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THE TINTIN PROJECT AND THE NEED FOR INTEGRATED ANTENNAS AT TERAHERTZ FREQUENCIES

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Abstract

The TINTIN project is a collaboration between four British universities to develop a new range of integrated terahertz components. On-chip metal-pipe waveguides incorporating active devices on GaAs wafers have been reported which can be used as building blocks for fabricating terahertz integrated circuits. Particular attention is being paid to integrated antenna structures to couple power between the on-chip waveguide and free-space beams.

1. Introduction

The Terahertz Integrated Technology Initiative (TINTIN) project is a collaboration between four British universities (Bath, Leeds, Nottingham, and Reading) to develop a range of active and passive terahertz components which can be combined on a single chip in integrated circuit form. Applications already exist at millimetre wave frequencies which would benefit from the introduction of such an integrated circuit technology, and further applications at terahertz frequencies are waiting to be exploited when a suitable cost-effective technology becomes available.

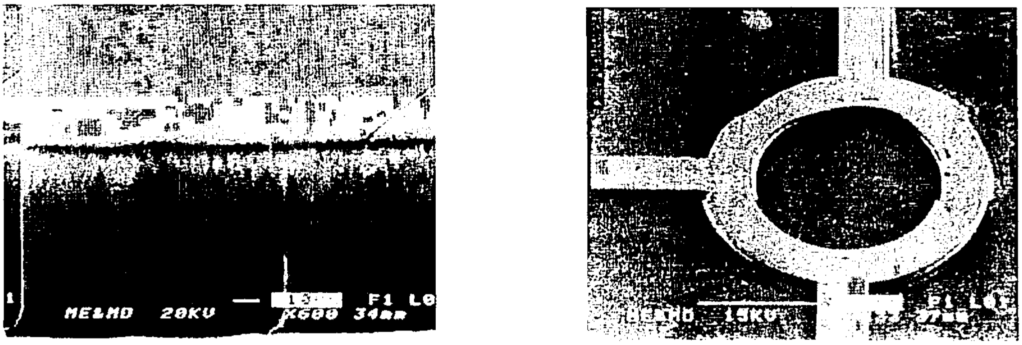
In the millimetre wave and terahertz frequency range, fundamental mode rectangular waveguide becomes increasingly difficult to machine due to its small size. The University of Bath has demonstrated a novel micro-machining technique for fabricating metal-pipe waveguides directly onto the surface of a semiconductor wafer [1] - a technology that could revolutionise the way in which devices and subsystems are constructed at millimetre wave and terahertz frequencies. These waveguides can be fabricated directly onto a semiconductor wafer containing the layers required for active devices to be incorporated directly into the on-chip guide. This has been demonstrated for a Schottky detector [2]. The viability of designing oscillators and power combining at millimetre wave and terahertz frequencies using resonant tunnelling diodes (RTDs) has previously been shown [3], [4], and such a device has been successfully integrated into an on-chip guide by the TINTIN team [5].

A technique is required for coupling power in and out of such on-chip metal-pipe waveguide structures. A mechanical connection to conventional waveguide would be difficult to achieve and also somewhat negate the ease-of-manufacture and low-cost benefits of this integrated technology. Consequently, an integrated antenna design is required which can be fabricated directly onto the on-chip waveguide using the micromachining techniques.

2. Terahertz On-Chip Metal-Pipe Waveguides

The on-chip waveguide is fabricated by firstly evaporating a layer of gold onto the surface of a semiconductor wafer to form the bottom wall of the guide. A photoresist former defining the internal cross-section of the waveguide is then produced on top of this layer using photolithographic techniques.

The former is coated in gold by evaporation or sputtering, and electroplated for extra strength. Subsequent removal of the photoresist with solvent leaves an air-filled gold-walled rectangular waveguide. Any shape of structure which can be produced on a photographic mask can be fabricated as a waveguide. Photographs of on-chip waveguide structures are shown in Figure 1. The walls must be at least a skin depth thick to avoid excessive power loss. The maximum height of the guide is governed by the thickness of photoresist former which can be produced, and is 80μm to date, corresponding to an eighth of full height at 200 GHz and full height at 1 THz. The loss per wavelength calculated, using formulae given in [6], for various heights of 1300μm wide guide for operation around 200 GHz is shown in Figure 2. It can be seen that, although reduced height guide is intrinsically more lossy than full height, the loss is still small for the lengths of transmission line involved at these frequencies.



(a) Detail of Waveguide Wall

(b) Waveguide Structure

Figure 1. Photographs of On-Chip Waveguide.

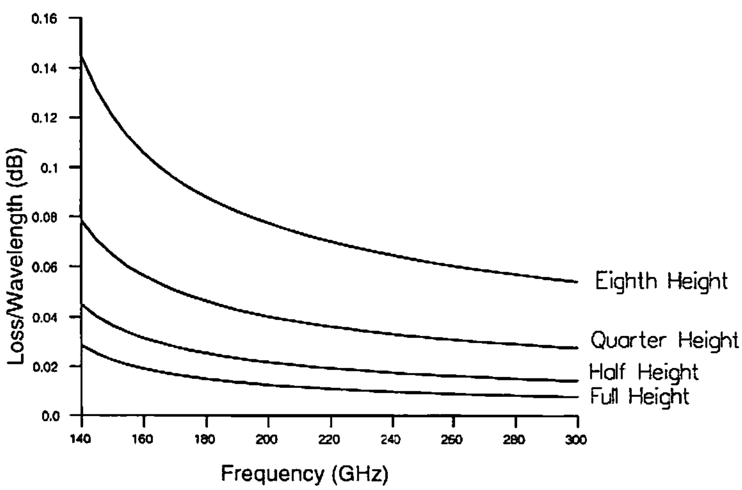


Figure 2. Loss per Wavelength for Various Heights of 1300μm Wide Fundamental Mode Rectangular Waveguide.

3. Integrated Active Devices

A GaAs/AlAs resonant tunnelling diode (RTD) has been integrated into a reduced-height waveguide. The RTD layers were grown by molecular beam epitaxy. An on-chip waveguide, such as described in Section 2, was then fabricated onto the same wafer, and a tapered plated via hole from the top wall of the waveguide through a hole in the bottom metallisation to the active device layers was used as a whisker contact. The arrangement of the waveguide and whisker contact are shown in Figure 3. The RTD demonstrates NDR behaviour consistent with oscillation at millimetre wave and terahertz frequencies. This device will be used in the design of integrated oscillators and mixers at millimetre wave and terahertz frequencies.

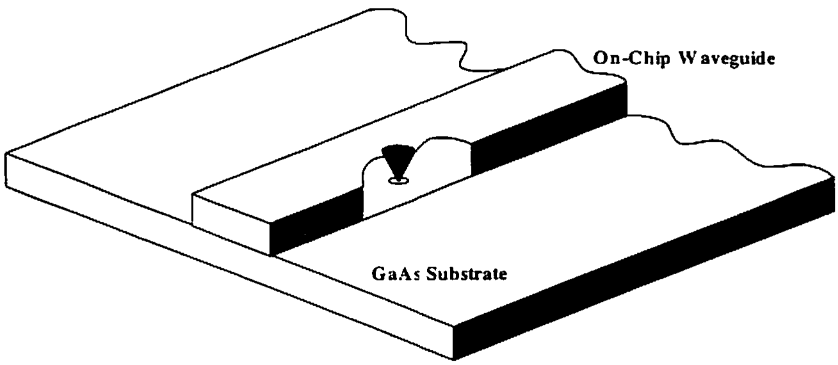


Figure 3. Plated Via Hole Whisker Contact to a GaAs/AlAs RTD in On-Chip Waveguide.

4. Integrated Antennas

A method of coupling power out of on-chip metal-pipe waveguides into free-space beams is required so that the terahertz integrated circuits can be used to design transmitters and receivers for future applications such as wireless LANs. This could be achieved by physically connecting the opening of an on-chip guide to a standard machined waveguide horn, however this would be difficult and expensive to manufacture, and therefore would counteract the philosophy of this technology. A dielectric waveguide probe to connect an on-chip guide to a standard guide was considered. This still required a mechanical connection, the dielectric itself would need machining, and also quarter height dielectric waveguide was found to be very lossy. An integrated antenna is therefore required which can be fabricated at the same time as the guide itself using the same micromachining techniques.

A horn antenna design can be fabricated on the ends of on-chip waveguides simply by defining the required shape in the mask set used to produce the photoresist pattern. Due to the limit on the maximum height of photoresist former which can be produced (80μm), it is only possible to flare the horn outwards in the H plane and not the E plane. This limitation should make only a small difference to the beam shape produced in the E plane, but a much larger difference to the H plane beam shape. Simulated H plane antenna patterns (using Hewlett Packard's HFSS) for horns flared in the E and H planes, and just the H plane, from quarter height waveguide are shown in Figure 4. It can be seen that the H-plane flared horn produces significantly poorer directive gain; techniques for improvement are presently under examination.

5. Conclusions

The universities involved in the TINTIN project are working together to introduce a new integrated circuit technology at terahertz frequencies. Micromachining techniques for fabricating rectangular waveguide structures directly onto semiconductor wafers have been successfully demonstrated, achieving maximum waveguide heights of 80μm. Although the reduced-height nature of these guides means that they exhibit greater loss than a full height guide, the loss is still small for the lengths of transmission line that would be used in integrated circuits at these frequencies, and they are substantially easier and cheaper to mass produce than using conventional techniques. They have the added advantage that any shape of structure which can be produced on a photographic mask, can be reproduced as a waveguide. Active devices can be incorporated directly into these waveguides as active components in integrated oscillators and mixers. This has been demonstrated with a Schottky detector and resonant tunnelling diode.

Integrated antennas are required so that the on-chip terahertz components can be used in transmitter/receiver systems. It is not possible to fabricate a horn antenna with an E-plane flare due to the restriction on the maximum height of on-chip waveguide that can be produced. A horn with a flare in the H-plane only does not give a very directional beam, and improvements to this design are currently being pursued.

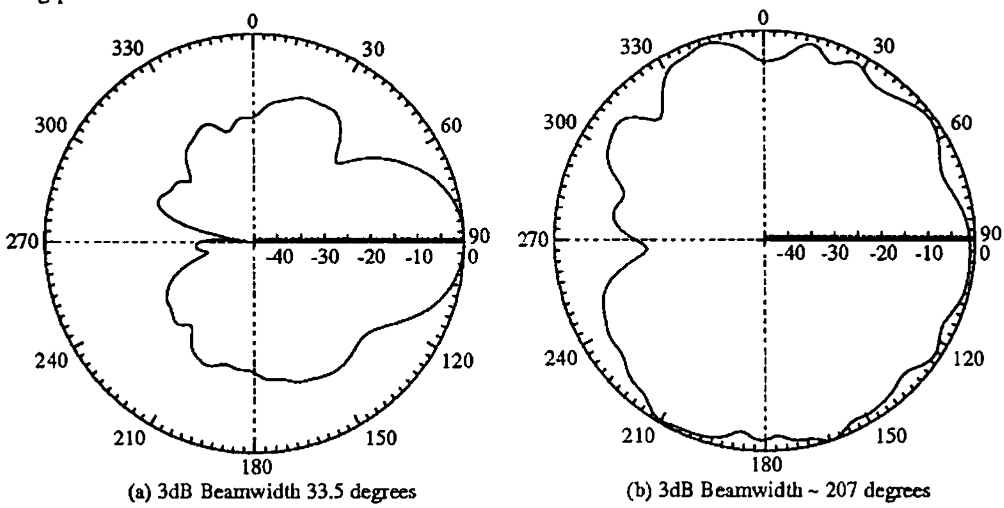


Figure 4. Simulated Far-Field Pattern of (a) E and H Plane, and (b) H-Plane Only, Flared Horns Fabricated On Quarter Height Fundamental Mode Rectangular Waveguide.

6. Acknowledgements

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7. References

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