GaAs Schottky Diodes Development for Millimeter Wave Doubler

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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^{-2} 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 µm 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 µm GaAs substrate thickness.

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

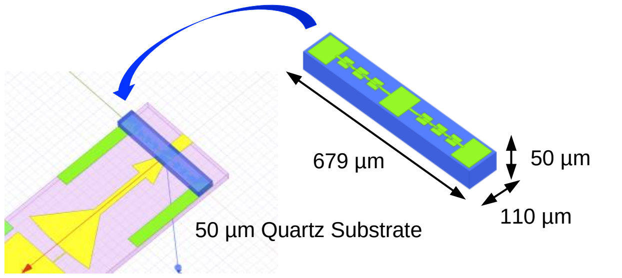

Figure 1. 3D model of 6 anodes doubler

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^{-3}, a 20 nm GaInP etch stop and a 200 nm n++ GaAs layer both doped at 1.10^{19} at.cm^{-3}.

Thickness (Å)	Material	Doping (cm^{-3})
3500	GaAs	1×10^{17} : n$^-$
200	GaAs	5×10^{18} : n^{++}
200	Ga(0,5)In(0,5)P	1×10^{19} : n^{++}
2000	GaAs	1×10^{19} : n^{++}
200	Ga(0,5)In(0,5)P	NID
500	GaAs	Buffer
Substrate	Semi-insulating GaAs Substrate	

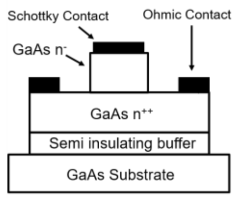

Figure 2. GaAs Schottky diode structure

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 µm² which means that dry processes are not necessary. The process uses a $NH_4OH/H_2O_2/H_2O$ 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 5×10^{-7} Ω.cm² 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.

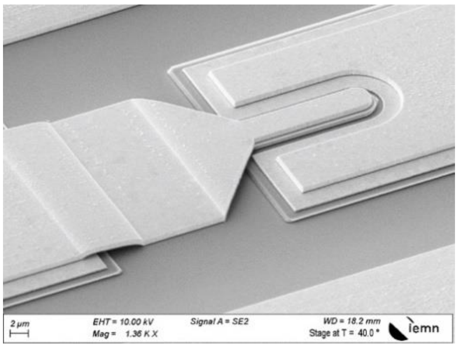

Figure 3. SEM picture of 6µm air bridge connection between 75 µm² series diodes

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/cm², the value increases to -15V at about 15kA/ cm². The breakdown voltage destruction is obtained for a value of 15.2 V. This performance is in accordance with the theorical 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.

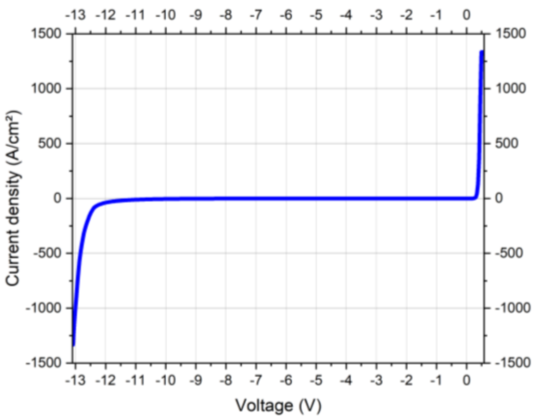

Figure 4. Typical 75µm² anode IV characteristic

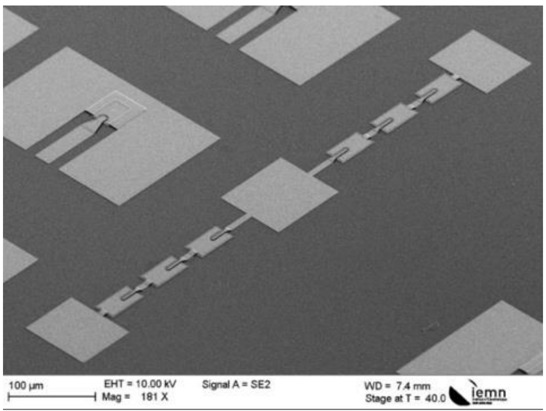

Figure 5. On wafer bar diode cell

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.

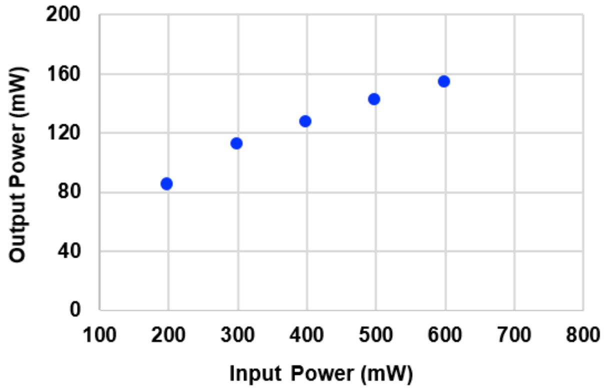

Figure 6. Predicted performance at 150 GHz with input power sweep.

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

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