Substrateless Schottky Diodes for THz Applications

C.I. Lin#, A. Simon#, M. Rodriguez-Gironés#, H.L. Hartnagel#
P. Zimmermann*, R. Zimmermann*

Institut für Hochfrequenztechnik, Technische Hochschule Darmstadt, 64283 Darmstadt, Germany
Tel : 49-6151-162562, Fax : 49-6151-164367, e-mail : hfmwe013@hrzpub.th-darmstadt.de
* Radiometer Physics GmbH, Bergerwiesenstr. 15, 53340 Meckenheim, Germany
Tel : 49-2225-15953, Fax : 49-2225-14441

Abstract

Although planar Schottky diodes have been significantly improved, whisker contacted Schottky diodes still dominate as nonlinear devices in mixer and frequency multiplier applications in the sub-millimeter regime. Because of the skin effect the performance of whisker contacted Schottky diodes above 1 THz is limited. A novel device structure of a whisker contacted schottky diode, the substrateless Schottky diode, was proposed in 1995 [1] and the final fabrication process was defined in 1996 [2]. This structure improves some shortcomings of whisker contacted Schottky diodes. This paper presents the state-of-the-art development of this structure and discusses recent multiplier results. Tripler efficiencies of 12% (6mW) at 279 GHz and 6.7% (1mW) at 474 GHz show that the substrateless Schottky diode extends the capabilities of whisker contacted Schottky diodes in the THz regime.

Introduction

Many recent research activities are focused on planar Schottky diodes, but whisker contacted diodes still provide better RF performances. For the submillimeter regime the performance of a conventional whisker contacted Schottky diode is limited by the skin effect. In order to overcome this problem the first structure of a substrateless Schottky diode has been proposed by Seidel in 1989 [3]. In 1995 Simon proposed a novel structure that demonstrated excellent performance in a mixer at 545 GHz [1]. After the optimization of the fabrication process the yield and reproducibility of substrateless Schottky diodes has been improved significantly [2]. Fig.1 shows the structure of the substrateless Schottky diode.

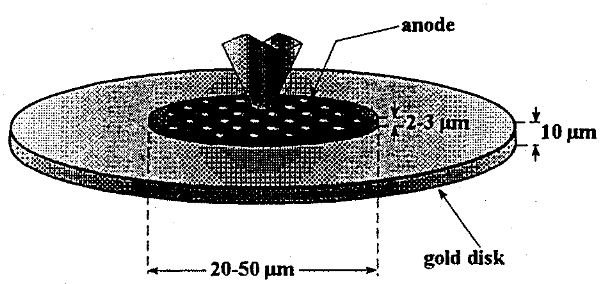

Fig.1 Drawing of a substrateless diode

Compared with the conventional diode chip the thickness of the n^+-GaAs substrate is strongly reduced from 100 μm to 2μm. Using a 5-10 μm thick Gold disc promotes the mechanical stability of the device and simplifies the handling. Due to the reduced geometry substrateless Schottky diodes offer several advantages compared with conventional whisker contacted Schottky diodes [2]:

- Due to minimized dimensions the structure is less affected by the skin effect [4].
- The n^+-substrate thickness is reduced to a few microns reducing its contribution to the resistance.
- Small distance between the active n-layer and the backside metal provides a good heat sink. Therefore, substrateless Schottky diodes can operate more reliably at high current densities without thermal degradation and the contribution to the system noise is reduced.
- Reduced semiconductor surface area decreases the leakage current.
- Reduced device volume allows a better coupling of the input signal into the diode within the waveguide.

Due to these advantages substrateless Schottky diodes give a prospect to attain improved performance of mixers and frequency multipliers in the submillimeter regime.

Fabrication process

Fig. 2 shows the material used to produce substrateless Schottky diodes, which is the same as the quasi-vertical planar Schottky diodes [5]. In fact both structures have very similar process steps from backside processing to Schottky contact formation. Thus, another advantage of substrateless Schottky diodes is the possibility to use its fabrication process in controlling the fabrication of quasi-vertical planar Schottky diodes.

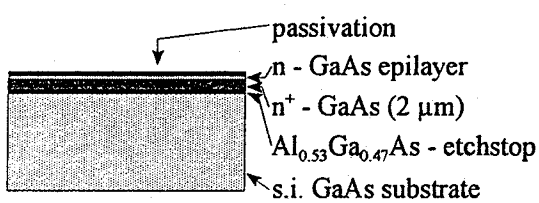

Fig.2 Layers of a MBE-wafer for substrateless Schottky diodes

The process steps for the substrateless Schottky diode fabrication are outlined below:

- Passivation (SiO_2 / polyimide) on the active n-layer

- Backside process steps
  1. Sample thinning to 70 µm from the backside
  2. Samples thinning to 30 µm from the backside in the middle of the chip
  3. Backside ohmic contact/metal disks structure definition (ø=100 µm) through selective spray etching to etchstop layer (H_2O_2/NH_4OH).
  4. Etchstop layer removal using spray etching ($H_2O_2/NH_4OH/H_2O$)
  5. Ohmic contact (Ni/GeAu/Ni) evaporation and annealing at 480°C for one minute
  6. Ohmic contact Gold plating to achieve a 10 µm thick Gold substrate
- Frontside process steps
  1. Schottky contact definition using Reactive Ion Etching, pulse plating with Platinum and Gold [6].
  2. Mesa definition using selective spray etching (H_2O_2/NH_4OH)
  3. On chip measurements
- Device separation
  1. GaAs-substrate removal from the backside using selective spray etching (H_2O_2/NH_4OH)

Device characteristics

Since last year several batches of substrateless GaAs Schottky diodes have been successfully fabricated and measured. Table 1 records the used materials and electrical characteristics of different varistors and varactors for mixer and frequency multiplier applications:

Device	**N_d [cm^{-3}]**	**$d_{n\text{-}epi}$ [nm]**	**d_{anode} [µm]**	**R_s [Ω]**	**n**	**C_{jo} [fF]**	**V_{br} [V]**	**C_{j0}/C_{min}**	**f_c [GHz]**
1030SDK	8E16	560	5	5	1.04	20	9.5	2	1.6
P1030SDK	8E16	560	5	5.7	1.03	20	18	3.2	3.1
1030SGF	8E16	560	3.5	11.5	1.05	9	8.5	2.2	1.9
733SIB	3E17	100	0.8	14	1.14	1.5	5.1	--	7.6
733SJA	3E17	100	0.5	17	1.17	0.7	5.8	--	13.4
867SIB	5E17	70	0.5	15	1.22	1.2	3.3	--	8.84

Table 1 : Characteristics of fabricated substrateless Schottky diodes

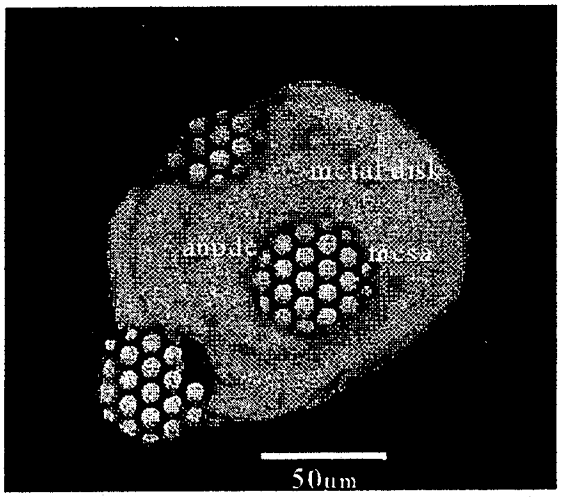

Fig.3a : Picture of device P1030SDK

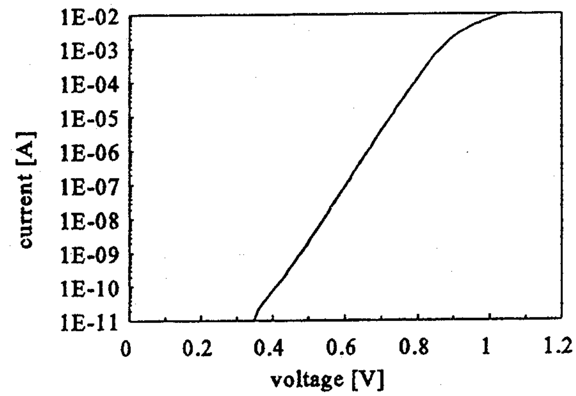

Fig.3b: I/V-characteristics of device P1030SDK

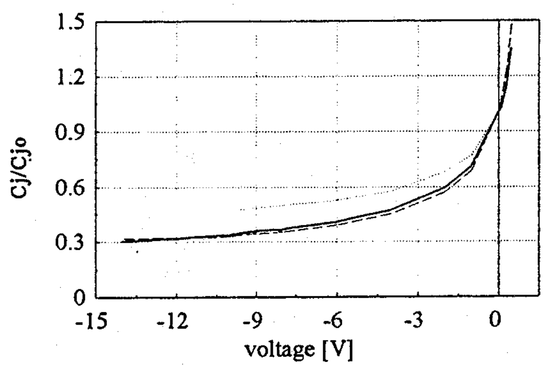

Fig.3c:C/V-curves of device 1030SDK, P1030SDK and simple simulated result
(solid line:simulation, dash line:P1030SDK, dot line:1030SDK)

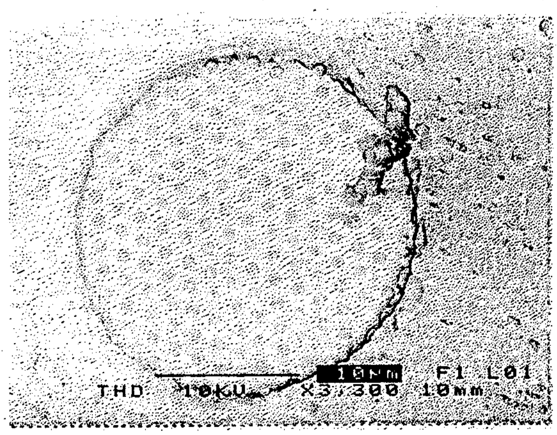

Fig.4a: SEM-picture of a mesa of device 733SIB

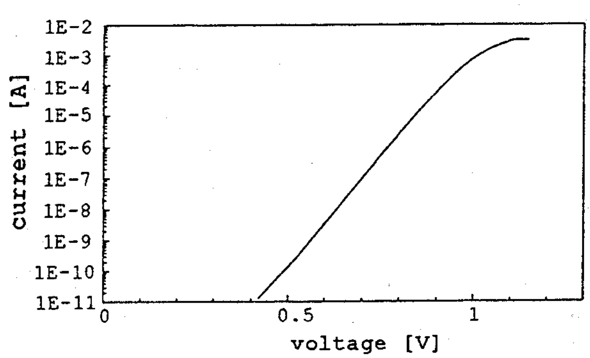

Fig. 4b : I/V-characteristics of this diode

Fig. 3a and fig. 4a show different devices. Fig. 3b and fig. 4b show the forward I/V-characteristics of diode P1030SDK (varactor) and 733SIB (varistor). It is important to note that these forward I/V-characteristics are nearly ideal values even at a current less than 1nA and follow a straight line within a very large voltage regime. That means, the complicated backside fabrication process does not have any influence on the quality of the Schottky contacts at the frontside.

Fig. 3c shows the C/V-curves of devices 1030SDK, P1030SDK and simulated results. PECVD-SiO_2 and polyimide are used for the passivation of 1030SDK and P1030SDK, respectively. Because of the in oxide-related fixed charges, device 1030SDK has a lower breakdown voltage and a smaller capacitance modulation [7]. Polyimide passivation offers a much higher breakdown voltage and an excellent capacitance modulation (P1030SDK). Therefore, polyimide can be used as a good passivation layer without the problem of fixed charges. Due to difficulties in the fabricaton the polyimide process still needs to be optimized for an anode diameter of less than 2 μm.

Radiometer Physics GmbH has tested devices 1030SDK, P1030SDK and 1030SGF, in different triplers for the frequencies 93GHz/279GHz, 125GHz/375GHz and 158GHz/474GHz. Table 2 shows the achieved output powers and efficiencies, which are comparable or better than the best results of conventional whisker contacted diodes.

Tripler	input power	output power	efficiency
93GHz/279GHz	50 mW	6 mW	12%
125GHz/375GHz	50 mW	3 mW	6%
158GHz/474GHz	15 mW	1 mW	6.7%

Table 2 : RF results of devices in tripler.

Some 733SIB devices have been delivered to University Erlangen, Germany and assembled in a corner-cube mixer. First RF measurements of the video sensitivity at 600 GHz show similar results (150mV /mW) compared with the results of two referent conventional Schottky diodes (120mV/mW and 200mV/mW). Further measurements for 2.5THz are in progress.

Conclusion

A reliable fabrication process for substrateless Schottky diodes has been presented. The proposed device structure offers reduced overall dimensions and improved power handling capabilities. The achieved output power and efficiencies of frequency triplers (6 mW, 3 mW and 1 mW at 279 GHz, 375 GHz and 474 GHz) demonstrate the capabilities of the substrateless Schottky diode in the submillimeter regime. Furthermore, the presence of oxide-related fixed charges has been avoided by polyimide passivation. Polyimide passivation offers a higher breakdown voltage and an increased capacitance modulation. The processing of the polyimide passivation for diodes with anode diameters smaller than 2 µm still needs to be optimized.

Acknowledgment

The authors would like to express their acknowledgments to Dr. H. Grothe and Dr. J. Freyer, both from the Technical University of Munich, Germany, for supplying the high-quality epitaxial materials.

References

[1] A. Simon, A. Grüb, M. Rodriguez-Gironés and H. L. Hartnagel, "A Novel Micron-Thick Whisker Contacted Schottky Diode Chip", Sixth Int. Symp. on Space Terahertz Technology, pp 5-12, 1995

[2] C. I. Lin, A. Simon and H. L. Hartnagel, "Fabrication of Substrateless Schottky Diodes for THz Applications", Fourth Int. Workshop on Terahertz Electronics, Erlangen, 1996

[3] L. K. Seidel and T. W. Crowe, "Fabrication and Analysis of GaAs Schottky Barrier Diodes Fabricated on Thin Membranes for Terahertz Applications", Int. Journal IR and Millimeter Waves, Vol.10, No.7, pp 779-787, 1989

[4] U. V. Bhapkar, T. W. Crowe, "Analysis of the High Frequency Series Impedance of GaAs Schottky Diodes by a Finite Difference Technique", IEEE Trans. Microwave Theory Tech., Vol. 40, No. 5, pp. 886-894, 1992

[5] A. Simon, C. I. Lin and H. L. Hartnagel "Fabrication and Optimization of Planar Schottky Diodes", this proceedings

[6] A. Grüb, C. I. Lin and H. L. Hartnagel, "Electrolytic Deposition Techniques for the Fabrication of Submicron Anodes", Sixth Int. Symp. on Space Terahertz Technology, pp 54-65, 1996

[7] S. M. Sze, "Physics of Semiconductor Devices", 2nd Ed., John Wiley Inc., pp. 390-395