LIMITATIONS OF THE IMPULSE RESPONSE OF GAAS MSM PHOTOSWITCH

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ABSTRACT

As symmetrical data characteristics I (V) of the Metal-Semiconductor-Metal (MSM) photodetector, we wondered how this device can be used as a photoswitch as well as the low temperature on GaAs photoconductive generally used for this purpose. The impulse response of interdigitated metal-semiconductor-metal photoswitch fabricated on GaAs non-intentional doped (NID) absorbing layer is investigated. The photocurrent response was measured after excitation and we found that the screening of the dark electric field and charge accumulation exceedingly modify the drift conditions of the photogenerated electrons and holes in active region of the MSM photoswitch.

KEYWORDS: Impulse response, MSM photodetector, space charge.

I.   INTRODUCTION

High speed photodetectors are a key component of optoelectronic switching in coplanar transmission lines growth semiconductor material [1]. Planar metal-semiconductor-metal (MSM) photosensing structures with Schottky barriers have attracted much attention, inherent advantages include: lower capacitance, a large photosensitive surface, easy to integrate, low dark current and faster responses compared to PIN photodetectors [2], [3]. While mainly III-V semiconductor materials have been used for optoelectronic applications. This device is an interdigital comb (Ti(250 A˚)/Pt(250 A˚)/Au(4000 A˚)) leaving a free semiconductor surface between the two contacts which forms the active region in which light will be absorbed [4]. It located in the central strip of coplanar line, deposited over a non-intentional doped GaAs layer ($10^{14}cm^{-3}$), with thickness equal to 1μm, epitaxially grown on a Semi-Insulating (S.I) substrate of 400 mm thick and crystal orientation <1 0 0>. The number of fingers (N) and inter electrode spacing (s) that is equal to the widths of fingers (l) and varies between 0.2, 0.3, 0.5 and 1 μm [5]. Our work has been concentrated on the response behavior of the MSM photoswitch, and how optical illumination and polarization will give appear to variety effect [6].

II.   EXPERIMENTAL DETAILS

In this article, the MSM photodetector is introduced into the center line of a microwave transmission line of coplanar type. The time resolved photocurrent response was studied experimentally by exciting the photoswich with femtosecond laser with low-jitter pulse (Maï Taï HP of Spectra-physics), pulse width 100 fs, wavelength 780nm, repetition rate 80MHz, Two microwave signal generators were used, the first for mounting up to 3 GHz (Rhode and Schwartz SMA 100A) and the second to go up 20 GHz (Anritsu MG3692A). The output signal was collected by tektronix DSA8200 oscilloscope.

Depending on the characteristics of the laser pulse, including the wavelength and spectral width length, we arrive at a dispersion of 2 ps (fiber length of 1 meter, spectral width of the pulse at 0.8μm to 16 nm), which is much higher to the original duration of the laser pulses (200 fs). Taking the value of the injection efficiency and the data of the chromatic dispersion giving pulse duration of about 2 ps, if we take 1,1 mW through lensed fiber output, a power peak is obtained ~7 Watts. The test bench microwave coupled to a fiber illuminating the device from above.
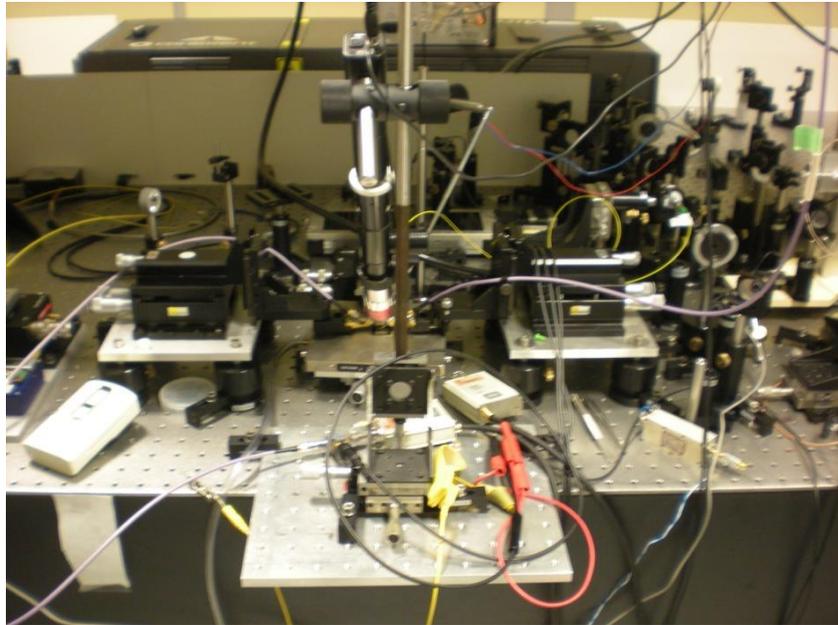

Figure 1. The test bench microwave

III.   RESULTS AND DISCUSSION

Figure 2, shows the measured impulse response for MSM photoswitch with 3x3 μm2 active surface whose electrode spacing are 0.2 μm, 0.3 μm, 0.5 μm and 1 μm based on GaAs (N.I.D), as function of bias voltage.
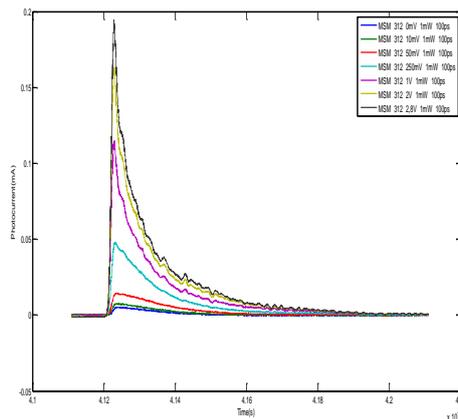

Figure 2. Pulse response of GaAs MSM312 photoswitch at λ=780μm with different bias voltages (Popt=1mW, A=3x3 μm2, s=l=1μm)
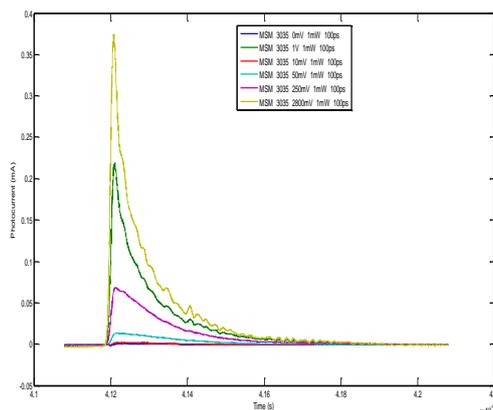
Figure 3. Pulse response of GaAs MSM3035 photoswitch at λ=780µm with different bias voltages
(Popt=1mW, A=3x3 µm^2, s=l=1µm)

When a semiconductor material is illuminated by photons, this allows electron-hole pairs generated by the absorption of light and they start to distribute with field dependent drift velocities and gives rise to a photocurrent [6]. It may be noted that the pulse response of photoswitch at zero bias voltage is not negligible, the internal electric field is sufficient to collect the photogenerated carriers. The pulse shape is similar at different bias voltages; it has a faster rise time response, and faster initial sweep-out of the carriers, this fast leading part of the impulse response is chiefly due to the drift of electrons, followed by a slower long tail. The oscillations in the tail are most likely due to the impedance mismatch in the bond wires [6, 7].

To determine the lifetime of the carriers, we normalized the signal and we have shown in a logarithmic scale. Which of the following can we determine the lifetime of electrons by calculating the slope of the falling portion of the curve [8].
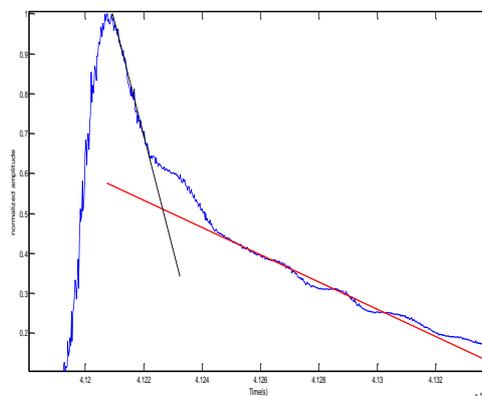

Figure 4. Normalized amplitude of the temporal response of the MSM3035 at 2,8V to determine the lifetime of electrons and holes.

The rise and fall time (l0%-90% of the maximum), and FWHM (Full width at half maximum) for the GaAs MSM3035 are indicated in Table 1.

Table 1. Pulse response of GaAs MSM3035 photoswitch.

V[V]	Rise time[ps]	Fall time[ps]	FWHM[ps]
2,8	10	200	40
1	10	220	50
0,25	10	260	110
0,05	14	330	160

Figure 3 shows the measured photocurrent of MSM with 0,3µm finger distance with different bias voltage (0, 0.05, 0.25, 1 and 2.8V) and 1mW optical power level as function of time delay. After excitation, the carriers start to move with field dependent drift velocities, for GaAs, vd increases linearly with electric field for fields up to about 3.2 kV/cm. The finger distance is in submicron range it conducts to a full depletion region between electrodes, and this is result of the rapid extraction of electrons [8, 9], this leads to faster rise time of 10ps, it is almost constant independent of voltage. The photogenerated carriers distribute in the semiconductor, they have a new velocity vectors. This fast rise time is flowed by fairly fast decay corresponding to the rapid collection of electrons and holes at contacts; this conducts to decrease of FWHM (Table 1), subsequently to slower long tail which reflects the difference in drift velocities of electrons and holes [9, 10].

With small interelectrode distances, although with increasing bias voltage, this leads to high electrical field, and ensure velocity saturation, due to the initial opposite movement of electrons and holes cloud toward contacts [12], so the electric field is screened by the space charge. Near the anode, in the low field region electron-hole plasma is formed, this region contains more holes than electrons, where they move at much lower velocities [6, 10, 12, 13, 14]. When substrate is deeper, these carriers are collected at much lower speeds [11], it explained as follows: inside the space-charge region, a strong field accelerates electrons towards the bulk just beyond this region, a retarding filed sweeps the electrons toward the surface [15], this leads to increase fall time.

In addition, increasing of carriers' velocity with increasing field usually called 'Negative Differential Resistivity' (NDR) often is mentioned 'Gun effect' [16]. Gunn has discovered a new kind of current oscillations at microwave frequencies, in n-type GaAs, as the electric field increases, it leads to transfer of electrons from the high-mobility conduction band valley centered (low value of the wave vector k) (Γ valley), to higher energy, low-mobility satellite valleys (L and X), therefore, an increase in the electron effective mass and an increase in the density of electron states from the low-energy valley to the high-energy valley leads decrease in velocity[16, 17, 18], figure 5.
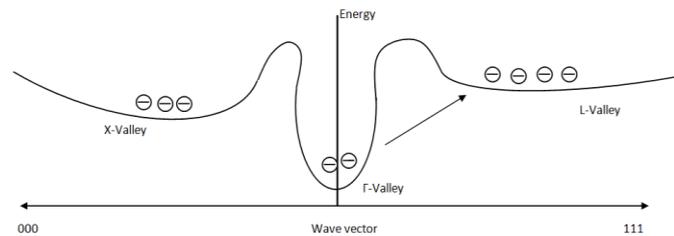

Figure 5. Gunn Effect

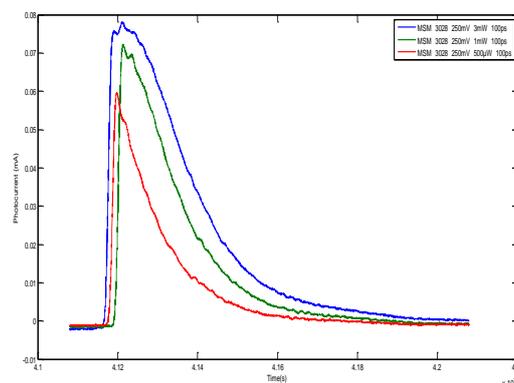Figure 6, presents the pulse response of MSM3028 photoswitch as function of incident optical power.

Figure 6. Pulse response of GaAs MSM3028 photoswitch at λ=780nm with different optical power levels
(V=250mW, A=3x3 µm^2, s=l=0,2µm)

The rise and fall time, FWHM are shown in table:

Table 2. Pulse response of GaAs MSM3035 photoswitch.

P_{opt}(mW)	Rise time [ps]	Fall time [ps]	FWHM[ps]
3	10	340	198
1	14,8	280	140
0,5	15	240	90

The increase of FWHM and fall time of pulse response with increasing optical power is explained as follows. The pulse energy is high enough to cause accumulation in the active region, screening of internal electric field, and formed an electron hole plasma near the anode, this region behave like virtual anode because a lot of holes are still staying in this region [6, 13].

The transient current response is limited by another factor, the trapping at the surface states of semiconductor states carriers create surface charge layer, [15, 19], also, at active layer metal-semiconductor interface and/or at deep layer defects in band gab of the material can trap photgenerated carriers [10, 12, 13, 20, 21, 22].

We can neglect the screening of the internal electric field to have no effect on the MSM photoswitch response if the space charges are much less than the total charge accumulated at the contacts [13, 22, 23]. If each photon creates one electron-hole pair, the total number of the photogenerated carriers with total area L2 [6, 13]:

$$N = \frac{E\lambda s}{hc(s + l)}(1 - r)[1 - exp(-\alpha d)] \qquad (1)$$

Where d is the thickness of the active layer, α is the light absorption coefficient, r is the reflection coefficient, λ is the wavelength, c is velocity of light in a vacuum, h is the Planck constant, E is the optical pulse of energy. The condition can be expressed by [23]:

$$E < \frac{\varepsilon_0(\varepsilon_s + 1)L^2 V(l + s)hc}{4\lambda q s^2 (1 - r)[1 - exp(-\alpha d)]} \qquad (2)$$

Where q is the elementary charge, V is the external bias voltage.
We finally obtain [13]:

$$N_{ph} \ll \frac{CV}{qL} \qquad (3)$$

Where, C is the dark capacitance:

$$C = \frac{\varepsilon_0(\varepsilon_s + 1)L^2}{4s} \qquad (4)$$

The interdigited MSM photoswitch geometry can be optimized, in order to achieve a fast pulse response, the width of interelectrode gap [23]:

$$s = \frac{M}{s + l}[6.5\eta^2 + 1.08\eta + 2.37] \qquad (5)$$

Where:

$$\eta = \frac{l}{l + s} \qquad (6)$$

$$M = 4.4RL^2 \frac{V}{\chi}(\varepsilon_s + 1)10^{-12} \qquad (7)$$

χ is carrier driftdistance corrective coefficient
V is velocity of ambipolar carrier drift

By solving this equation, we found the optimum inter-electrode gap:

$$s_{opt} = \frac{L}{2}\sqrt{2.2RV_{sat}\varepsilon_0(\varepsilon_s + 1)} \qquad (8)$$

V_{sat} is the saturation velocity, for GaAs MSM ($\sim 10^5$m/s), and R=50Ω [6, 23]:

$$s_{opt} \approx 0.02L \qquad (9)$$

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IV.   CONCLUSIONS

The impulse response of GaAs MSM photoswitch for different bias voltage and optical power and gap between fingers, for λ=780nm was studied experimentally. The pulse shape of the impulse response is similar, it achieves maximum after fast rise time due to fast electron drift velocity, flowed by fairly fast decay corresponding to the fast escape of electrons and holes to the interdigitated contacts, small Schottky contact spacing permitting rapid carrier extraction after photoexcitation, however, it followed by long tail. High electric field reaches a threshold level, the mobility of electrons decrease as the electric field is increased, due to the screening of internal field; thereby producing negative resistance (NDR). The trapping effect is another feasible way to reduce the carrier transit time. It is advantageous to use thin active layers to reduce the transient response,

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