsored by National Science Council of TAIWAN R.O.C. under grant number NSC 89-2215-E-002-064 and National Science Foundation of USA under award number INT-9813411.

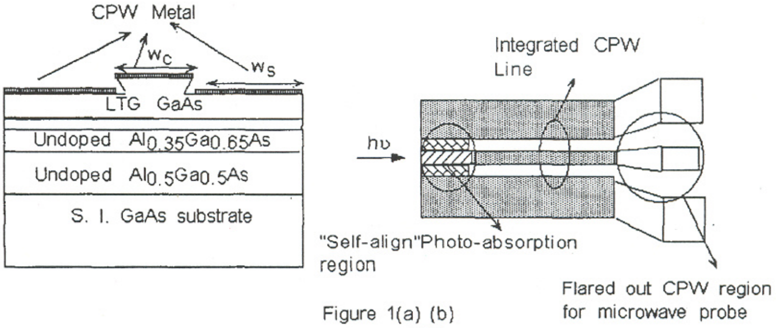

Figure 1(a) (b)

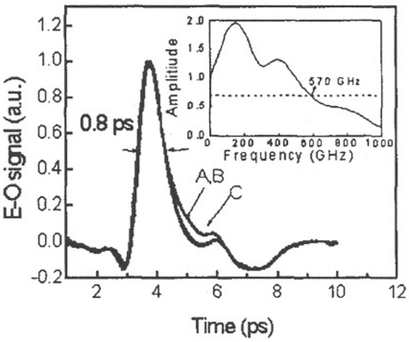

Figure 2

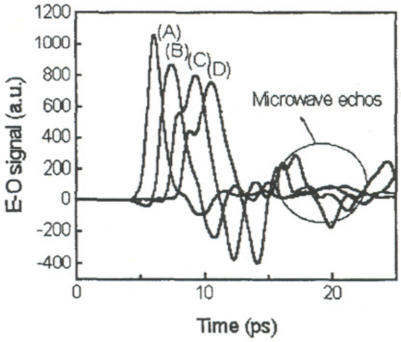

Figure 3

Figure Captions:

Figure 1 (a) Cross sectional diagram and (b) top view of MSM-TWPD. This structure can be easily fabricated by wet etching and self-aligned process. The integrated CPW line is for EO sampling measurement purpose.

Figure 2 Measured transient responses of with E-O sampling technique at a fix bias of 5V with different average optical input power of 1mW (trace A), 1.8mW (trace B), and 2.2mW (trace C). These traces show 0.8ps FWHM, and the inset is corresponding Fourier transform of the 1mW trace, with 570GHz 3dB electrical bandwidth.

Figure 3 Measured transit responses by E-O sampling technique at different position of integrated CPW line. Trace (A) is nearest the photoabsorption region, and the probe spacing between each trace (B, C, D) is about 100μm. The selected area of traces is from the microwave reflection between probe and CPW line.

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