Implementation of MSM-detectors in a commercial GaAs PHEMT process

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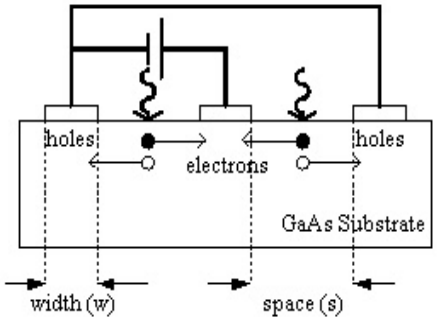
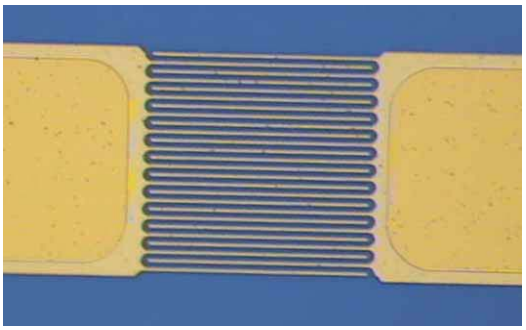
Abstract
The integration of an optical detector with a transimpedance amplifier (TIA) is a very attractive solution for high speed fiber optical communication links. This article presents our studies of the possibility of integrating a Metal-Semiconductor-Metal (MSM) detector on the same material structure as used for commercial HEMT-MMICs. Future applications such as 10 Gb/s fiber optical links are investigated. The first generation MSM detectors were fabricated for proof-of-concept. The DC and RF responsitivity at 850 nm wavelength was measured as a function of bias-voltage. A DC-responsitivity of approximately 0.5 A/W and a bandwidth above 2 GHz was achieved for an applied voltage of 10 V. An electrical model was extracted from S-parameter and DC-measurements.

Introduction
GaAs based Metal-Semiconductor-Metal (MSM) detectors are promising components in optical communication links based on 850 nm VCSEL transmitters. [1] The planar structure, which is the same as a HEMT structure, allows the detector to be integrated in an MMIC process. A first generation of MSM detectors with different layout has been developed and characterized with DC- and RF measurements for proof-of concept.

Fabrication and layout
We have fabricated an MSM detector on a commercial HEMT-MMICs wafer. The GaAs wafer is from OMMIC's MMIC processes. The planar structure of the MSM detector is shown in figure 1b and the cross section of an MSM detector in figure 1a. The pattern is made by photolithography at Zarlink Semiconductor AB, and it includes devices with different metal electrode width (1 and 2 µm) as well as electrode spacing (2 and 4 µm). [2] All devices have a detector area of 80·µm 80 µm, large enough to be covered by the laser beam from a multimode fiber.



(a)



(b)

Fig.1a) Cross section of MSM detector. b) Top view of MSM detector.

Analysis and measurements of DC performance

The current of the MSM detector is derived from the absorbed photons and the dark current. [3]

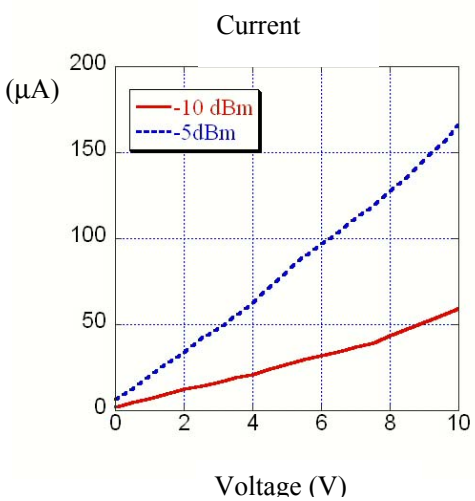
$$i_{current} = \frac{\eta \cdot q}{h \cdot \lambda} \cdot \left(\frac{\tau_{carrier}}{\tau_{transit}} \right) \cdot P_{optical} + i_{darkcurrent} \qquad (1)$$

where $\tau_{carrier}$ is the mean carrier lifetime of an electron-hole pair, $\tau_{transit}$ is the transit time between the electrical contacts, and $P_{optical}$ is the incident optical power to the MSM detector.

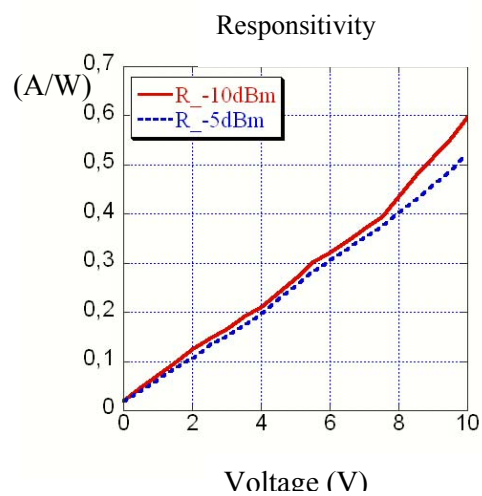
The quantum efficiency η and responsivity of the detectors depends on the layout parameters, thus a large spacing compared to electrode width results in a high quantum efficiency. [3] A ratio between $\tau_{carrier}$ and $\tau_{transit}$ larger than one corresponds to a current gain. The current gain, the number of electron-hole pairs created by each photon, depends on the bias voltage and position of the laser beam. The dark current is related to the leakage current of the MSM detector.

Figure 2a shows the current for an MSM detector. The electrode width is 1 µm and the spacing is 2 µm. The device is illuminated by a VCSEL [4], which generates –10 (solid line) and -5 (dotted line) dBm optical input power. The bias voltage of the detector is varied from 0 to 10 V. The measurement is done at the same time as the high frequency measurement in figure 5.

The responsivity of the detector may be calculated as the current divided by the optical power from a multimode fiber. (see figure 2b) The responsivity is measured to 0.5 A/W at a bias of 10 V for a detector with a spacing of 2 µm and a width of 1 µm.



(a)



(b)

Fig. 2a) Current versus bias voltage. 2b) Responsivity versus bias voltage.

Response analysis of MSM detector

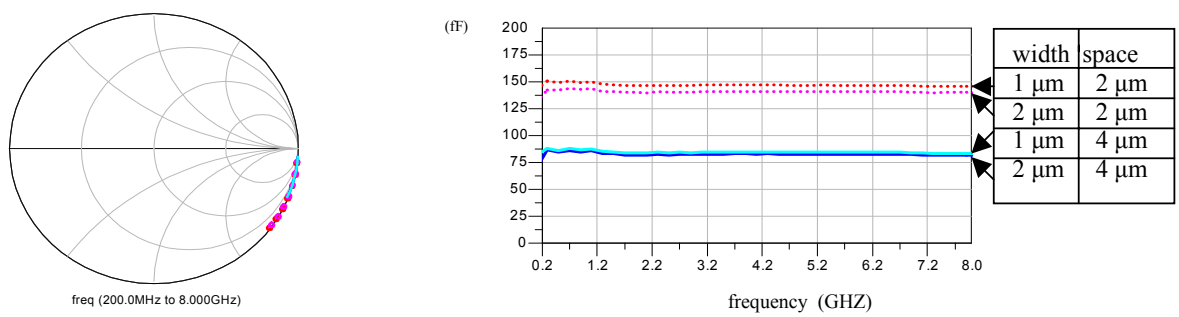
The response time τ of the MSM detector depends on the intrinsic carrier response $\tau_{transit}$ and the RC-constant τ_{RC}. A decrease of the space s between the metal electrodes will increase the capacitance (see figure 3b), which results in a higher τ_{RC}, but on the other hand the $\tau_{transit}$ will decrease. The $\tau_{transit}$ is determined to be the most limiting factor. A first order approximation of the response time gives [5]:

$$\tau \approx \left(\tau_{transit}^2 + \tau_{rc}^2\right)^{1/2} = \frac{1}{2 \cdot \pi \cdot f_{3dB\_bandwidth}} \qquad (2)$$

The transit time of the MSM is primarily depending on the bias voltage to obtain fast carrier velocity. It is complex to evaluate since it depends on the depth of the photons in the substrate. [2]. Comparing eqns. (1) and (2), there is apparently a trade-off between bandwidth and the responsitivity of the MSM detector.

S-Parameters measurements and modeling

The small signal S-parameters were measured in a probe station using an HP8510C network analyser from 200 MHz up to 8 GHz. The MSM detectors are measured without light and a bias voltage of 7 V. The result is presented in the Smith Chart in figure 3a. The capacitance of the MSM detector was estimated from measurement to be ~ 140 fF (dotted line) and 80 fF (solid line) with a spacing of 2 µm and 4 µm. (see figure 2b).



(a) (b)

Fig. 3a) Smith Chart b) MSM capacitance with different layouts.

From the S-parameters an equivalent circuit model is derived [6]. (see fig. 4) The series resistance is estimated to be 1 and 3 ohm with a spacing of 2 µm and 4 µm respectively. The parallel resistance is very large. The current source depends on the optical input signal, and it is given by eqn. (1).

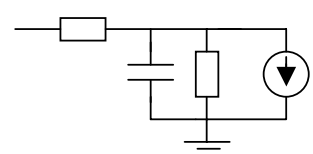


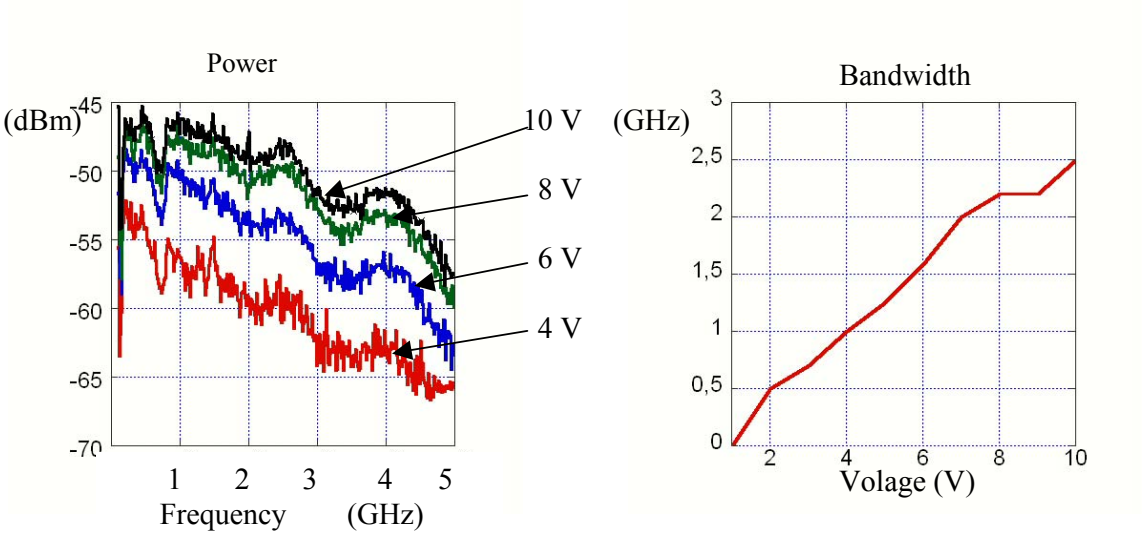
Fig. 4 Circuit diagram of MSM detector.

The RC-constant of the MSM detector indicates a 3dB bandwidth of 22 GHz and 40 GHz for a spacing 2 and 4 µm with a 50 ohms load.

An optical test system

An optical test system was set up to study the performance of the MSM detector. The transmitter of the system was an 850 nm VCSEL. The VCSEL is designed for low threshold current, high optical output power, wide temperature operation and high modulation efficiency. It also shows good behavior at large signal modulation up to 10 Gb/s [4].

The receiver, in this case the MSM detector, detects the optical signal from 100 MHz to 5 GHz. Figure 5a shows the frequency response of an MSM detector with a spacing of 2 µm and a width of 1 µm. The bandwidth versus bias voltage is presented in figure 5b. The voltage varies from 1 to 10 V.



(a) (b)

Fig. 5) Frequency response of MSM detector. b) Bandwidth versus voltage.

The obtained bandwidth of the MSM detector is above 2 GHz at a bias of 10 V. The bandwidth is mainly limited by the transit time. The carrier velocity is increasing with bias voltage, see figure 5b. For higher bias than 10 V, the breakdown starts to become a problem.

The detector with a spacing of 4 µm was measured to half of the bandwidth at a bias voltage of 10 V.

Conclusions

We have fabricated and characterized an MSM detector on a commercial HEMT-MMICs wafer as a proof-of-concept. The electrical and optical performance of the MSM detector has been studied. A bandwidth exceeding 2 GHz, with a responsitivity of 0.5 A/W. For further improvement of the bandwidth, dimensions have to be further decreased.

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REFERENCES

[1] V.Hurm, W Bronner, W. Benz, K. Köhler, J-R Kropp,R Lösch, M. Ludwig, G. Mann, M. Mikulla, J. Rosenzweig, M. Schlechtweg, M. Walther and G. Weimann “Large area MSM photodiode array for 0.85 µm wavelength 10 Gbit/s per channel parallel optical links” Electronics Letters , Volume: 38 Issue: 18 , 29 August 2002, 1051-1052

[2] S. V. Averine, Y.C. Chan and Y.L. Lam, “Geometry optimization of interdigitated Schottky-barrier metal-semiconductor-metal photodiode structures”, Solid-state Electronics, Volume: 45, 2001, 441-446

[3] Stephen B. Alexander, “Optical Communication Receiver Design”, IEE Telecommunications Series Volume 37

[4] Aggerstam, T.; Lovqvist, A.; Stevens, R.; Jonsson, S.; Von Wyrtemberg, R.M.; Schatz, R.; Dubois, M.;Ghisoni, M.; "Selectively oxidized vertical-cavity surface emitting lasers for high speed data communication" at Photonics West2001.

[5] J. Burm, K.I. Litivin, W.J. Schaff and L. Eastman “Optimization of High-Speed Metal- Semiconductor-Metal Photodetectors”, IEEE Photonics Technology Letters, Volume: 6 No.:6 , 6 June,1994

[6] K.I. Litivin, J. Burm, , W.J. Schaff and L. Eastman “High Speed Optical Detectors for Monolithic Millimeter Wave Integrated Circuits”, IEEE MTT-S Digest 1993