'Towards the Realisation of Space Borne Terahertz Waveguide Devices'

C M Mann, B J Maddison, D N Matheson, *M L Oldfield, B N Ellison

Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 OQX, UK

* University of Kent, Canterbury, Kent, UK

Abstract

A new method for assembling dot matrix Schottky diode mixing structures in a single moded terahertz waveguide is described. A novel integrated 'whisker-filter' has been developed which allows very low inductance whiskers to be implemented. The quasi-planar whisker/diode structure is extremely rugged and has obvious applications for space borne devices. In addition, the simple lithographic technique used to fabricate the whisker makes it ideal for applications in place of the more traditional wire whisker.

Introduction

Although open structure terahertz mixers have been reported with excellent sensitivity [1] there are good reasons for pursuing the development of terahertz waveguide devices. Waveguide devices can be built with near perfect antenna coupling, and this may be important in atmospheric sounder applications. It is easy to incorporate tuning elements into waveguide cavities, and a wide range of circuit embedding impedances can be implemented: this may allow greater flexibility in the choice of diode design than in current open structure devices. The frequency dependent nature of waveguide allows harmonic frequencies to be easily separated; this is an advantage when building harmonic mixers and multipliers. Finally, there is a vast heritage of waveguide design and fabrication techniques.

For these and other reasons waveguide devices are invariably chosen for low noise radiometers in preference to open structure devices at wavelengths longer than ~500 microns. However, the feasibility of terahertz waveguide devices depends crucially on the answers to three questions, and these will be considered in turn.

- Can mechanical cavities of suitable tolerance be manufactured?
- Are associated waveguide losses acceptable?
- Can a low inductance whisker contacting scheme be realised?

Firstly, it is clear that structures with suitable mechanical tolerance can be manufactured. Preliminary results reported elsewhere [2] show that corrugated feedhorns with good beam efficiencies can be manufactured at frequencies at least as high as 2.5 THz.

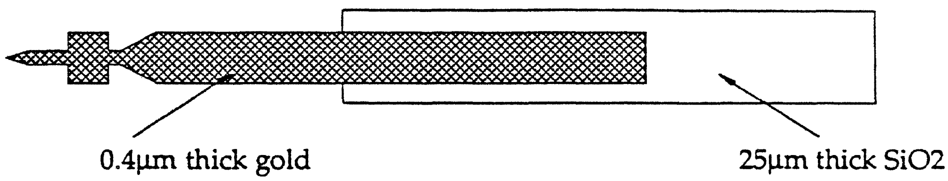
Waveguide and feedhorn loss, however, remains a concern and is currently being investigated. But there are good grounds for optimism. A simple estimate suggests that waveguide loss remains small compared with intrinsic mixer loss even at 3 THz, and we are encouraged by mixer conversion loss measurements which demonstrate that waveguide loss remains low at frequencies at least as high as 700 GHz. Of course, loss may be a strong function of waveguide surface finish and conventional machining techniques may not be adequate at terahertz frequencies: but in this case it should be possible to fabricate waveguide with mirror finish surfaces using standard lithographic techniques [3].

We therefore expect that it is realistic to scale the mechanical cavity. It is doubtful, however, whether a traditional wire whisker can be made sufficiently short to operate at terahertz frequencies because of excessive circuit inductance. For example, a simple calculation suggests that even a ~50μm long whisker will have a high inductance, and this will make it difficult to couple power efficiently to the diode. Furthermore, excessively short wire whiskers are often mechanically unstable, a problem exacerbated by the small area diodes which are inevitable at terahertz frequencies. In order to circumvent this problem we have developed and prototyped a new 'quasi-planar' whisker which is fabricated photolithographically.

The 'quasi-planar' whisker structure

The 'quasi-planar' whisker [4], a schematic diagram of which is illustrated in figure 1, has a number of potential advantages. For example, it can be made very short, is easy to fabricate and all dimensions can be specified to a very high tolerance (< 1 μm). Finally, the natural spring of the thin strip obviates the need for a bend in the whisker.

The Planar Whisker



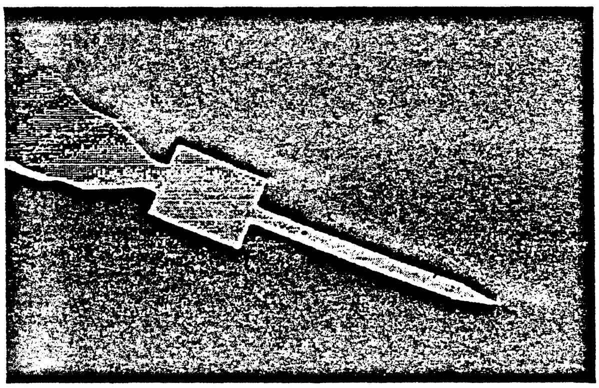


Figure 1

The fabrication process involves only straightforward lithographic techniques used in conjunction with some micro-machining carried out on a precision dicing saw, and is described as follows. The whisker is formed from a pure gold film which is deposited onto a quartz substrate using either evaporation or sputtering. The thickness of the film (and hence the whisker) determines the smallest diode that can be contacted: the whisker discussed here was made from an 0.4µm thick film. Thicker films have been tried successfully and we do not expect problems to arise from the use of even thinner films.

The basic form of the whisker is patterned into the gold using standard wet etch lithography. Wet etching has an unexpected advantage over dry etching in that it is not necessary to accurately reproduce the exact dimensions of the whisker tip in the photoresist used. This is due to the undercutting action of the gold etch resulting in a natural sharpening of the whisker tip.

Next, the whole substrate is mounted face down onto a carrier substrate using a proprietary wax. The back side of the quartz substrate is back lapped to the required thickness and a trench is cut directly behind the array of whiskers (figure 2).

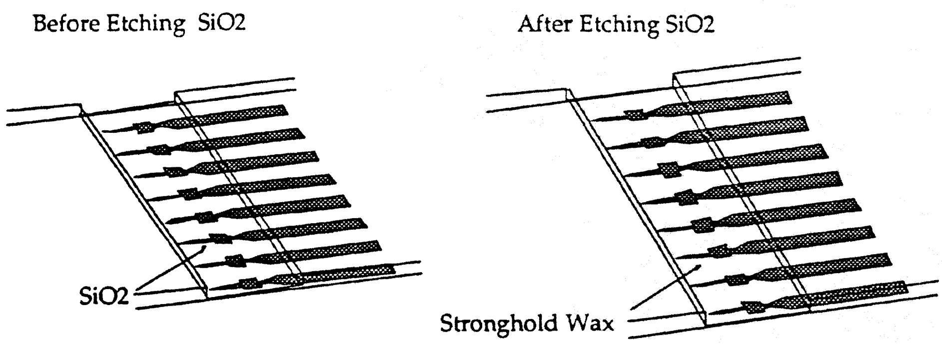


Figure 2

A few microns is left directly above the whiskers, and this is then completely removed using a standard quartz etch. The whisker array is then diced and all of the individual whiskers are then washed off the carrier substrate using acetone. By leaving the whisker attached to a quartz substrate, handling problems are greatly alleviated because by comparison the substrate is very large.

Large numbers of identical whiskers can be produced in a few hours, typically 100-200 in each run and this dramatically reduces the time required to assemble an RF device when compared with the traditional whisker.

The integrated whisker/RF filter

Whilst the whiskers described in the last section are useful for incorporating into standard millimetric or sub-millimetric devices it is a very simple step to integrate the whisker with another element of the circuit, in particular the RF/IF filter circuit upon which normally a diode chip or whisker is mounted. This simplifies the device construction procedure considerably (compared with using a normal wire whisker) and the size to which the components can be made is dependent only upon the photolithographic process used. Thus, it becomes relatively straightforward to fabricate RF circuits that have the low parasitics required for terahertz operation. A schematic diagram of such an integrated whisker/RF filter is shown in figure 3 and the prototype component fabricated using the technique previously described is shown in figure 4. In this example the dimensions of the whisker structure have been designed for operation at 2.5 THz.

For these novel whisker structures the substrate has been removed from underneath the four section RF/IF filter so as to avoid the presence of a dielectric in the microstrip filter channel where it breaks through into the waveguide. In order to demonstrate the electrical feasibility of this arrangement scale model measurements have been carried out. These show that this is a valid electrical structure, and that a good range of diode embedding impedances can be accessed by varying the 'whisker' length and/or the length of the first filter section.

The Integrated Whisker/ Filter

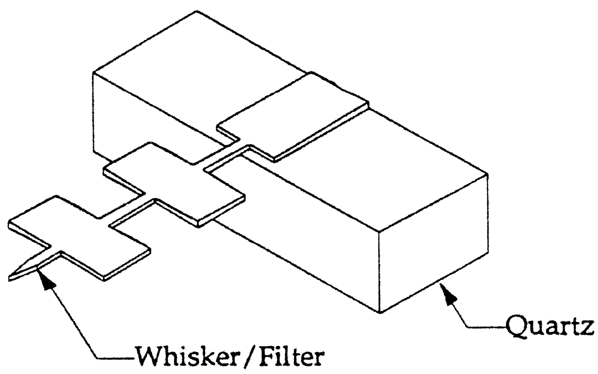


Figure 3

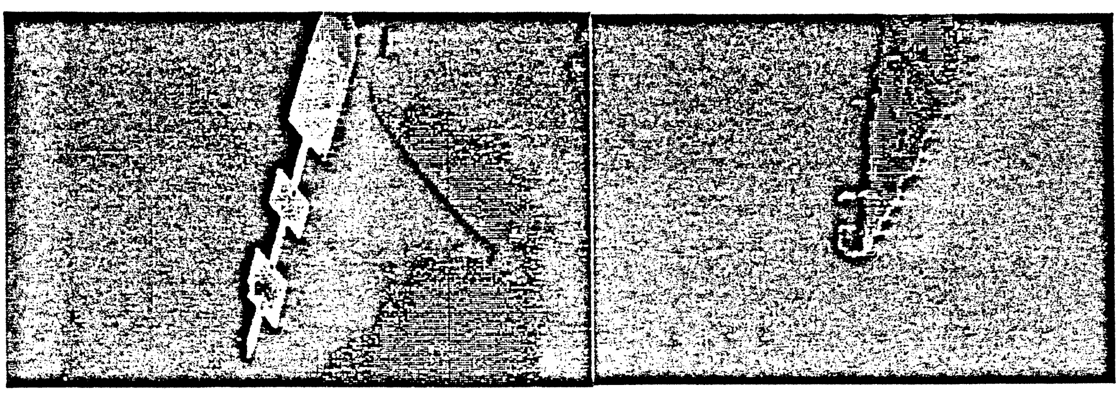


Figure 4

Diode contact tests

The mechanical feasibility of the whisker arrangement has been assessed by repeatedly contacting a dot-matrix diode in a simple test jig which allows diode and whisker to be positioned and contacted with sub-micron precision under an optical microscope, whilst monitoring the IV characteristic. A number of interesting and perhaps surprising features have been noted. Firstly, once a contact has been achieved it is possible to continue to move the diode and whisker together by many microns without changing the diode characteristic: rather, the whisker is observed to bend in a smooth arc along its length, and spring back flat once the pressure is removed. Secondly, even after repeated contacts the whisker tip remains essentially undamaged. The whisker/filter in figure 4 has made twenty diode contacts prior to this SEM photograph being taken. This behaviour is attributed to the 'two dimensional' nature of the structure: because it bends more readily than a wire whisker, the force on the diode tip and anode is dramatically reduced, thereby allowing it to be recontacted again and again. This behaviour has been observed with whiskers which are as thin as 0.4 μm. In similar circumstances the tip of a wire whisker (even when thinned to a few microns) rapidly blunts, shears, or punctures through the diode anode.

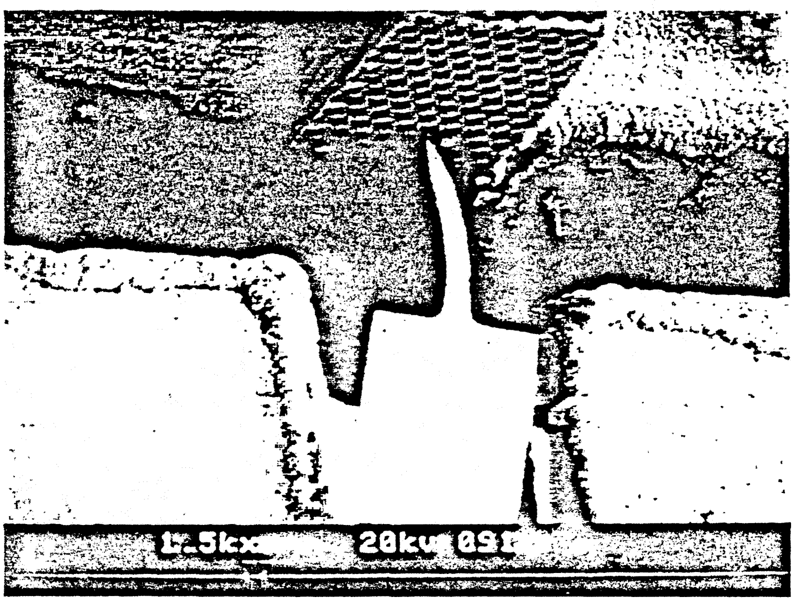
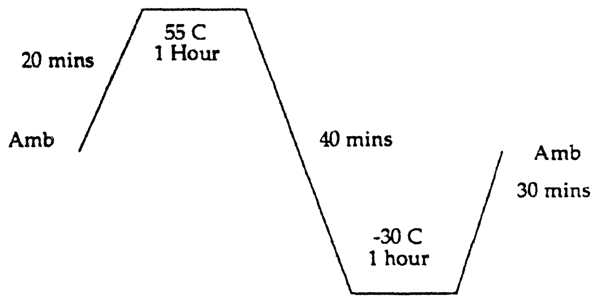


Figure 5

Once a contact has been established a small bend is left in the whisker to hold it in place, the quartz IF substrate is glued into the block and the final IF connection is made. Figure 5 shows a finished 'mixer circuit' fabricated in this way. In this example, which uses a whisker-filter similar to that in figure 4, the whisker is 25μm long. The mixer diode is a UVA 1H24, a type used in the UARS MLS space instrument, and was chosen for this test to demonstrate known contact reliability.

In order to be a realistic arrangement it is important that the whisker diode contact is rugged. We have therefore subjected the test structure to a series of rigorous environmental tests. These included a thermal test (described in figure 6).

Thermal cycle profile



12 Thermal cycles carried out.

Contact monitored throughout.

I/V characteristics taken at 55 C & -30 C.

Figure 6

No change was noted to the ambient IV characteristic. In addition to the thermal cycle the test structure was also put through a three axis vibration test. The vibration test specification is shown in tables I and II, and is believed to be representative of a 'typical' space application.

Vibration Test Levels

Table I

Sine	Frequency (Hz)	Level	Duration
All models	5 - 20.35	18 mm pk pk	1 sweep
	20.35 - 100 2 oct/min sweep	15 g	

As was the case with the thermal test, no change was observed to the IV. This was a very encouraging result and it is believed that this is the first time that a whisker contact suitable for terahertz operation has survived this level of testing.

Table II

Random	Frequency (Hz)	Level	Duration
Qualification level	20 - 50	+ 3 dB/Oct	3 Minutes
	50 - 300	0.3 g^2/hz	
	300 - 2000	- 3 db/Oct	
		15.7 GRMS	

Conclusion

In the course of investigating waveguide technology for terahertz applications we have developed a new type of 'quasi-planar' whisker technology which may permit the use of dot-matrix diodes in single moded waveguide at wavelengths as short as 100 μm. A representative whisker and RF/IF filter structure designed for use at 2.5 THz has been prototyped and used to contact various diode types in a mechanically realistic terahertz mixer test block. The whisker diode structure has been shown to be encouragingly rugged.

The new whisker technology has a number of other benefits. It is simple to make, does not require prior bending and can be handled with ease. Diode contact tests show that both anodes and whisker tip are extremely difficult to damage. If, as in the example described here, it is integrated with the RF/IF filter, circuit design and assembly is simplified and mechanically (and therefore electrically) similar circuit structures can be more easily repeated than is the case with wire whiskers.

We expect that the new whisker technology may find applications at lower frequencies. The tolerant mechanical behaviour, circuit simplicity and potential for making electrically similar structures are all attractive features.

Acknowledgements

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