Extended Abstracts of the 1994 International Conference on Solid State Devices and Materials, Yokohama, 1994, pp. 235-237

Material Characterization and Optimization for Ultra High Speed MSM-Photodetectors

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MSM photodetectors fabricated on different semiconductors are investigated and optimized for applications in high speed optical transmission systems. The devices exhibit FWHM times from 0.9 ps to 8 ps corresponding to carrier velocities exceeding $5 \cdot 10^7$ cm/s. In contrast to the common opinion the results indicate that the use of low doped materials is recommended due to much better linearity and dynamic responsivity.

1. Introduction

Metal-semiconductor-metal photodetectors are well known for various advantages: The devices exhibit very short rise and FWHM times, low dark currents of 30 pA [1], and high quantum efficiencies of up to 90 %. Their simple planar structure with capacitance in the fF regime leads to extremly low RC times. Moreover, the structure is inherently compatible to MESFET technology for high speed applications and direct receiver integration. However, MSM detectors are rarely used in optical transmission systems due to the fact that the pulse response of commonly investigated MSM devices on semi-insulating or high defect density material is known to be deteriorated by very long exponential tails caused by trapping and diffusion of carriers. These tails result in a strongly increased noise level on the receiver side and higher BERs. Semi-insulating (s.i.) MSM or low temperature GaAs devices are optimized for shortest FWHM times due to lifetime limitation of the carriers in the crystal [2]. A loss in signal-to-noise ratio and dynamic responsivity is accepted.

To optimize the semiconductor material for MSM devices with regard to system applications and to understand the ultrafast and ballistic processes in the devices a detailed investigation of the responsible effects with sub-picosecond resolution is necessary. However, in this time range commercially available measurement systems, e.g. sampling oscilloscopes, are no longer applicable because they are only capable of sensing signals up to frequencies of 50 GHz (τ_r = 7ps). Spectrum analyzers extended by external mixers have an enlarged frequency range of up to about 350 GHz, but the essential phase information for signal reconstruction is lost.

In this paper we use an electro-optical sampling system with a time resolution of less than 400 fs for device characterization. Complementary investigations with a novel correlation technique are carried out. Photodetectors are fabricated on differently doped epitaxial layers. The results indicate that optimum device design can diminish the typical disadvantage of MSM photodetectors with respect to high speed transmission systems.

2. Experimental Setup and Devices

For high speed electrical characterization MSM photodetectors are integrated with coplanar transmission lines on a single chip. Parasitic capacitances due to device packaging and inductances of bond wires are avoided. The optical setup of the electro-optical

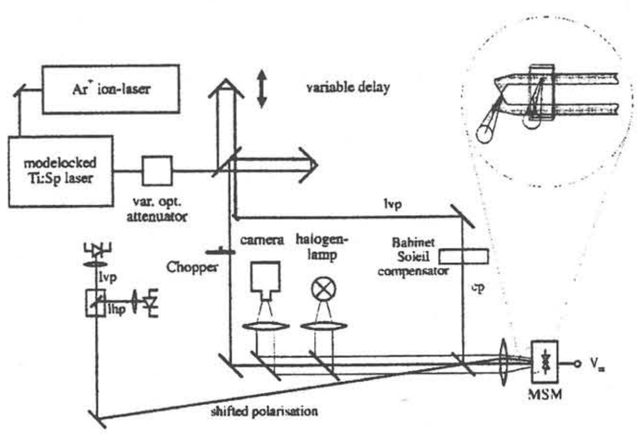


Fig. 1: Optical setup for electro-optical sampling.

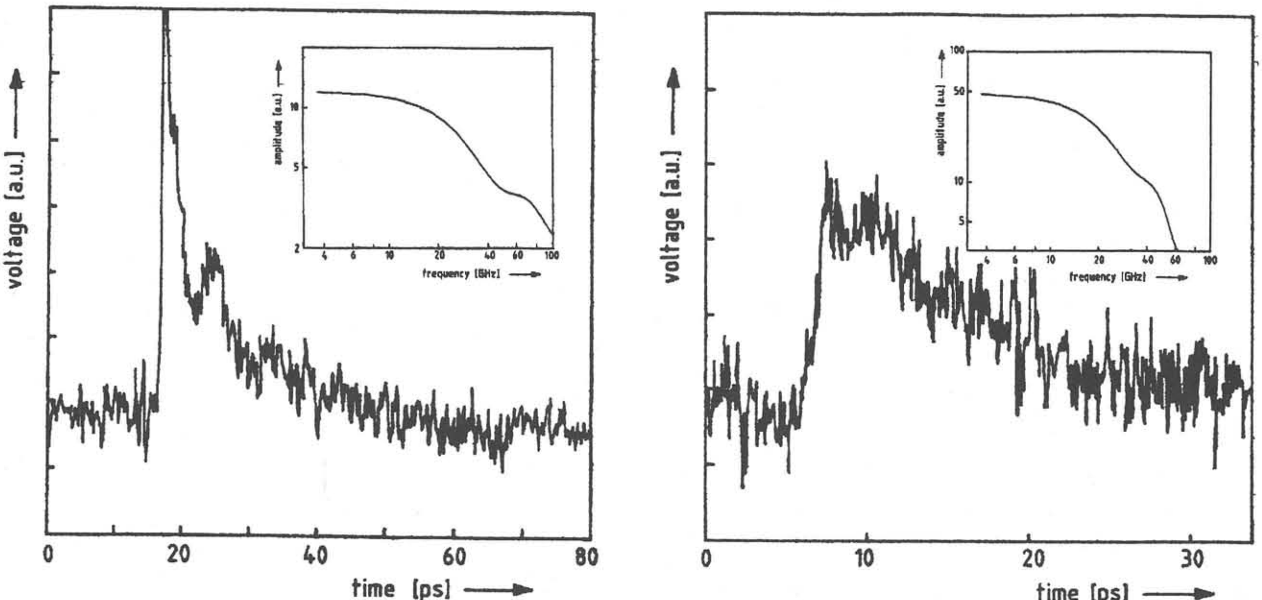


Fig. 2: Pulse responses of differently doped GaAs MSM detectors: a) s.i. material, b) n^--material. Insets show the Fourier transforms of the pulse traces.

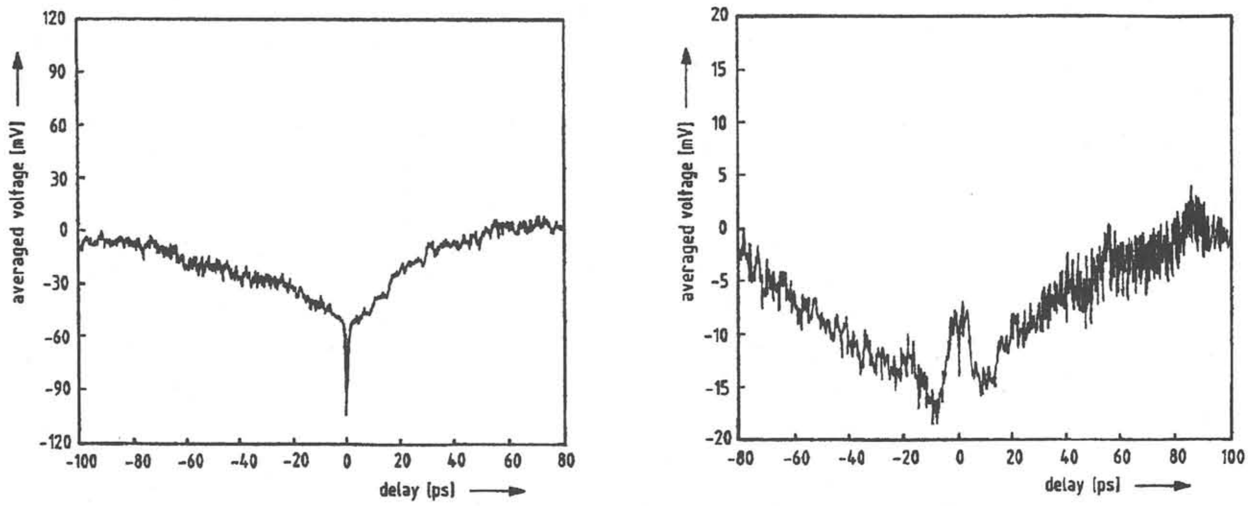
sampling system is depicted in Fig. 1. An argon ion-laser pumped, modelocked Ti:Sp-laser is used as pulse source. This laser emits 100 fs pulses with a repetition frequency of 76 MHz and is continuously tunable from 700 nm to 1030 nm. Two pulse trains of variable delay are generated in a Michelson interferometer. The first beam is used to excite the MSM photodetector at the end of the transmission line. The other time delayed beam is circularly polarized by a Soleil Babinet compensator to enhance the amplitude resolution of the setup and probes the electric field on the transmission line using the field induced birefringence in a BSO crystal. The crystal is placed directly onto the metal contacts as shown in the inset of Fig. 1. To avoid dispersion effects of the transmission line the signal has to be probed in a distance of less than 150 µm of the detector. The ellipticity of the reflected light is detected in lock-in technique. The signal is proportional to the amplitude of the propagating wave in the sampling period. The time resolution of the system is less than 400 fs mainly given by the time of interaction of sampling beam and electrical wave and by the extension of the optical focus on the transmission line.

The correlation technique is able to provide information about the short time behavior of devices using a cw measurement technique. The photodetectors are excited by two subsequent pulses of the laser. The electrical responses of the photodetector to two subsequent exciting laser pulses are correlated. A delay dependent change of the output signal is measured because of mixing terms of the two responses caused by the nonlinear characteristics of the current transport. Nonlinearities in the device exist because free carriers, generated by the first exciting pulse and still remaining in the device, influence the response to a second pulse. The correlation traces allow a separation of different physical effects like recombination, trapping, and diffusion in the investigated structure. A more detailed description of the measurement technique is given in [3].

Different layers of low doped materials are grown by standard solid source MBE on semi-insulating GaAs substrates and compared to semi-insulating layers. The MSM detectors are patterned by a standard lift-off process. The evaporated Schottky contacts consist of 50 nm platinum reinforced by 300 nm gold. The gold contact is also used as high reflective surface for the sampling beam in the electro-optical measurements. The electrode spacing of the devices is 5 µm.

3. Results and Discussion

Two typical pulse responses of MSM structures processed on semi-insulating (s.i.) GaAs material and on low Si-doped ($n = 5\cdot10^{15}$ cm^{-3}) GaAs are depicted in Fig. 2. The second peak in the trace for the semi-insulating device is caused by reflections of the signal at the end of the crystal on the coplanar transmission line. Both devices exhibit very short rise times of less than 1 ps. The FWHM times of 900 fs and 8 ps, respectively, differ by a factor of 9. The response of the semi-insulating detector is limited by the lifetime of free carriers. The drift time limited low doped detector shows carrier velocities in the regime of $5\cdot10^{7}$ cm/s indicating a strong overshoot. The fall times are in both cases about 14 ps. However, a very long exponential tail with an amplitude below 10 % of the maximum signal is seen in the response of the s.i. MSM detector, whereas the response of the n^--GaAs MSM returns to the zero line. The dynamic responsivity defined by the area of the pulse



`Fig. 3: Correlation traces at low excitation power of MSM photodetectors fabricated on:
a) s.i. material, b) n^--material.

response above 10 % of the maximum signal of the low doped device is by a factor of about 5 higher than the value for the detector on semi-insulating material. The cut-off frequencies of the structures commonly estimated at first glance only from the FWHM times of the pulse responses, e.g. [4], are 350 GHz and 42 GHz, respectively. However, Fourier transforming the pulse responses as depicted in the insets of Fig. 2, known as a more exact method to determine the frequency limit, leads to results of 30 GHz and 20 GHz. These values indicate the strong influence of the low amplitude long tail on the high frequency behavior of the devices.

In addition correlation measurements are carried out to investigate the physical phenomena responsible for these results. Two typical correlation traces corresponding to the pulse responses in Fig. 1 are shown in Fig. 3. A much higher amplitude of the correlation trace of the s.i. MSM detector with a saturating power dependency is observable. This indicates a strong influence of trapping in the device that leads to the long tail in the pulse response and strongly deteriorates the high frequency behavior. The low doped MSM detector shows a much lower correlation amplitude indicating a nearly linear device characteristic limited by the carrier transit time in the device. Further material optimization and additional BER measurements should help to develop the potential of MSM detectors for high speed optical transmission systems.

4. Conclusion

To summarize, investigations of the time domain behavior of MSM photodetectors fabricated on different materials were carried out to optimize these detectors for high speed applications e.g. in optical transmission systems. Two measurement techniques, electro-optical sampling and correlation of the pulse responses, were used for device characterization. The results obtained with the two measurement techniques show that the commonly preferred semi-insulating materials are not optimal for photodetector applications in optical transmission systems. Although the s.i. devices exhibit a very fast first peak in their pulse response (τ_{FWHM} = 900 fs), a very long tail with low amplitude strongly deteriorates their high frequency behavior. MSM devices fabricated on low doped material show at first glance a slower response (τ_{FWHM} = 8 ps), but the dynamic responsivity, higher by a factor of 5, and the fast exponential decay recommend the use of low doped semiconductors with respect to applications in high speed transmission systems.

5. References

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