Highly Reliable GaAs Planar Airbridged Schottky Diodes for Flight Qualified Millimeter-wave Circuits

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Abstract

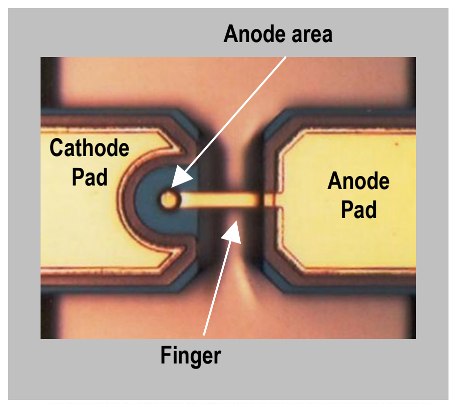
A GaAs planar airbridged Schottky (PAS) diode process has been developed for insertion in high performance circuits at millimeter-wave frequencies and beyond. The PAS diodes have shown a very low resistance, accompanied by low capacitance values resulting from the small anode geometry and optimization of the diode resistance. The process is developed on 4” GaAs wafers and show diode yield of >95% per wafer. The reliability of the junction is also discussed with an elevated 200 degrees thermal cycle test over a period of 24 hours showing no change in diode parameters such as ideality factor and breakdown voltage.

INTRODUCTION

The Schottky barrier diode has a long history of use in mixers, multipliers and switches throughout the microwave and millimeter wave frequency range [1,2]. With the ever-increasing need for bandwidth in communication systems, and new horizons for novel applications such as millimeter wave imaging, the need for faster and more reliable devices has increased. Schottky diodes serve as main components in mixer blocks for down conversion of signals in the millimeter range and above. In multipliers, the high breakdown Schottky diodes have shown to be the most affordable and sometimes the only path to generate power in the frequency range beyond 100 GHz [3]. These millimeter wave Schottky diodes are generally fabricated on GaAs substrates to take advantage of the high mobility and doping density of the material system and to provide cut-off frequencies in the THz range.

HIGHLY RELIABLE HIGH FREQUENCY SCHOTTKY DIODES

In this paper, we discuss the manufacturability of GaAs planar airbridged Schottky (PAS) diodes on 4” wafer substrates. The achieved wafer-yield of the devices is in 95% range with an associated cut-off frequency of 3 THz. The fabrication process includes a dimensionally controlled anode junction area which defines the junction capacitance of the diode. This process could yield capacitance ranges from 2fF to 100fF. The associated resistance of the PAS diodes, which is one of the most important performance criteria, is minimized by reducing all contributing resistive elements in the path of the RF current through the device. These are ohmic contact, finger airbridge and the junction area resistances. The finger connects a larger pad to the much smaller Schottky anode junction as shown in Figure 1. The geometry of the diode finger is an important design parameter. The finger provides an inductance to resonate with the diode capacitance at the frequency of operation for



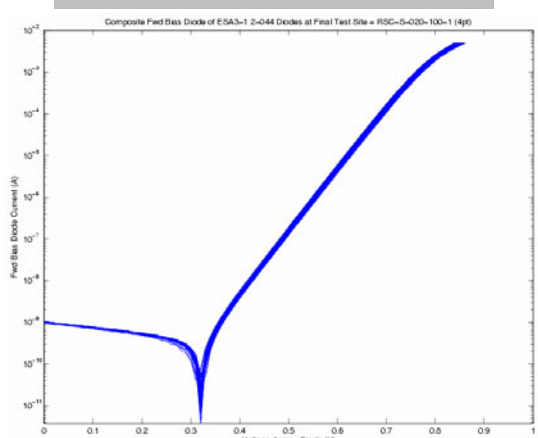


Figure 1 – Top- microscope photopgraph of the PAS diode with device sections marked. Bottom- Current voltage characteristics of 2UM anode PAS diodes plotted on top of each other from 40 sites across 4” GaAs wafer, showing very uniform characteristics

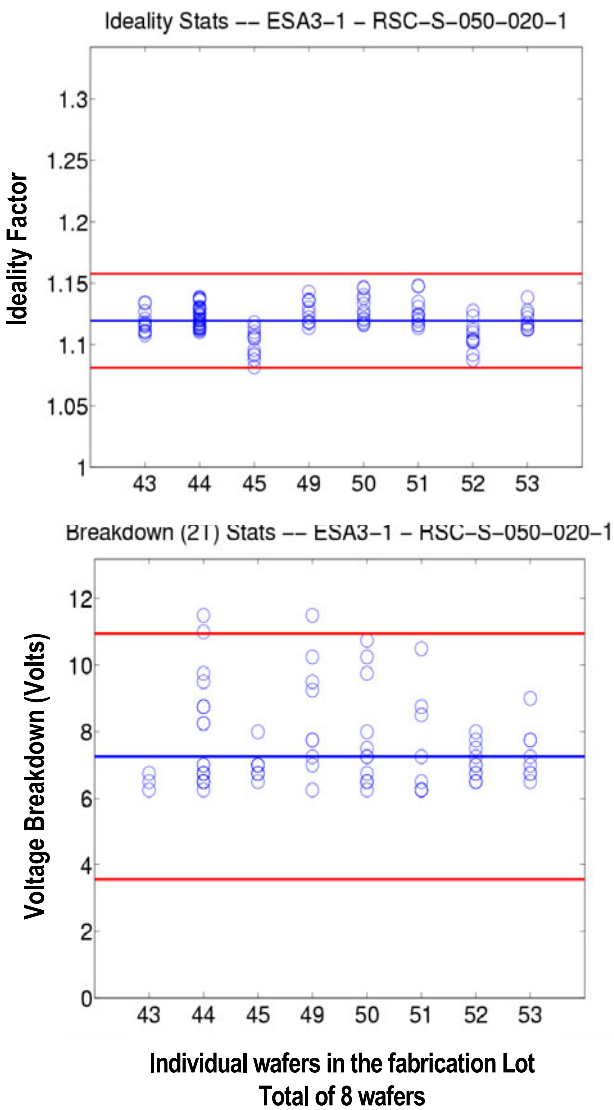


Figure 2- shows the statistical 5um(anode diameter) diode parameter map as a function of 8 processed wafers in the fabrication wafer lot. The data points are multiple measurements on various sites on each wafer. (Bottom) shows the voltage breakdown measured at 5μA reverse bias voltage. The lower limit is most important for device performance and set as 4 Volts for this particular diode design.

impedance matching to the load. To minimize the parasitic nature of the finger, an airbridged structure is developed to completely eliminate any parasitic capacitance between the ohmic contact and the anode finger contact. This is achieved by raising the finger metal above the GaAs substrate by at least 1um. To reduce the resistance, all contacts have a large thickness of gold, which also provides mechanically stable airbridged parts.

Figure 1 shows the PAS diodes DC characteristics on multiple sites on a 4” GaAs wafer plotted on top of each other to show the yield and uniformity. There are 40 individual plots from multiple sites across the wafer shown on top of each other in Figure1 representing a very high uniformity across the wafer. The ideality factor of the Schottky diodes is within 1.12-1.14 range for a 2um anode diameter, resulting from a defect free metal-semiconductor Schottky interface. Diode parameters such as ideality, breakdown voltage, zero bias capacitance and its saturation current are monitored throughout the fabrication process and kept within design and process limits. Figure 2 shows a plot

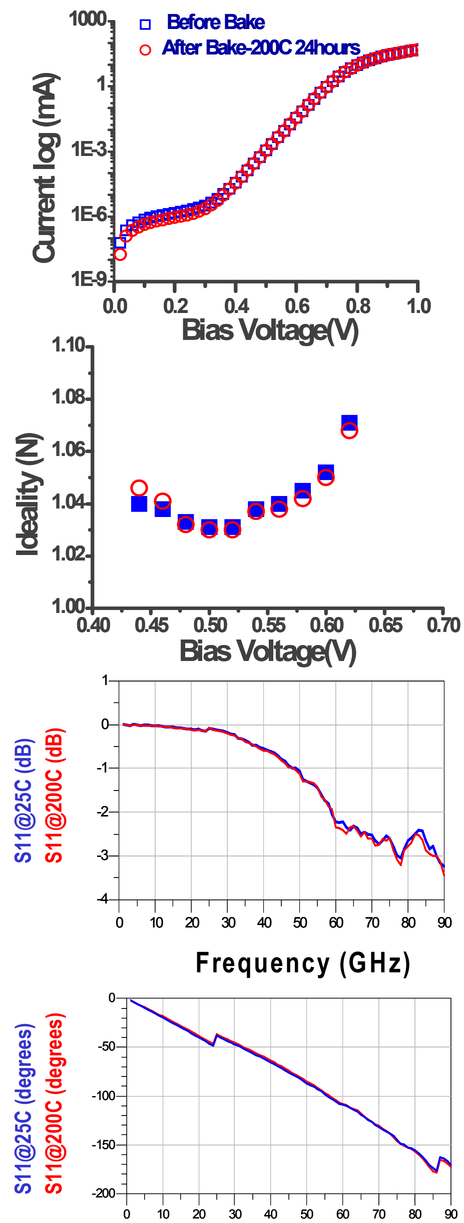


Figure 3 – Dc and S-parameter measurements (Magnitude and phase) comparison for before and after the 200C-24 hour bake cycle showing no degradation in the diode performance

of the ideality factor and breakdown voltage of the multiple site of each wafer across many wafers. The ideality factor of each diode size is measured for each wafer and all show very high junction quality close to a theoretical value of 1. The breakdown voltage is defined as the voltage in reverse bias with a 5µA of current flow. It is shown that the minimum breakdown voltage for this specific epitaxial wafer and anode geometry is 4V while all measurements are exceeding the value and are close to 6V. The zero bias capacitance data was also measured and show a variation of 2% across the wafer for various anode geometries. The uniformity and yield of these devices are direct results of multiple design-fabrication-test cycles performed to establish controls.

Also discussed in this paper is the initial reliability tests performed on the fabricated planar airbridged Schottky diodes. The diodes are measured at an elevated temperature and their DC and RF characteristics are compared before and after the bake cycle. Figure 3 shows the DC characteristics of a 5.4um PAS diode before and after a 200C bake after a 24-hour period. The current voltage characteristics show no sign of change between the two conditions. Also plotted is the ideality factor as a function of forward voltage which also show no major sign of change after the 200C bake. The devices are also characterized at millimeter wave frequencies with their S-parameters measured from DC-90 GHz. Figure 3 shows the S-parameter measurements in magnitude and phase of the PAS diode before and after the 200C bake. The device is very stable and shows no sign of RF degradation after the bake.

CONCLUSIONS

A highly reliable GaAs Schottky fabrication process has been demonstrated on 4" GaAs substrates. The diode parameters measured include ideality factor, breakdown voltage and capacitance of the diode all show very high yield in excess of 95%. All resistive paths have been optimized to improve the device performance throughout the MMW frequencies and above. An initial reliability test shows very stable performance with no change in the device performance criteria.

It is our understanding that the combination of very high performance and yield of the PAS diode process with high reliability, capable of flight and space qualification, is very unique. This allows the resulting devices emerging from this process, to provide high performance such as conversion and power efficiency in systems operating well into the millimeter and sub-millimeter wave range.

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ACRONYMS

PAS: Planar airbridged Schottky