ULTRA LOW CAPACITANCE SCHOTTKY DIODES FOR MIXER AND MULTIPLIER APPLICATIONS TO 400 GHZ

Byron Alderman, Hosh Sanghera, Leo Bamber, Bertrand Thomas, David Matheson

Space Science and Technology Department, STFC Rutherford Appleton Laboratory, Chilton, Didcot, OX11 0QX, UK
E-mail: B.Alderman@rl.ac.uk

Abstract

Low capacitance GaAs Schottky diode technology is essential for millimetre and sub-millimetre wave heterodyne receivers. Schottky diodes operate at both ambient and cryogenic temperatures and are uniquely able to cover the frequency range from DC to above 1 THz. Schottky diode technology has been evolving for many years and has traditionally been driven by the demands of radio astronomy and remote sensing of the atmosphere. Ground based applications, e.g. security imaging, are now increasing in importance. For these applications, Schottky based technology offers an attractive alternative to detectors and sources that require cryogenic cooling.

Precision fabrication techniques are required to form the diode structures. These typically consist of two parallel 20 µm long gold air-bridges passing over a channel, of depth 4 µm, to make contact to anodes which have a sub-micron radius. This approach is required to reduce parasitic capacitance, which increasingly dominates the response as the frequency rises. The on-wafer diode-to-diode variation in electrical parameters for fabricated devices is low and mechanical yields in excess of 95 % are achieved. Incorporation of the Schottky devices in heterodyne detectors yields near state-of-the-art results at 183 GHz, the characteristic frequency of a molecular line that is important for remote sensing.

A process to further improve the reliability of this Schottky technology will be reported. In this, we integrate the air-bridged diode structures with impedance matching networks. This eliminates the traditional process step of flip-chip soldering discrete diodes onto gold-on-quartz filters.

1) Introduction

Most parts of the electromagnetic spectrum are well understood and exploited, but the terahertz region between the microwave and infrared is still relatively under developed. Potential receiver applications are wide-ranging and cross-disciplinary, spanning the physical, biological, and medical sciences. In this spectral region, Schottky diode technology is uniquely important. InP MMIC amplifiers are generally limited to frequencies less than ~200GHz, above which their noise performance rapidly deteriorates. Superconducting circuits, which require cooling, may not always be practical. Either as varistor diodes (heterodyne mixing), or varactor diodes (sub-millimetre power generation), Schottky technology underpins terahertz receiver development.

Two important developments have occurred in recent years. First, the underpinning technology base has demonstrably matured in recent years. Planar Schottky diode technology has been shown to be practical at frequencies as high as 2,500 GHz, and circuit designs can be optimised theoretically with CAD electromagnetic structure simulators and non-linear analysis programs [1]. New high-speed computer controlled mills, improved lithographic capabilities and micro-machining techniques offer exciting new options for cavity and circuit manufacture. Second, it has become increasingly clear that circuits that use individually fixed diodes are not the best way of making mixers and frequency multipliers that operate at millimetre and sub-millimetre wavelengths. Rather, there are obvious advantages to be gained from integrating the diode with its embedding circuit, since this avoids design errors associated with diode positioning and fixing, and promises improved performance and better reliability.

We report here on the recent developments of air-bridged Schottky diodes that have been manufactured in our facility. The performance of sub-harmonic mixers over a range of frequencies from 183 to 380 GHz is presented. These devices use discrete flip-chip diodes soldered to a gold on quartz filter and housed in a waveguide cavity. Furthermore, an MMIC-like structure operating at 183 GHz is presented. These devices represent near or equivalent to state-of-the-art performance.

2) Air-bridged Schottky structures

Air-bridged Schottky structures were demonstrated in the late 1980's as a reliable, high quality alternative to whisker contacted diodes for use at the highest frequencies [2]. This approach gives a mechanically stable structure with low parasitic capacitance and where the anodes are in a reproducible electromagnetic environment [3,4]. For these reasons, air-bridge devices rapidly became the standard technology. The generic structure of this device is shown schematically in Figure 1. The Schottky metallization to semiconductor contact is defined by an opening in a layer of oxide. The principle function of the air-bridge is to reduce the parasitic capacitance, which originates between the contact pads and from the bridge to the neighbouring n+ contact region, as indicated on this image. This linear capacitance acts in parallel to the non-linear current-voltage and charge storage functions of the diode, reducing harmonic conversion in mixer and multiplier applications.

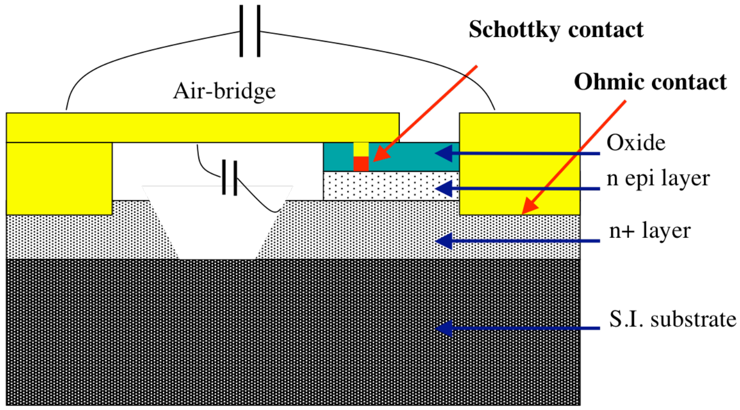

Figure 1: Schematic of air-bridged Schottky diode

3) Diode fabrication

In order to optimise the fabrication of Schottky diodes, it is fundamental to have a stable and reliable production process. Only then can minor modifications be made and the resulting change characterised. The optimisation process at RAL is based on air-bridged structures, in single and anti-parallel configurations, as shown in **Figure** 2. The process optimisation therefore occurs on the same physical structure as the final devices. Optimisation using a simpler 'honeycomb' structure would be possible, but there is no guarantee that the same conditions would apply to the more complex air-bridged structure.

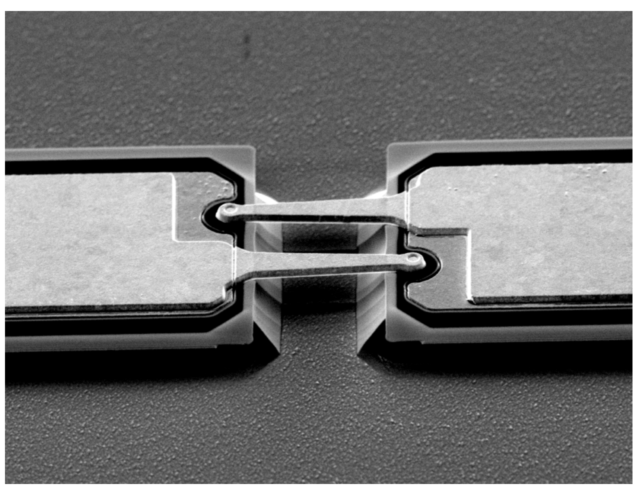

Figure 2: RAL anti-parallel air-bridged diode pair. The length of the air-bridges shown is 20 μm

These diodes are fabricated as an array of devices of varying anode sizes and single/double diode combinations that allow the maximum information to be extracted from a batch. A patterning code at the end of the contact pads indicates the nominal anode diameter; these tags can be easily identified using an optical microscope [5]. An optical image of an array of diodes, on-wafer, with the tags at the end of the ohmic pads is shown in Figure 3. After fabrication the diodes are diced to form discrete flip-chip structures, typically of overall dimensions 120 x 35 x 15 $(\mu m)^3$ (L x W x H).

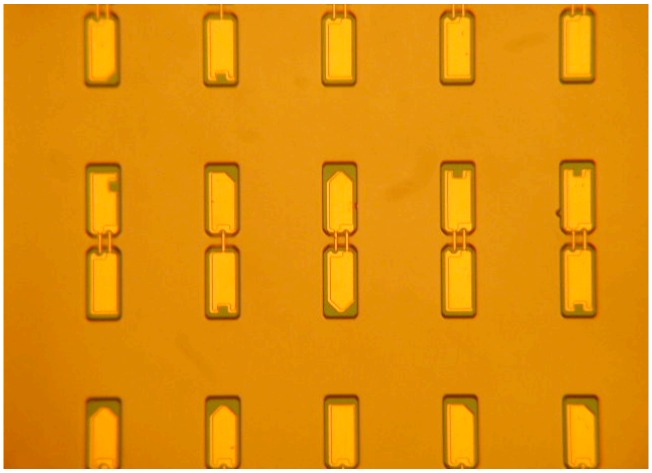

Figure 3: An array of air-bridged diodes shown on-wafer, i.e. before dicing.

An example of the optimisation process is summarised in Figure 4, in which a batch of 800 anti-parallel diodes has been processed in three distinct ways, marked here as “A”, “B” and “C”, each occupying a third of the wafer space. The results are summarised as a scatter plot of series resistance *vs.* diode ideality. All 1600 Schottky contacts from this wafer are presented in the data. The plot clearly shows that process “A” produces diodes with lower series resistance and diode ideality, as well as lower dispersion of these parameters. This plot exemplifies the level of control and stability within the Schottky process.

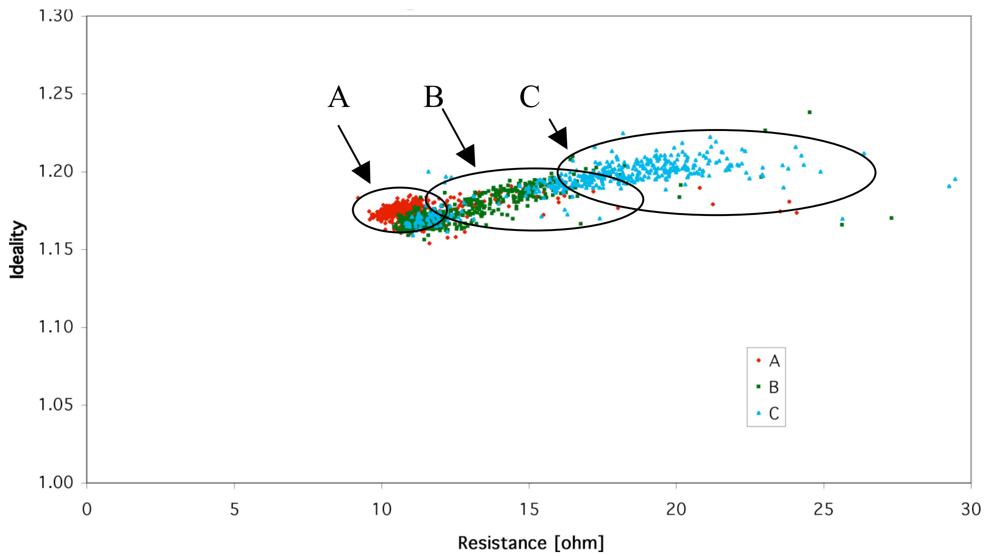

Figure 4: Scatter plot of series resistance vs. diode ideality indicating the preferred conditions of process "A".

Discrete Schottky diodes have been tested in a range of mixers at frequencies from 160 to 380 GHz: measured mixer noise temperatures are presented in Figure 5. The double side band (DSB) mixer noise temperature of 500 K at a frequency of 183 GHz is at the state-of-the-art. The remainder of the results generally fit within the scatter of published data with noise temperatures quoted at specific frequencies. The result at 380 GHz was measured in a non-optimal fixed-tuned cavity at a high IF. A cavity is being designed specifically for these diodes at 380 GHz, where we would expect improved performance from the results presented here.

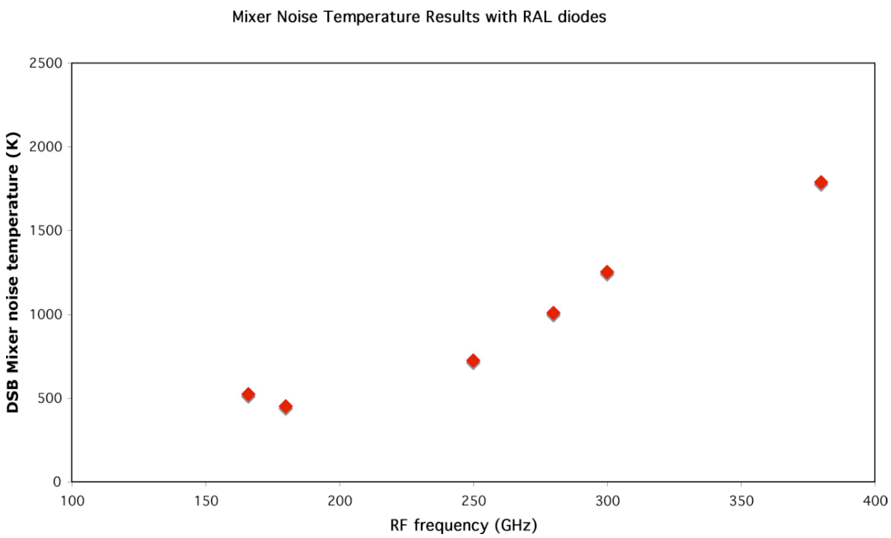

Figure 5: Summary of mixer noise results obtained using RAL's planar Schottky diodes.

4) Integrated circuits

Integrated filter/diode structures have been fabricated in order to demonstrate an integrated 183 GHz sub-harmonic mixer. The entire circuit, including a filter for the IF, was fabricated on a 50 μm thick GaAs substrate. The overall circuit dimensions were 4.2 x 0.3 x 0.05 $(mm)^3$ (L x W x H). An image of an array of these structures is shown in Figure 6 together with a magnified view of the air-bridge structure. An image of this device in a mixer cavity is shown in Figure 7 with the results present as the lowest frequency data point of Figure 5.

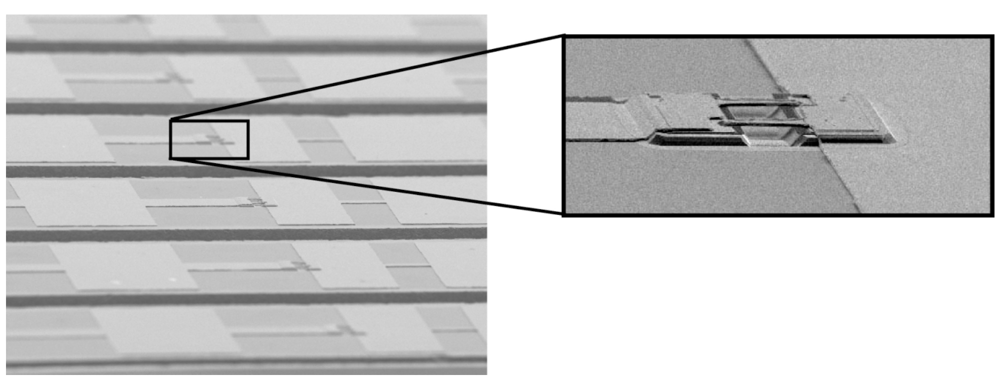

Figure 6: Integrated diode/filter structure for a 183 GHz sub-harmonic mixer.

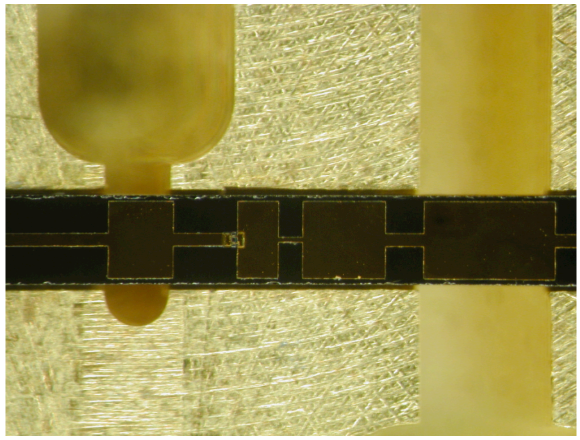

Figure 7: Optical image of integrated diode/filter structure in a fixed tuned waveguide cavity.

5) Conclusion

Ultra-low capacitance Schottky diodes have been fabricated that are suitable for applications to approximately 400 GHz. The fabrication process is stable and results in a very high yield. Flip-chips with anti-parallel pairs of these diodes have been incorporated in sub-harmonic mixers in a range of frequencies to 380 GHz. Additionally, an integrated sub-harmonic mixer has been fabricated and tested at 183 GHz. State-of-the-art mixer performance has been recorded over this frequency range.

References

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