A Ka-Band Detector Diode with High Sensitivity

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In this work the design and matching of a zero bias InGaAs-Schottky detector diode for 35 GHz is described. High voltage sensitivity at zero bias is achieved by incorporating indium and by matching the input impedance to 50 Ω. This diode is used as the receiving part of a Doppler-radar front-end.

1. Introduction

In millimeter-wave systems suited for automotive applications Schottky-barrier diodes are used for detecting and mixing signals because of their high switching speed which results from the unipolar conduction mechanism. III-V semiconductors are the preferred materials because of their higher electron mobility at low fields compared to Silicon. Important parameters of Schottky barrier detector diodes are series resistance, barrier height, and junction capacitance. There are two types of detector diodes: zero-bias devices and detector diodes used with bias, which need a more complicated circuitry.

2. InGaAs Diode

The voltage sensitivity of a detector diode is a function of its reverse saturation current [1]. For optimum sensitivity this current has to be in the range of 10^{-6} A. To achieve this value with GaAs technology at zero bias – which is desirable to keep the circuit as simple as possible – the barrier height must be tailored to 0.22 – 0.25 eV by incorporating indium. With increasing In content the energy gap of the semiconductor is lowered from 1.42 eV (GaAs) to 0.33 eV (InAs). With $In_{0.38}Ga_{0.62}As$ the desired barrier height of the Schottky contact can be achieved.

The diodes were fabricated using epitaxial layers of GaAs and InGaAs grown by metal organic chemical vapor deposition (MOCVD) on GaAs-substrates. Ni/GeAu/Ni/Au films were evaporated thermally and by e-beam, respectively, and annealed to form ohmic contacts on n-type layers, Ti/Au and Cr/Au were evaporated and used for Schottky contacts. The ohmic contacts were recessed by wet chemical etching and the connection to the Schottky contact on the top was led over a SiO_2 bridge. The SiO_2 layers were etched in a reactive ion etching (RIE) reactor. The patterns for the contact pads, the interconnections and the circuit were transferred to the substrate using e-beam lithography. The layer sequence of the Schottky-barrier diodes is shown in Fig. 1. Details of the fabrication can be found in [2].

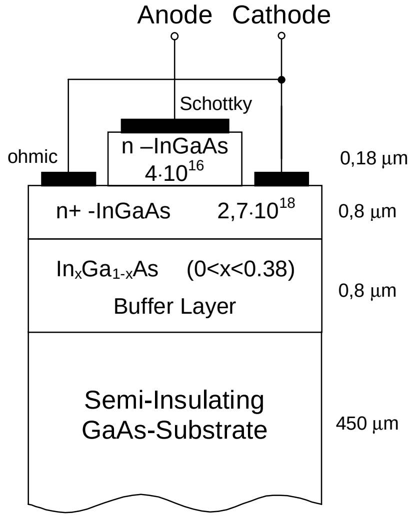

Fig. 1: Layer sequence.

The DC parameters were determined from computer controlled *I-V* measurements. The measured forward current-voltage relationship of a typical device is shown on a semi-logarithmic scale in Fig. 2. The semi-logarithmic plot also allows to calculate ideality factor, series resistance, and barrier height of the devices. A straight line was fitted to the semi-logarithmic data to extract the parameters. Typical values for reverse saturation current I_S, series resistance R_S and ideality factor n of diodes with contact area 3x3 μm^2 are shown in Table 1.

ideality factor	saturation current	series resistance	barrier height	capacitance
1.45	$8.2 \cdot 10^{-6}$ A	9.7 Ω	0.22 V	10.7 fF

Tab. 1: Typical values of $In_{0.38}Ga_{0.62}As$ Schottky barrier diodes (3 µm x 3 µm)

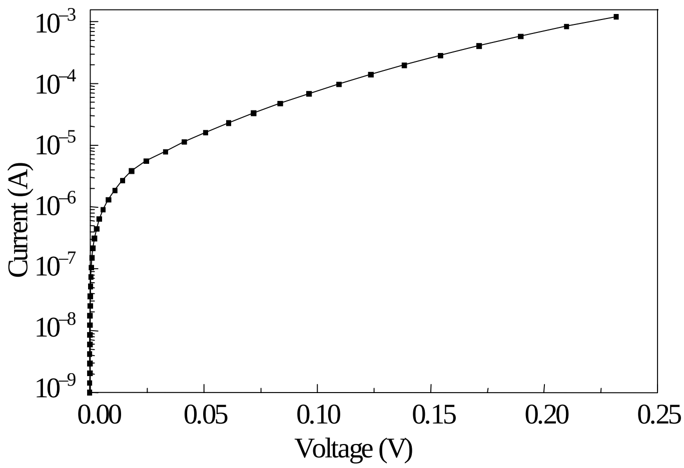

Fig. 2: Semi-logarithmic plot of measured current voltage relation.

From the measured junction capacitance of a diode with 100x100 μm^2 Schottky contact area, the junction capacitance for diodes with 3x3 μm^2 anode area can be calculated. The resulting cut-off frequency $f_{co} = 1/2\pi R_S C$ for these devices is approximately 1500 GHz.

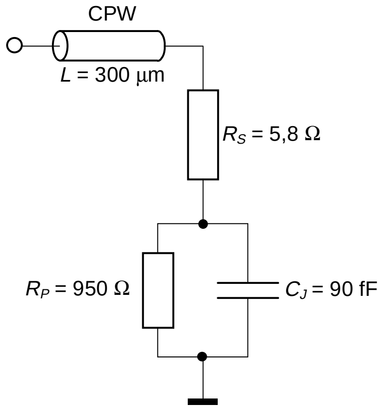

Fig. 3: Small signal model of the diode.

3. Impedance Matching

A connection of the diode to a 50 Ω microstrip line with no further impedance matching yielded a sensitivity of 1 mV/μW. In order to enhance sensibility it is necessary to match the diode impedance to the 50 Ω of the transmission line.

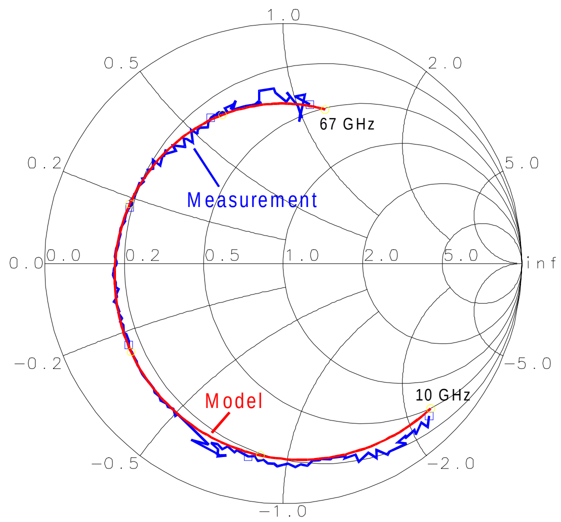

Fig. 4: Reflection coefficient of unmatched diode, frequency range 10 – 67 GHz.

Firstly, a small signal model of the diode was established by fitting the reflection coefficient (S_{11}) of the circuit shown in Fig. 3 to the measured data. The measurement of the diode was accomplished using a vector network analyzer and a wafer prober with coplanar probe tips. For these measurements the diodes were connected via coplanar transmission lines (CPW) deposited on the semi-insulating GaAs substrate. Figure 4 shows both measured and simulated reflection coefficients. The phase shift of S_{11} is mainly caused by the coplanar transmission line between probe tip and diode.

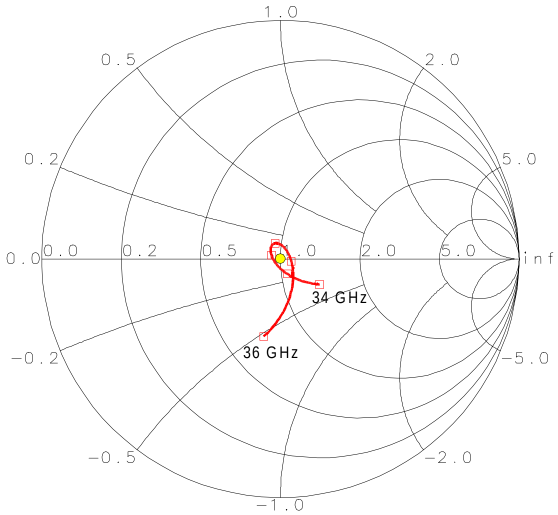

Fig. 5: Reflection coefficient of matched diode, frequency range 34 – 36 GHz.

Next, a three element T-structure matching network was optimized with respect to low S_{11} using HP-EESOF's Series IV Design Suite. The matching network was realized using microstrip technology with radial stubs serving as RF-grounds. Since the operating frequency of the radar front-end is restricted to 34 – 36 GHz a narrow band design is sufficient. Figure 5 shows the reflection coefficient obtained with the matching circuit. With this approach the voltage sensitivity exceeded 5 mV/μW [3]. The dependence of the sensitivity on the input power as well as the frequency dependence are depicted in Fig. 6. A photograph of the realized chip is shown in Fig. 7.

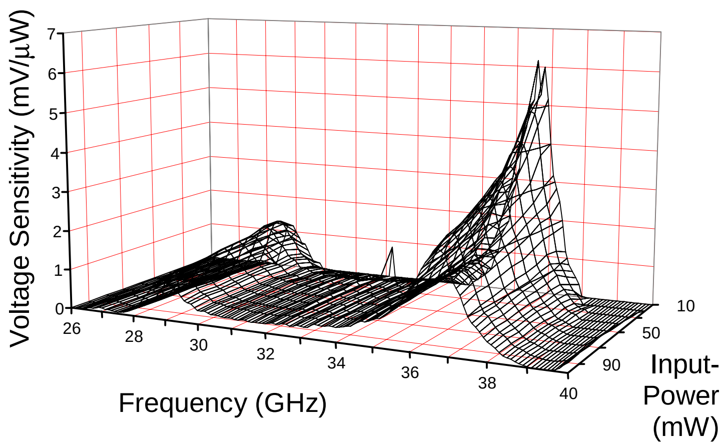

Fig. 6: Voltage sensitivity vs. frequency and input power

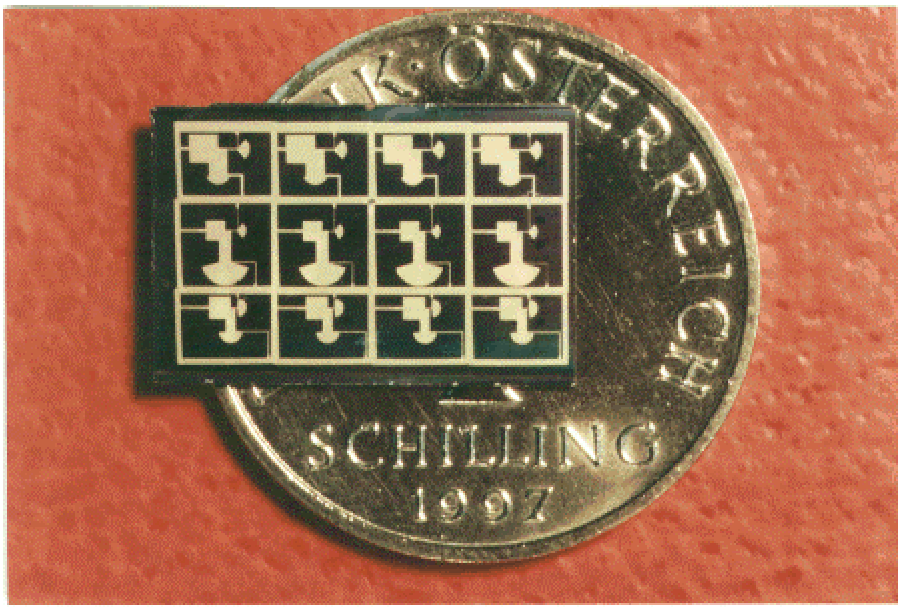

Fig. 7: Chip with three different matching circuits

4. Results

The described diode is used as a mixer in the receiving path of a Doppler-radar front-end. The signal is amplified with automatic gain control to achieve a sufficiently high signal level at the A/D-converter. A digital signal processor (DSP) analyzes the sampled signal and calculates the target speed. With a corner reflector moving at constant speed an accuracy of 0.1% is possible.

Acknowledgements

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References

[1] Bahl I., Bartia P.; “Microwave Solid State Curcuit Design”; Wiley, New York 1988

[2] A. Efanov, K. Lübke, Ch. Diskus, A. Springer, A. Stelzer, H. W. Thim: “Development of a 35 GHz Radar Sensor”, Proceedings of the Seminar *Basics and Technology of Electronic Devices*, organized by the Society for Microelectronics (Gesellschaft für Mikroelektronik - GMe), 19th – 22nd March 1997, Großarl / Pongau, pp. 11 – 16. ISBN 3-901578-02-1

[3] C. G. Diskus, A. Stelzer, K. Lübke, A. L. Springer, G. Haider, H. W. Thim: “A Matched InGaAs Detector Diode for a Ka-Band Radar Front-End”, Digest to the 22nd *Workshop on Compound Semiconductor Devices and Integrated Circuits* (WOCSDICE ’98), May 24 – 27, 1998, Zeuthen/Berlin, Germany, pp. 135 – 136