



**HAL**  
open science

## GaAs Schottky Diodes Development for Millimeter Wave Doubler

H. Bouillaud, Priyanka Mondal, Giuseppe Di Gioia, Mohammed Samnoui, Malek Zegaoui, Guillaume Ducournau, Yannick Roelens, Jeanne Treuttel, Mohammed Zaknoute

► **To cite this version:**

H. Bouillaud, Priyanka Mondal, Giuseppe Di Gioia, Mohammed Samnoui, Malek Zegaoui, et al.. GaAs Schottky Diodes Development for Millimeter Wave Doubler. Wocsdice 2021 - 44th Workshop on Compound Semiconductor Devices and Integrated Circuits held in Europe, Oct 2021, Bristol, United Kingdom. hal-03827748

**HAL Id: hal-03827748**

**<https://hal.science/hal-03827748v1>**

Submitted on 24 Oct 2022

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# GaAs Schottky Diodes Development for Millimeter Wave Doubler

**Hugo Bouillaud<sup>1,3\*</sup>, Priyanka Mondal<sup>2</sup>, Giuseppe Di Gioia<sup>1</sup>, Mohammed Samnoui<sup>1</sup>, Malek Zegaoui<sup>1</sup>, Guillaume Ducournau<sup>1</sup>, Yannick Roelens<sup>1</sup>, Jeanne Treuttel<sup>2</sup>, Mohammed Zaknoue<sup>1</sup>**

<sup>1</sup> IEMN, University of Lille 1, avenue Poincaré BP-60069, 59652 Villeneuve d'Ascq, France

<sup>2</sup> Observatory of Paris (LERMA), 61 avenue de l'observatoire, 75014 Paris, France

<sup>3</sup> Lytid, 10 rue Alice Domon et Léonie Duquet, 75013 Paris, France

\*[h.bouillaud@lytid.com](mailto:h.bouillaud@lytid.com)

## Abstract

*We report the fabrication of GaAs Schottky diodes to be integrated in a 75/150 frequency doubler device. It is a collaborative work between IEMN and LERMA relied on the development of a process with optimizing several technological steps. As a result, very high-quality GaAs Schottky diodes have been fabricated with a reverse breakdown voltage as high as 15.2 V at about 15 kA.cm<sup>-2</sup> current density and an ideality factor of 1.1.*

*These results enabled to consider the design and simulation of a millimeter-wave frequency doubler with estimated efficiency and output power up to 30% and 120mW at 150 GHz, respectively.*

## Introduction

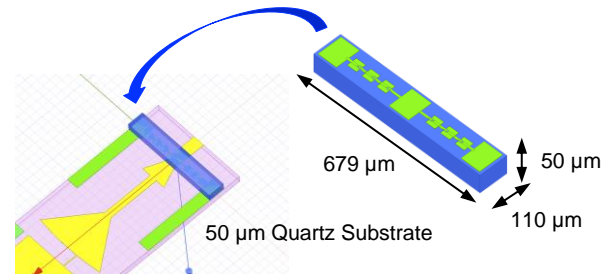
The THz range offers a wide variety of applications such as sensing molecules, security, imaging, space science, non-destructive testing, medical science and very high data rate wireless communications. These applications require low cost, compact, portable, reliable and non-cryogenic THz sources with high power level [1]. The only technology that has proven its maturity and usability considering these requirements relies on the frequency multiplier principle and a historical material system: GaAs [2].

In this context, a collaboration is presently led between LERMA (Laboratory for Studies of Radiation and Matter in Astrophysics and Atmospheres) which has a worldwide recognition on GaAs design and multiplier technology [3], and IEMN for its III-V device fabrication expertise. The device fabrication has been done at IEMN while the design and integration of the chip in the waveguide will take place at LERMA.

## Goal

Our objective is the fabrication of a 150 GHz doubler by the transfer of a bar diode cell of 6 diodes in anti-series configuration. Figure 1 shows the 3D model of the doubler along with the bar diode cell. This diode cell will be soldered on a circuit fabricated on a 50  $\mu\text{m}$  quartz substrate. The designed circuit on the quartz substrate includes biasing and passive filtering functions. According to the simulation work carried out at LERMA, it is necessary to thin the GaAs substrate on which the circuit is fabricated in order to reach high RF performance. The design has been optimized for 50  $\mu\text{m}$  GaAs substrate thickness.

Finally, the circuit with the transferred diode cell will be mounted in a waveguide.



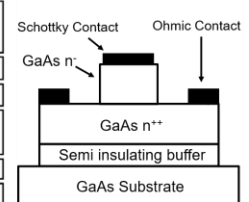
**Figure 1.** 3D model of 6 anodes doubler

The design and simulation of the waveguide, passive filter circuit and active part of the doubler were carried out by LERMA.

## Experimental

The Schottky diode active layer (Figure 2) included a 350 nm GaAs n- layer doped at  $1.10^{17}$  at.cm<sup>-3</sup>, a 20 nm GaInP etch stop and a 200 nm n++ GaAs layer both doped at  $1.10^{19}$  at.cm<sup>-3</sup>.

Thickness (Å)	Material	Doping (cm <sup>-3</sup> )
3500	GaAs	$1 \times 10^{17} : n^-$
200	GaAs	$5 \times 10^{19} : n^{++}$
200	Ga(0.5)In(0.5)P	$1 \times 10^{19} : n^{++}$
2000	GaAs	$1 \times 10^{19} : n^{++}$
200	Ga(0.5)In(0.5)P	NID
500	GaAs	Buffer
Substrate	Semi-insulating GaAs Substrate	

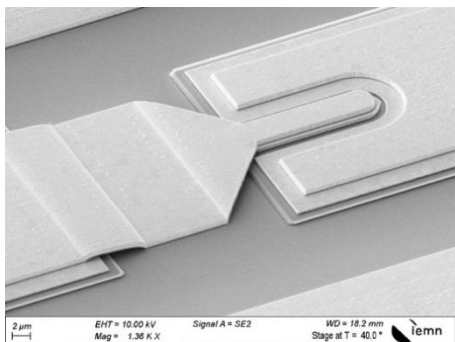


**Figure 2.** GaAs Schottky diode structure

About the etching steps, we have opted for a wet etching method for its ease of use and to avoid damages to the material that can be caused by dry etching methods. Furthermore, for our application the typical anode sizes are between 60 and 80  $\mu\text{m}^2$  which means that dry processes are not necessary. The process uses a  $\text{NH}_4\text{OH}/\text{H}_2\text{O}_2/\text{H}_2\text{O}$  wet etching system for active layer and isolation, which lead to excellent uniformity and repeatability.

The ohmic contact is based on a Ni/Ge/Au/Ti/Au metallization which is well known to provide good results on GaAs [4]. Then, a 400°C, 40" rapid thermal annealing (RTA) has been achieved. The characteristics of the ohmic contact have been extracted using the TLM method [5]. The contact showed excellent results with a specific contact resistance about  $5 \times 10^{-7} \Omega \cdot \text{cm}^2$  with an excellent contact morphology.

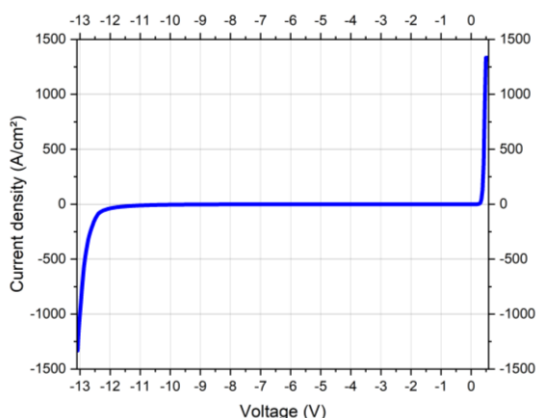
Figure 3 shows an air bridge connection between two diodes. The mask included many geometric patterns variation. The aim is to determine an optimal geometry in order to minimize the series resistance and parasitic capacitance.



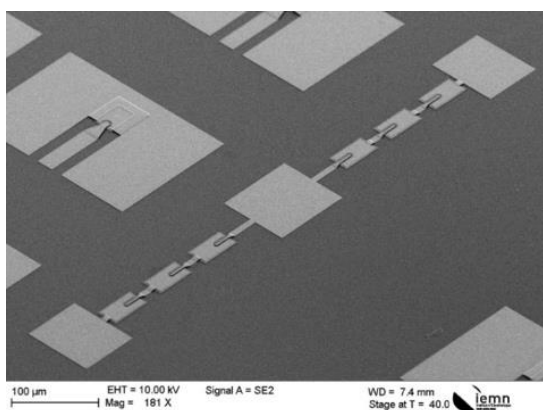
**Figure 3.** SEM picture of 6 $\mu\text{m}$  air bridge connection between 75  $\mu\text{m}^2$  series diodes

## Results and discussion

The typical characteristic of the fabricated diodes is showed in Figure 4. Device characteristics showed a very good reverse voltage behavior with -13V obtained at 1kA/cm<sup>2</sup>, the value increases to -15V at about 15kA/cm<sup>2</sup>. The breakdown voltage destruction is obtained for a value of 15.2 V. This performance is in accordance with the theoretical GaAs electric field breakdown. The ideality factor is between 1.1 and 1.15 for all measured diodes. Figure 5 shows the SEM picture of the fabricated bar diode cell before dicing and report on the quartz substrate.

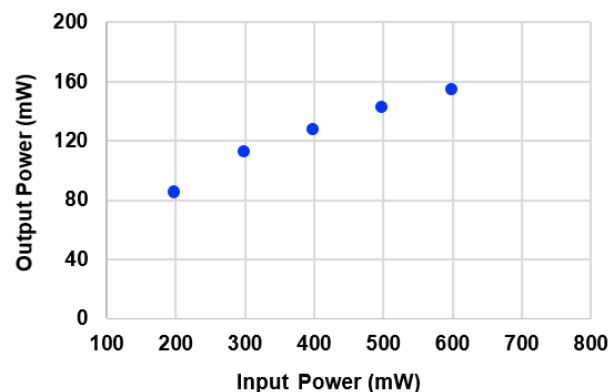


**Figure 4.** Typical 75 $\mu\text{m}^2$  anode IV characteristic



**Figure 5.** On wafer bar diode cell

Predicted performance of the multiplier with input power sweep 200 mW to 600 mW is shown in Figure 6. In each case, the reverse bias voltage is optimized for the maximum output power within the limit of breakdown voltage @-13V. Efficiency of the doubler is estimated to be 30% with an input frequency at 75 GHz, which results in an output power of 120mW for an input power of 400 mW at 150 GHz.



**Figure 6.** Predicted performance at 150 GHz with input power sweep.

## Conclusions

GaAs Schottky diodes has been fabricated and good results have been obtained. The Schottky diodes shows a low reverse current even near the breakdown point which will be very appreciated for power handling and be used for defining process related design methodology.

A 75/150 GHz frequency doubler has been simulated; this work is still in progress at LERMA and IEMN and allows the fabrication and characterization of a 75/150 GHz frequency doubler in a few months.

## Acknowledgments

This work was supported by the French Network RENATECH.

## References

- [1] P. H. Siegel, "Terahertz technology," *IEEE Trans. Microw. Theory Tech.*, vol. 50, no. 3, pp. 910–928, 2002, doi: 10.1109/22.989974.
- [2] I. Mehdi, J. V. Siles, C. Lee, and E. Schlecht, "THz diode technology: Status, prospects, and applications," *Proc. IEEE*, vol. 105, no. 6, pp. 990–1007, 2017, doi: 10.1109/JPROC.2017.2650235.
- [3] J. Treuttel, C. Lee, J. Kooi, and I. Mehdi, "A Novel 300-520 GHz Tripler with 50 % Bandwidth for Multipixel Heterodyne SIS Array Local Oscillator Signal Generation," *Int. Conf. Infrared, Millimeter, Terahertz Waves, IRMMW-THz*, vol. 2018-September, pp. 25–26, 2018, doi: 10.1109/IRMMW-THz.2018.8510271.
- [4] E. V. Erofeev, S. V. Ishutkin, V. A. Kagadei, and K. S. Nosaeva, "Multilayer low-resistance Ge/Au/Ni/Ti/Au based ohmic contact to n-GaAs," *Eur. Microw. Week 2010 Connect. World, EuMIC 2010 - Conf. Proc.*, no. September, pp. 290–293, 2010.
- [5] G. R. HB Harrison, "Obtaining the specific contact resistance from transmission line model measurements," *IEEE Trans. Energy Convers.*, vol. 4, no. 2, pp. 160–165, 1989, doi: 10.1109/60.17906.