Extended Abstracts of the 1993 International Conference on Solid State Devices and Materials, Makuhari, 1993, pp. 663-665 **PD-1-1**

Characterization of Dynamic Behaviour of MSM-Photodetectors by Correlation Technique

W. Kowalsky, M. Sickmöller, and P. Urbach

Department of Optoelectronics,
University of Ulm,
D-89069 Ulm, Federal Republic of Germany.

The frequency response, linearity, and sensitivity of MSM-photodetectors are investigated by pulse correlation experiments. This measurement technique allows the separation of different phenomena affecting carrier transport . A short risetime (13 ps limited by the measurement setup) and pulse width (25 ps) and excellent linearity are attained using n-type epitaxial layers. In contrast to semiinsulating layers no pulse tails are observed.

1. Introduction

An important device in the chain of an optical data transmission system which often little notice is taken of is the photodetector. Good device performance requests a high speed response, high dynamic responsivity, low noise, and power linearity. Due to a well established technology and satisfactory device performance pin-photodetectors are most convenient in system applications. Whereas a remarkable feature of MSM-detectors is a very short risetime, they are lacking in sensitivity and often exhibit long pulse tails. These disadvantages can be diminished by choosing an optimized semiconductor and by an improved contact geometry. We attain frequency limits up to 50 GHz, a quantum efficiency of 90 per cent, and dark currents as low as 30 pA [1]. Furthermore, the simple planar structure of MSM-detectors provides process compatibility to MESFET technology.

Designing detectors, high speed is often traded off for high responsivity. High speed detectors are obtained by using semiinsulating materials with short carrier lifetimes. However, fast recombination may deteriorate the dynamic responsivity and linearity. In this case, low doped semiconductors should be preferred. To optimize photodetectors for both demands, the intrinsic detection and transport processes have to be investigated in detail. Therefore, the effects of recombination and drift of optically generated carriers in the device have to be separated from one another by a suitable measurement technique. The correlation experiments presented in this paper are based on the correlation of two subsequent pulse responses of the photodetector due to generation of mixing terms. The mixing terms result from nonlinearities of the device. Free carriers generated by the first exciting optical pulse which are still present in the device influence the response to a second pulse.

2. Theoretical Model

As a basic theoretical approach the correlation technique can be explained by a simple phenomenological model. The free carrier concentration $n(t)=n_0+n_1(t)$ in a volume element of the semiconductor is described by the differential equation

$$\frac{\partial n_1(t)}{\partial t} = -\frac{n_1(t)}{\tau_R(n_1(t))} + \eta I(t).$$

n_1 is the density of free carriers generated by pulse excitation and τ_R the time they stay in the volume element of the semiconductor. I(t) is the intensity of the incident light. In the nonlinear case, the time $\tau_R \approx \tau_0 + \tau_1(n1(t))$ is a function of the carrier concentration. For two exciting pulses $I=I(t)+I(t-t_0)$ a solution approach of the form

$$n_{ges}(t)=n_1(t)+n_1(t-t_0)+f(t,t_0)$$

is chosen, taking into account the two responses to the individual pulses and an additional term $f(t,t_0)$ of the interaction due to the nonlinearities. The solution of the differential equation we obtain after time averaging over a period T is

$$\langle f(t,t_0)\rangle = -2\frac{\tau_1}{\tau_0}\langle n_1(t)n_1(t\text{-}t_0)\rangle + 2\frac{\tau_1}{\tau_0}\eta\frac{\tau_0}{T}n_1(t_0) \quad .$$

The first term in this equation is the autocorrelation function of the electrical pulse response, the second

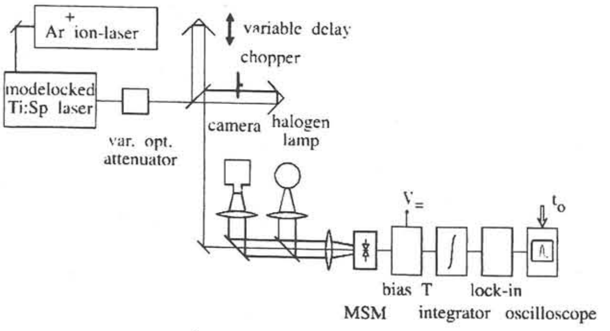

Fig. 1: Optical set-up of the correlation experiments

term describes the interaction of the free carriers generated by the first pulse with the second response. Numerical solutions of the nonlinear differential equation show, that the amplitude of the correlation function only depends on the time τ_0, whereas the width of the function depends on the nonlinear characteristics due to τ_1.

3. Measurement Set-up

The experimental set-up used for the correlation measurements is shown in Fig. 1. The MSM-devices are periodically excited by two subsequent laser pulses with variable delay. The pulses are generated by a modelocked Ti:Sp laser and have an autocorrelation-width of 150 fs. The variable delay is obtained by a path difference in a Michelson interferometer. The electrical output of the MSM-structure is time integrated, detected by a lock-in amplifier and displayed on an oscilloscope as a function of the pulse delay.

4. Results and discussion

For comparison MSM-devices are fabricated of different semiconductor materials: undoped (n^-), semiinsulating (s.i.), and two materials with high defect concentrations, low temperature (LT) GaAs and GaAs on Si. The epitaxial layers are grown by solid source MBE. The MSM-detectors are patterned by conventional lift-off technique. With regard to pigtail applications non-interdigitated asymmetrical contact geometries are designed to adjust the diameter of the absorption region to the diameter of the fiber core. Experimental results of these correlation measurements at different power levels and corresponding pulse responses in the time domain of n^--GaAs and s.i.-GaAs are depicted in Fig. 2. Symmetrical to the strong coherence peak in the centre of all traces three effects can be observed. In the time interval of about ±20 ps a positive contribution is observed increasing with the incident intensity. This results from the recombination of free carriers in the device. With increasing concentration of carriers the carrier lifetime is reduced, resulting in a positive contribution in the correlation function. In contrast, trapping of free carriers results in a negative term in a time regime of about ±60 ps: The relative share of carriers which are trapped is reduced with increasing concentration because of saturation of the traps. This leads to a longer average lifetime of the remaining free carriers. This effect increases nonlinearly with the optical pulse energy and saturates at higher levels due to the completely filled trap level. The third contribution is again with a negative sign in the time regime of the trapping effect. No saturation to higher power levels is observed This term is caused by carrier diffusion in the device. At the interface between depleted and non-depleted regions the carrier concentration is kept low on the first mentioned side due to the electrical field. In the non-depleted region the concentration increases linear with the optical power. The resulting diffusion current of the free carriers increases nonlinear, because of the negative concentration dependence of the diffusion coefficient.

These results obtained by the correlation technique allow a discussion of the corresponding pulse shape in the time domain. The n^--GaAs detector shows an abruptly rising pulse edge and a fast exponential decay. This device is mainly limited by the carrier drift. The pulse response of the s.i.-GaAs MSM-detector shows a nearly symmetrical pulse shape. Disadvantageous is a distinct exponential pulse tail. The difference in the sensitivity of the two detectors is caused by the limited extension of the depletion region of this detector due to the higher doping concentration. This results in only partial absorption of the incident beam in the depleted region. Measurements with LT-GaAs show fast pulse responses, but the sensitivity of these devices is poor.

5. Conclusions

To summarize, a correlation technique is presented to characterize the dominating effects influencing current transport in semiconductor devices. The influence of different effects like recombination, trapping and carrier diffusion can be separated. The experiments with MSM-photodetectors show that for system applications the choice of an undoped semiconductor material is favourable because a fast pulse response without disadvantageous tails is achieved. In contrast to other high defect materials this is not traded off for high sensitivity and linear behaviour.

6. References

1) U. Prank, M. Mikulla, and W. Kowalsky, Appl. Phys. Lett. 62 (1993) pp. 129-130.

2) M. Klingenstein, J. Kuhl, R. Nötzel, K. Ploog, J. Rosenzweig, C. Moglestue, A. Hülsmann, Jo. Schneider, and K. Köhler, Appl. Phys. Lett. 60 (1992), pp. 627-629.

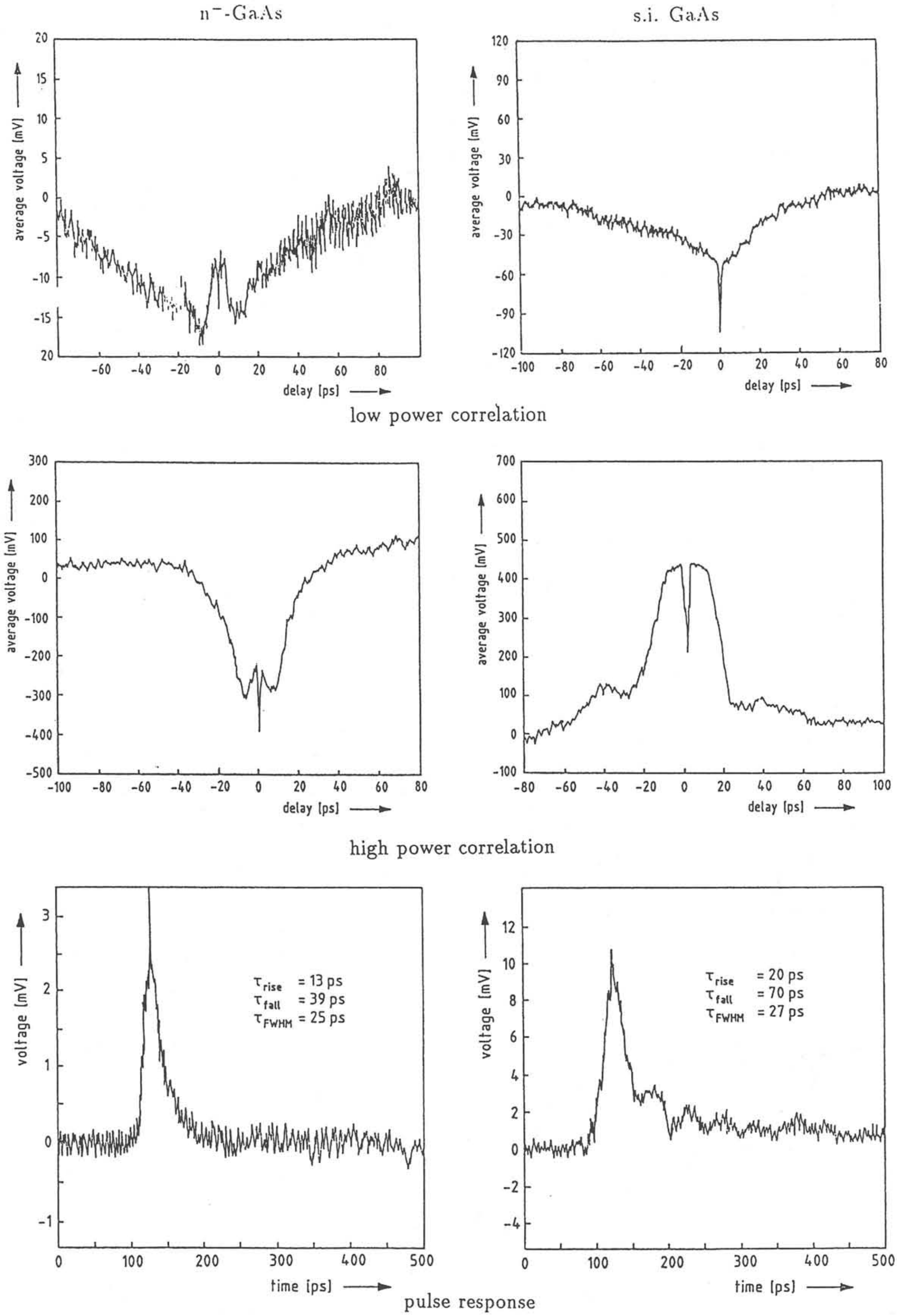

Fig. 2: Correlation functions and pulse response of MSM-photodetectors using undoped and semiinsulating GaAs-materials.