

MSM Photodetectors and Modulators for Long Wavelength Applications: Optimization of Solid Source MBE Growth of AlInAs/(Al)GaInAs-Heterostructures

T. Kummetz, M. Sickmüller, A. Fricke, D. Sowada, J. Mähnß, and W. Kowalsky
Optoelectronics Department, University of Ulm, D-89069 Ulm, Germany
Phone: +49 731 502 6038, Fax: +49 731 502 6049

Solid source MBE growth of AlInAs/(Al)GaInAs heterostructures for applications in MSM photodetectors and electrooptic MSM modulators has been optimized with regard to high frequency performance of the devices. The influence of the thickness of an AlInAs barrier enhancement layer on the dynamical characteristics is also investigated. In contrast to the commonly chosen thickness of about 10 nm we show that an increase to 100 nm AlInAs results in bandwidth enhancement and noise reduction. Using these improved structures with breakdown voltages exceeding $V_B=100$ V for electrooptic switching we attain a contrast of 19:1.

1. Introduction

For high speed photodetection MSM structures on wide band gap materials like GaAs exhibit frequency limits exceeding 100 GHz¹⁾ and low noise characteristics due to the high quality of the Schottky contacts.

Since the excellent high frequency characteristics are predominantly based on the planar contact design and the short carrier drift region of the MSM structure, and less on the material system, long wavelength devices should also show good device performance. For the near infrared region AlGaInAs lattice matched grown on InP by solid source MBE is advantageous for MSM photodetectors and electro-absorption modulators because of the high Schottky barrier. Integration with field effect transistors is simply realized due to the compatibility in the structure. In order to achieve low dark currents and low excessive noise figures a wide gap AlInAs Schottky barrier enhancement layer has to be grown on top of the narrow gap (Al)GaInAs absorption layer. However, carrier trapping at the resulting heterobarrier

may decrease the speed of the device. In our work we focus on growth and design optimization of the structures shown in Fig. 1 to obtain both high frequency limits and low noise characteristics.

2. MBE Growth

The AlGaInAs material system grown by solid source MBE is favorable for MSM structures compared to GaInAsP for two reasons: AlGaInAs composition control is much easier due to the incorporation of only one group V element and the Schottky barrier height on the wide bandgap ternary compound AlInAs ($\Phi_b = 0.85\text{eV}$) is nearly twice as large as on InP ($\Phi_b = 0.43\text{eV}$). Since no phosphorus source is included in our MBE system pre-growth surface stabilization of the InP substrate for oxide desorption has to be carried out under arsenic stabilization. The volatile phosphorus of the InP substrate is partially substituted by arsenic at temperatures above 500°C. This leads to an InAsP quantum well at the surface whereas at lower temperatures no complete removal of surface impurities and native oxide is

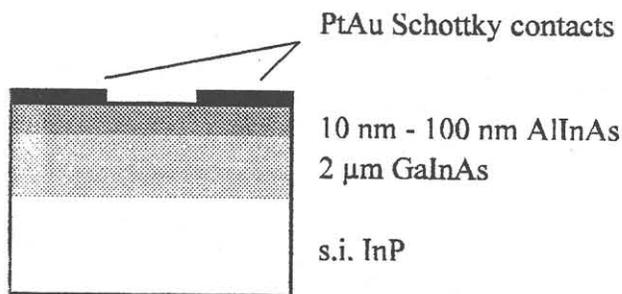


Fig. 1: MSM structure for long wavelength applications.

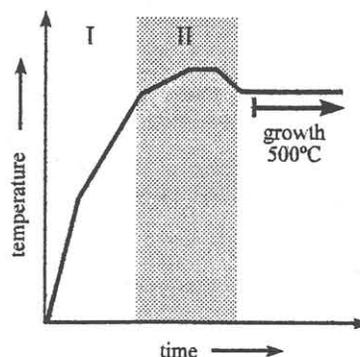


Fig. 2: Pre-growth temperature ramp. For device optimization additional overheating has to be inserted.

obtained. The optimization of the pre-growth temperature ramp is performed with regard to mobility and residual doping profile obtained by Hall and C(V) measurements of the grown samples. AlInAs/GaInAs heterostructures with non-optimized pre-growth heating show distinct doping spikes at the ternary interface although no effect on the rocking trace can be observed. In Fig. 2 an optimized temperature ramp is shown. The highest temperature value depends on the type of substrate used (typically 530°C for epi-ready s.i.-InP and 520°C for n-InP). Applying this pre-growth treatment room temperature hall mobilities exceeding 10^4 cm²/Vs are reproducibly obtained and no excessive impurity doping level is observed at the AlInAs/GaInAs interface.

3. MSM photodetector: Influence of AlInAs barrier enhancement layer thickness

After crystal growth PtAu Schottky contacts are prepared by a standard lift-off process. The contact geometry is chosen to allow microwave probing. Several characterization techniques are applied to the devices: Pulse response measurements at $\lambda = 830$ nm, pulse correlation technique²⁾ at 830 nm, and frequency response measurements at 1.55 μ m by heterodyne detection of a DFB laser and a tunable laser source with

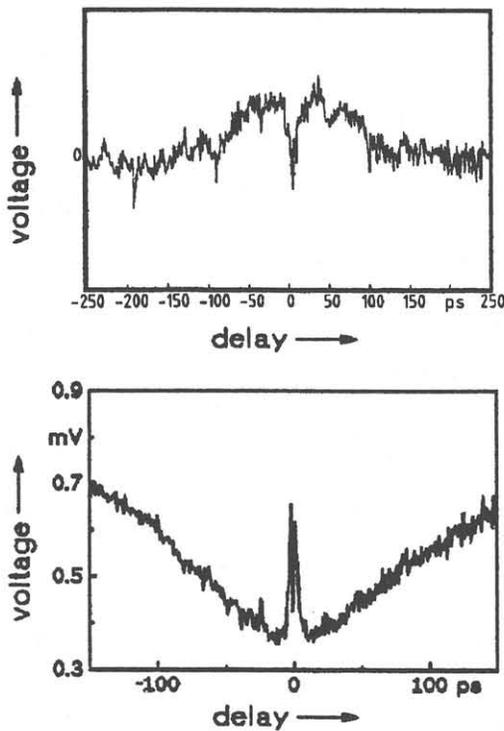


Fig. 3: Correlation measurements of MSM photodetectors at 830nm with different pre-growth procedures: a) linear temperature ramp, b) additional overheating.

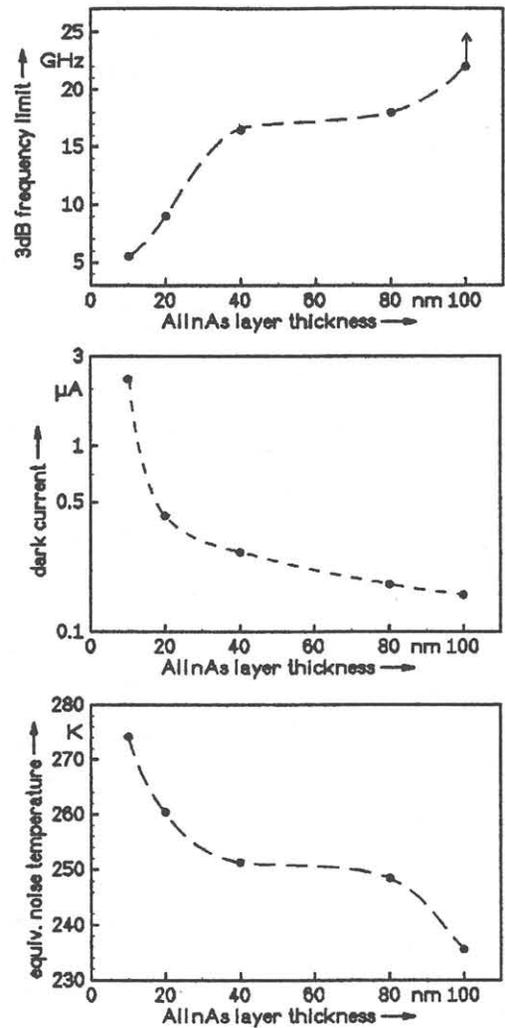


Fig. 4: 3dB frequency response (1.55 μ m), dark current, equivalent noise temperature under dark conditions at 1 GHz as a function of AlInAs layer thickness.

external cavity. The heterodyne detection offers the possibility to characterize the response of the photodetector in an almost unlimited frequency range at the system relevant wavelength of $\lambda = 1.55$ μ m. Additional measurements at 830 nm allow to investigate effects close to the surface and at the heterointerface due to the low penetration depth of light into the GaInAs layer. The pulse correlation technique - the photodetector is excited by two subsequent optical pulses of varying delay from a titanium:sapphire laser and the correlation of the electrical pulse responses is detected after averaging - is well suitable for the characterization of the AlInAs/(Al)GaInAs interface. Lower signals indicating smaller nonlinearities are obtained with structures which were grown applying the optimized pre-growth temperature ramp. From the signal shape depicted in Fig. 3a carrier trapping can be deduced for the MSM devices grown with a monotonous temperature ramp in the pre-growth phase. This results in pulse responses with

long tails and low frequency limits. For the device grown at optimized conditions the signal shape does not indicate carrier trapping but suggests that carrier transport is mainly governed by carrier drift as shown in Fig. 3b.

In a second step the thickness of the AlInAs barrier enhancement layer is varied. The effect on the MSM photodetector device performance is characterized by pulse response measurements at a wavelength of 830 nm, frequency response measurements by heterodyne detection at 1.55 μm , and dark current noise measurements at 1 GHz. Fig. 4 shows typical results.

Although a short pulse response with $\tau_{\text{FWHM}} = 60$ ps and a frequency limit of 5 GHz is obtained with a thin AlInAs layer high dark currents and high equivalent noise temperatures deteriorate the device performance of these structures. An increase of the AlInAs layer thickness to 100 nm results in shorter pulse responses with $\tau_{\text{FWHM}} = 35$ ps, the frequency limit increases up to 20 GHz, and the equivalent noise temperature attains its minimum value of 237 K. The dark current of these structures is about 140 nA. A graded gap structure with an effective AlInAs layer thickness of 60 nm shows no change of the photodetector dynamics. With this optimized structure high breakdown voltages are possible which are required for modulator applications.

6. MSM modulator with external cavity

For spectral characterization of electrooptic MSM modulators based on electro-absorption an external cavity composed of a monolithically integrated Bragg reflector and the end facet of an optical fiber coated with an evaporated dielectric reflector is used as shown in the inset of Fig. 5. This setup allows a variation of the cavity length and thus continuous tuning of the operation wavelength given by the Fabry-Perot resonances of the modulator over a wide spectral range. With this hybrid structure the switching contrast and its dependence on the wavelength and the resonator length can be characterized requiring only a single device. We attain a switching contrast of up to 19:1 at a switching voltage of only 10 V as shown in Fig. 5.

7. Summary

In conclusion, we experimentally investigate the influence of the thickness of AlInAs barrier enhancement layers in long wavelength MSM photodetectors. In contrast to the general assumption that an enhancement layer as thin as possible (typically 10 nm) assures best frequency characteristics we demonstrate that an increase of the thickness to about 100 nm improves frequency, dark current, and noise characteristics. This is based on the separation of the Schottky barrier and heterobarrier. Due to the increased breakdown voltage

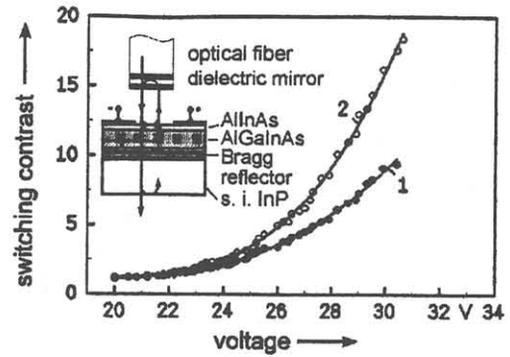


Fig. 5: Switching contrast versus voltage at $\lambda = 1.55 \mu\text{m}$ of the MSM resonant modulator with external feedback at two different lengths of the external resonator.

these optimized structures are well suited for electrooptic switching. We attain a maximum switching contrast of 19:1.

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References

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