QUASI-INTEGRATED PLANAR SCHOTTKY BARRIER DIODES FOR 2.5 THz RECEIVERS

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ABSTRACT

Schottky barrier diodes (SBDs) remain an important device for detecting and mixing at terahertz frequencies, particularly in atmospheric remote sensing and plasma diagnostics. The hydroxyl radical (OH), which plays a critical role in all cycles of ozone destruction and also acts as an oxidant for harmful gases in the atmosphere, has first significant spectral emissions at 1.8 and 2.5THz. Here we will present a new SBD configuration called a quasi-integrated planar (QUIP) SBD, to be used in 2.5THz receivers for measuring spatial distribution of the hydroxyl radical.

Submillimetre wave and terahertz applications require sub-micron anode SBDs. Traditionally, whisker-wire contacted diodes, with Schottky and Ohmic contacts at opposite sides of the device, are used in open structures such as corner-cube mixers. Here we propose a "planar" SBD with Schottky and Ohmic contacts on the same side of the device. Instead of mounting a small diode chip on a post, a large chip is used to form the wall of a waveguide which feeds a corrugated conical feedhorn antenna. A small area of this chip consisting of SBD anodes is placed near the feed of the antenna, while the rest of the chip provides the Ohmic contact and acts as a top cover for the waveguide. Thus, the diode is "integrated" into the mixer block. This greatly simplifies mixer block fabrication and assembly, and also minimises losses between the antenna and the diode by allowing the SBD contact to be placed at the feed of the antenna. The diode is then contacted using a planar whisker with an integrated RF/IF filter. QUIP SBDs with anode diameters of 0.25 - 0.3μm have been successfully fabricated and mounted into a mixer block for RF performance evaluation.

INTRODUCTION

Waveguide devices are now being used with some success in the terahertz region [1,2] and waveguide mixers are now showing comparable performance to the more common corner cube mixer configuration at frequencies as high as 2.5THz. The waveguide devices have the additional advantages of rugged construction, in-situ tuning capability and radiation properties that are isolated from the diode embedding circuit. However, the specialist fabrication level of machining required combined with the intricate fabrication procedures adopted make this approach one that is intended for applications where cost and time are not the main drivers.

The 2.5THz waveguide mixers used to date have made use of notch front diodes that have the soldered Ohmic contact on the faces that are perpendicular to the diode array. In order to realise the sub-miniature dimensions required, the chips are separated using deep Reactive Ion Etching (RIE) techniques. The fabrication process is therefore complicated requiring specialist equipment and careful process control. The resulting chips have dimensions in the order of 40μm across either as cubes or cylinders [2,3].

This paper describes a new novel approach where the diode chip itself is partially integrated with the waveguide circuit. In addition, the fabrication process is extremely straightforward as all processing steps are carried out on a flat or 'planar' surface.

By taking this approach a number of advantages result. Firstly, the chip becomes very easy to handle as it can be manufactured to be many times the size of the waveguide circuit rather than having to fit within it. Secondly, all unwanted GaAs is removed from the RF circuit itself and the soldering procedure is greatly simplified. Finally, the machining of the waveguide cavity becomes much easier so that when combined with the use of the planar whisker other types of waveguide device can be realised using this circuit architecture, for example, frequency multipliers or RTD oscillators.

BASIC CONCEPT

For a more detailed description of the mixer design see [3] in this proceedings. Use is made of the same circuit architecture. A schematic diagram showing the basic concept of the QUIP SBD chip is shown in figure 1. The mixer consists of three main components. The signal is coupled to the waveguide via a conventional corrugated feedhorn. This can be detached from the main part of the mixer block. The section of waveguide that contains the backshort and diode chip is machined from copper and electroplated in gold. A minimum of 2μm of gold is required as the soldering process used to mate the diode chip to the machined section uses a low melting point (130C) Indium solder. If an insufficient thickness of gold is used the solder can form brittle intermetallic compounds that can lead to poor electrical properties and mechanical failure.

The QUIP chip forms the waveguide lid thus completing the RF circuit.

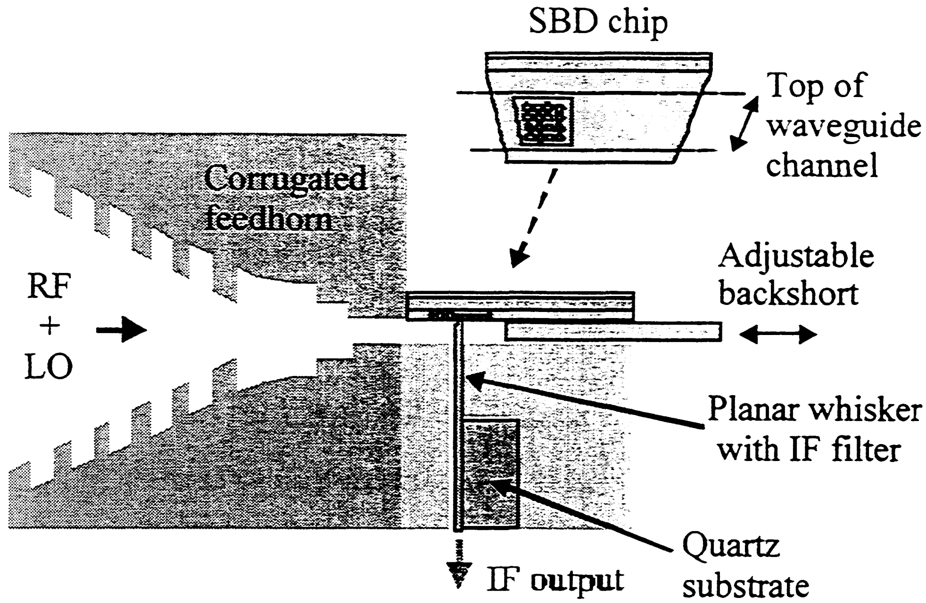


Figure 1: *The basic quasi-integrated planar diode concept*

A working drawing of the QUIP chip showing the relevant dimensions is given in figure 2. The dimensions of the chip can be set very accurately by using a commercial diamond dicing saw.

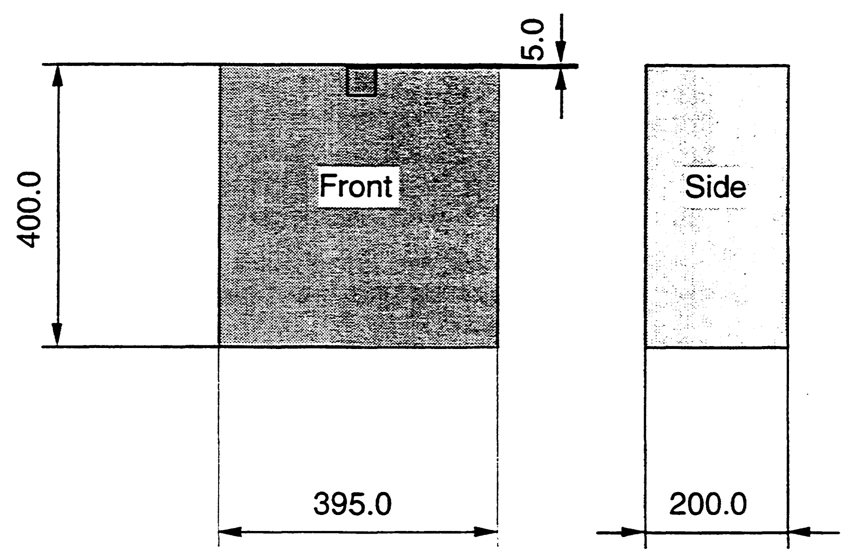
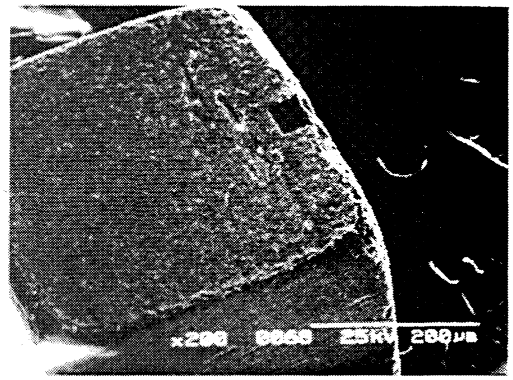


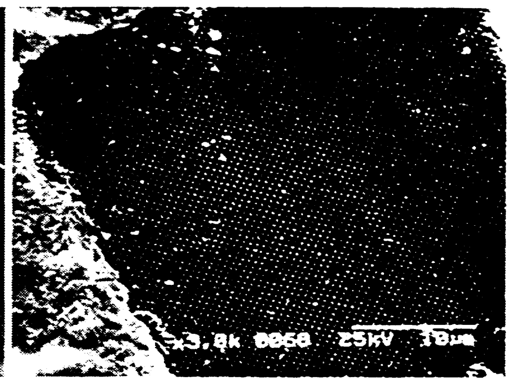
Figure 2: *Dimensions of the quasi-integrated planar diode chip used*

The diode sits in a 400µm wide recess machined into the mixer block above the channel which eventually forms the 27µm high by 105µm wide RF waveguide. This means that the 40x40µm array of diode anodes automatically aligns to the centre of the RF filter channel in which the planar whisker is housed. The soldering procedure for the QUIP chip is made very straightforward by its large dimensions.

A photograph showing a QUIP chip (X69) soldered into a mixer block is shown in figure 3 (d). The anodes are ≈ 0.25-0.3µm in diameter.



(a)



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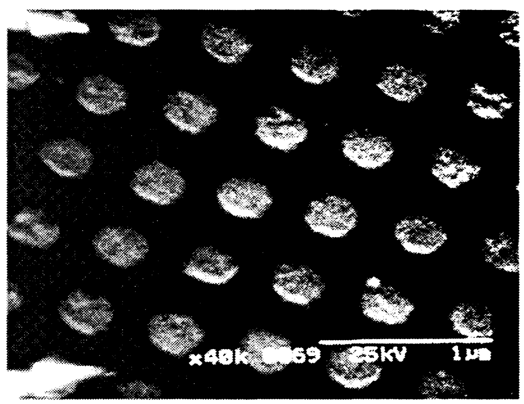

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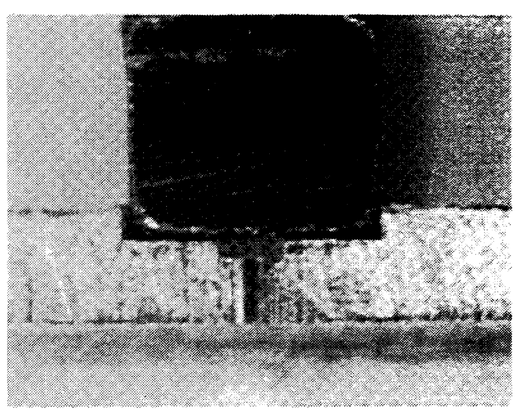

(d)

Figure 3: *An X69 QUIP chip and soldered into RAL block DW3*

DIODE FABRICATION

The fabrication procedure is very similar to that used for the fabrication of the conventional back contacted Schottky diode chips used in corner cube mixers. Much work has been carried out aimed at reducing the intrinsic diode noise. Various aspects of the fabrication process have been examined to determine if the diode noise can be minimised [4, 5]. For example, it was found that ECR (electron cyclotron resonance) plasma etching reduces the the number of defects when compared with RIE, and thus significantly lowers the 1/f noise. This is particularly important for mixers intended for Fusion Plasma Diagnostic applications. These mixers typically operate at IF frequencies of a few tens of megahertz and therefore the 1/f noise contribution becomes significant. Comprehensive results of this study will be published elsewhere [6].

A schematic of a QUIP diode chip is shown in figure 4. The Ohmic contact is made on the front side of the wafer. In the case of conventional diode chip, GaAs lies between the diode anode and the Ohmic and hence the bulk GaAs that makes up the chip now has to be included as part of the RF circuit. Even though it is formed from highly doped material it must still add extra loss into the signal path so in general the thickness of the chips has been kept to a minimum, typically 100μm, making handling difficult. For the QUIP chip the Ohmic contact is on the front face and leaving a minimum amount of exposed GaAs in the RF circuit. The chip can now be made as thick as thought practical with no detrimental effects on mixer performance. The Ohmic contact on the bottom of the QUIP chip is required only to facilitate Au/Pt plating of the anodes, and it does not effect the diode current. The details of the fabrication process will be addressed in [7].

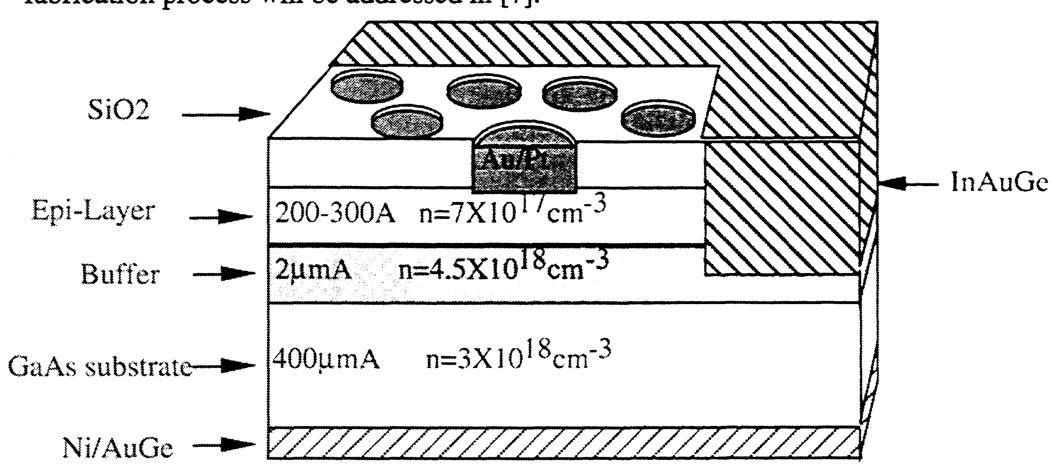

Figure 4 : *A **QUIP** diode chip with the Ohmic contact on the front*

RF MEASUREMENTS IN A WAVEGUIDE MIXER

The advantages of a waveguide mixer over a corner reflector mixer are particularly apparent when the RF embedding circuit is considered. For the corner reflector, the embedding impedance is theoretically set to be real somewhere in the range 80-200Ω. Knowledge of the absolute embedding impedance is more or less impossible to obtain and this is mainly because the antenna pattern and embedding impedance both depend on the whisker/antenna/reflector configuration. Small physical changes in the mount can modify the beam pattern adding additional optical coupling losses or alternatively introduce reflections on the whisker/antenna which result in an unknown reactive component in the embedding impedance. In the waveguide mount the radiation properties are isolated from the embedding circuit via the use of a corrugated feedhorn. The signal is matched to the diode via the use of a waveguide matching probe and a movable backshort tuner. Therefore in principle a complete range of embedding impedances can be presented to the diode the aim being to eventually find the optimum value.

RAL mixer DW3 was assembled as described in [3] and tested at 2.5THz. An SEM of a completed mixer assembly is shown in figure 5.

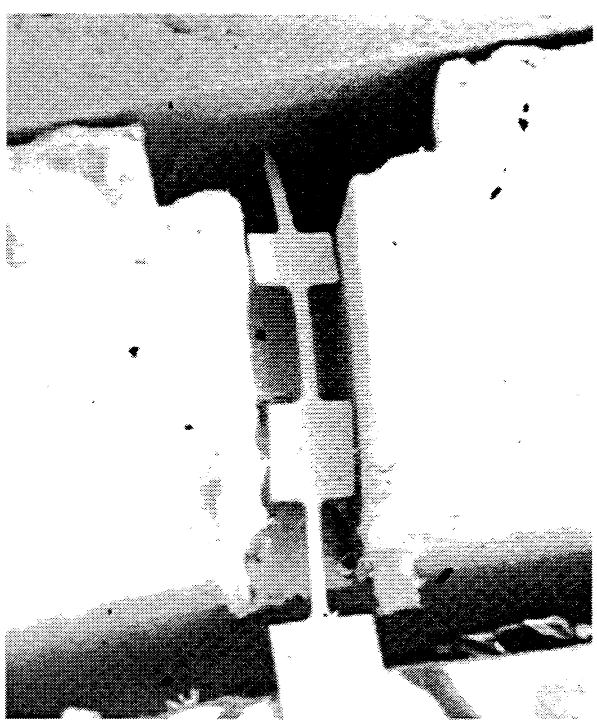

Figure 5: *An assembled mixer RF circuit*

Preliminary RF results at 2.5THz are very encouraging and are displayed in figure 6. A double sideband receiver noise temperature of 24,000K was obtained at the first iteration. This compares with our best receiver noise performance of ≈16,000K DSB obtained using a UVA 1T2 notch front diode. However, these are both very early results. A full empirical optimisation of the RF circuit is now required before accurate comparisons can be made between diodes.

Importantly, for the X69 QUIP diode, the LO requirement has been reduced to levels that are directly comparable to that required by a corner reflector mixer showing that the loss associated with the waveguide mount is not too prohibitive. In addition, this level of LO requirement is approximately 60% lower than for a UVA 1T2 notch front diode mixer. The RF circuit will now be empirically optimised in order to find the best impedance match for the X69 QUIP diode.

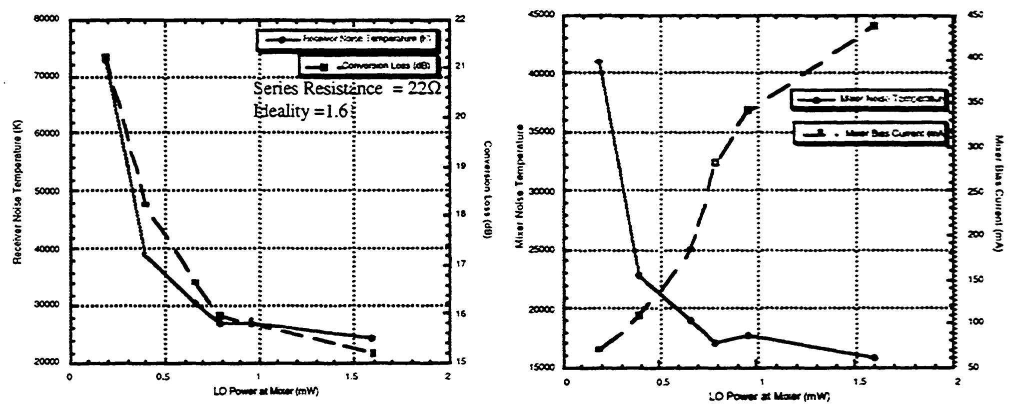

Figure 6: *2.5THz mixer RF performance for Tohoku diode X69 in RAL mixer DW3*

CONCLUSIONS

A new RF circuit architecture has been demonstrated. A novel Schottky diode chip configuration that allows it to be partly integrated with a waveguide mount has eased many of the fabrication and assembly problems encountered in previous designs that made use of sub-miniature notch front diodes. Good mixer performance has been obtained at first iteration and the circuit will now undergo further empirical optimisation.

This approach could be easily modified to accommodate different devices such as Schottky varactors, whiskered HBVs or RTDs.

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