Integrated Micro-Machined Antenna for 200 GHz Operation

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ABSTRACT

A new integrated micro-machined slotted horn antenna is reported which has been fabricated on a GaAs substrate. The far-field pattern has been simulated and measured showing good agreement, and the antenna has been used to successfully couple power in and out of a micro-machined rectangular waveguide.

INTRODUCTION

The dimensions of conventional rectangular waveguide at millimetre wave and terahertz frequencies become very small, therefore it is expensive, and difficult to mass produce. The use of micro-machining techniques to fabricate rectangular metal-pipe waveguides directly onto semiconductor wafers has been previously reported [1] in order to reduce cost and increase manufacturability. This has the added advantage that active devices can be incorporated to facilitate low-cost integrated circuit production at these high frequencies [2], [3]. A significant effort has gone into the design of submillimetre-wave integrated antennae in recent years in order for a wide range of applications to begin to exploit the large bandwidths available [4], [5], and these applications would benefit from the integrated circuit technology reported here.

In order for these integrated components to be useful, a technique is required for coupling power in and out of on-chip rectangular waveguides into free space beams [6]. An integrated micro-machined slotted horn antenna is reported here which has been fabricated onto the end of a micro-machined waveguide for use at G-band (140 GHz - 220 GHz). The antenna pattern has been simulated using a 3D electromagnetic field solver and measured with a quasi-optical measurement system [7]. Power has successfully been coupled into and out of this waveguide with integrated antennae fabricated on each end.

INTEGRATED ANTENNA FABRICATION

A length of waveguide with slotted horn antennae attached to it has been fabricated using the process outlined in Figure 1. A layer of titanium and then gold is first evaporated onto the substrate to form the bottom wall of the horn and waveguide, (i), and a 100μm thick layer of photoresist is spun on top of this gold layer, (ii). This is the maximum thickness of photoresist which has been successfully produced to date and corresponds to just over 1/8th height waveguide at 200 GHz. This thick film is then exposed and developed to define the shape of the outside walls of the waveguide using standard photolithographic techniques, (iii). Another layer of gold is evaporated on top of the photoresist former and

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then electroplated for extra strength, (iv). A thinner layer of photoresist is sprayed over the structure and baked, (v). This second resist layer is then exposed and developed using a second mask, with alignment marks, to accurately reveal a slot in the top of the resist, (vi). The exposed gold is then etched away to produce a slot in the top of the horn antenna, (vii). Removal of all the photoresist with solvent leaves an air-filled rectangular waveguide integrated with a slotted horn antenna, (viii). A photograph of a waveguide with an integrated antenna at either end produced using this technique is shown in Figure 2.

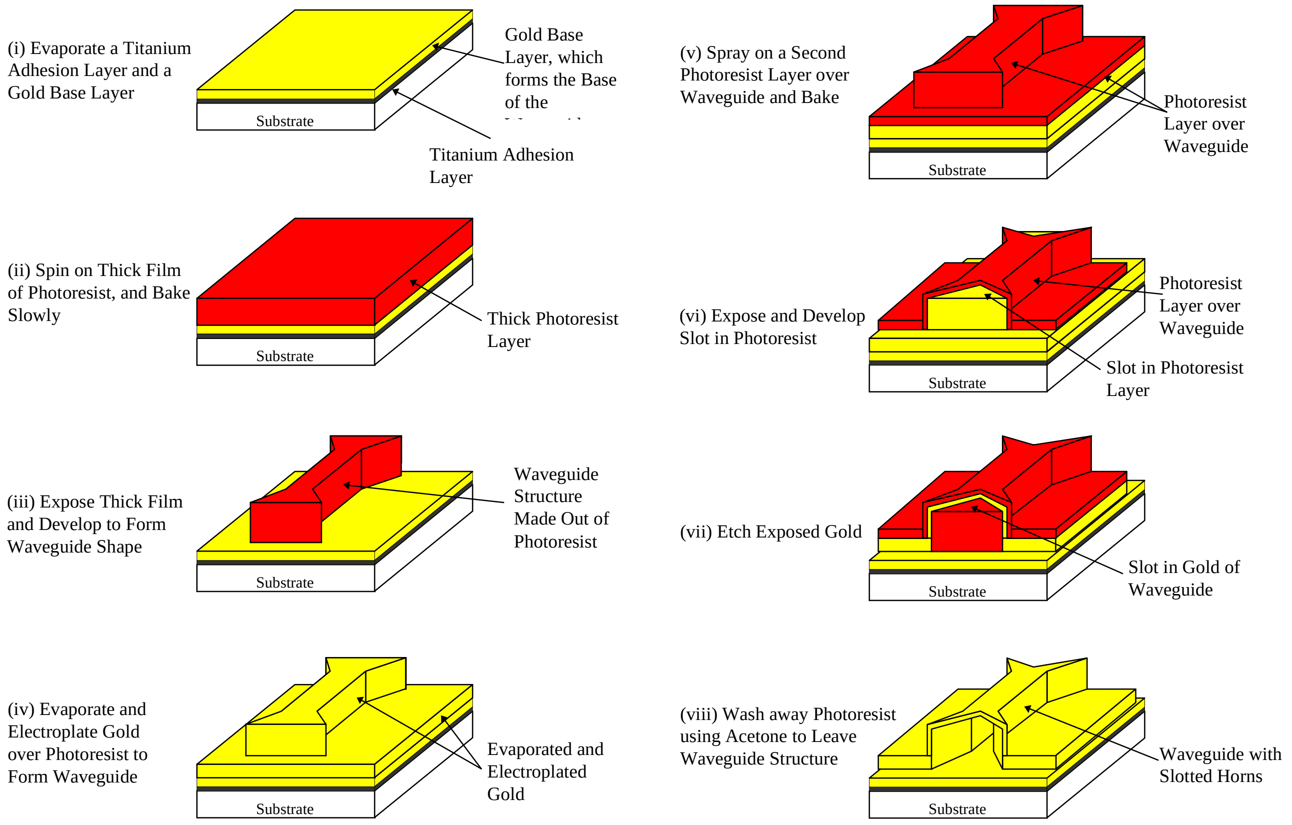

Figure 1. Fabrication of G-Band Waveguide with Slotted Horn Antennae Using Micro-machining Techniques

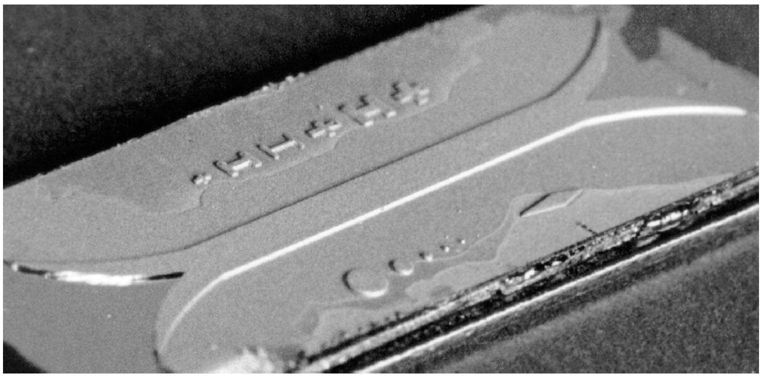

Figure 2. Photograph of Micro-machined Waveguide and Antennae.

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SIMULATED AND MEASURED RESULTS

The far-field antenna pattern of various slotted horn designs were simulated using a 3D electromagnetic field solver. An exponentially flared horn and slot with the dimensions shown in Figure 3 were found to provide the best far-field pattern. Two integrated antennae joined by a length of micro-machined waveguide were fabricated using the technique described in Section 2 and a quasi-optical measurement system [7] was used to couple power into this structure. Some preliminary measurements of the far-field pattern of the antenna were performed by measuring the power emerging from the output horn. Figure 4 shows the simulated and measured far-field patterns in the vertical plane. It can be seen that the beam radiates out of the slotted horn at an angle of approximately 27° upwards from the horizontal. Consequently, Figure 5 shows the simulated and measured horizontal far-field pattern at this elevation angle.

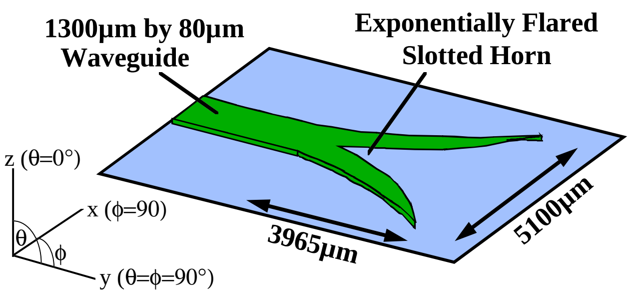

Figure 3. Diagram of Integrated Antenna Design

The noise floor in the measurements occurs below -20dB for the vertical plane and at approximately -10dB for the horizontal plane due to the measurement set-up and the low output power of the source used. It is hoped to reduce these levels in future measurements.

Good agreement between the measurements and simulations can still be seen with both sets of data showing approximately the same elevation angle of 27° for the main beam and a 3 dB beamwidth of 31° in the vertical plane. Also, the horizontal plane results agree on a 3 dB beamwidth of 23°.

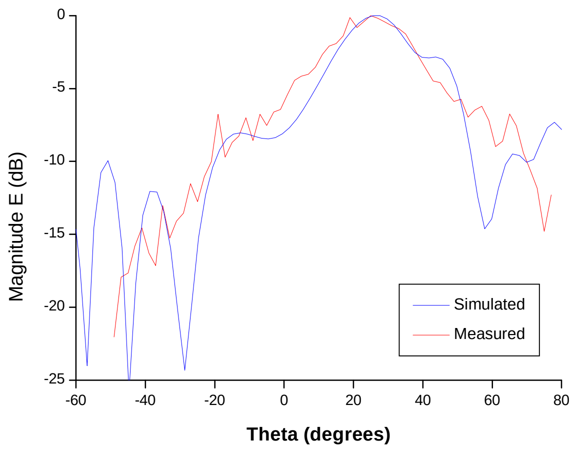

Figure 4. Vertical Plane Co-polar Far-field Pattern for Integrated Antenna at 200 GHz.

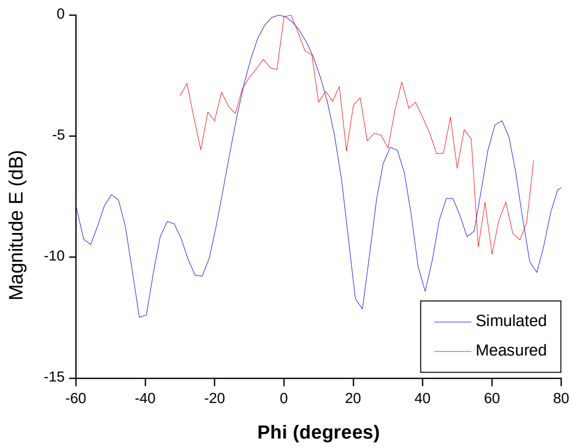

Figure 5. Horizontal Plane Co-polar Far-field Pattern at Elevation Angle of 27° for Integrated Antenna at 200 GHz.

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CONCLUSIONS

A new slotted horn integrated antenna for operation in the 140 GHz to 220 GHz band has been fabricated and its far-field pattern has been both simulated and measured. The measurements show a satisfactory 3dB beamwidth and agree well with the simulated results. The main beam points upwards out of the horn at a 27° elevation angle. Two of these integrated antennae have successfully been used to couple power into and out of a micro-machined waveguide and tested using a quasi-optical measurement system. The same antenna design may be used at higher frequencies in the future by scaling down the dimensions, and the performance is expected to improve as the waveguide height approaches closer to full height. The antenna will also be integrated with future active and passive micro-machined components for use in terahertz systems.

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REFERENCES

[1] A. S. Treen and N. J. Cronin, "Terahertz Metal Pipe Waveguides," in *Proc. of the 18th Int. Conf. on IR and Millimeter Waves*, pp. 470-471, Sept. 1993.

[2] D. A. Brown, A. S. Treen, and N. J. Cronin, "Micromachining of Terahertz Waveguide Components with Integrated Active Devices," in *Proc. of the 19th Int. Conf. on IR and Millimeter Waves*, pp. 359-360, Oct. 1994.

[3] G. M. Parkhurst, D. A. Brown, J. M. Chamberlain, J. R. Middleton, N. J. Cronin, C. Collins, R. D. Pollard, R. E. Miles, D. P. Steenson, J. Bowen, and M. Henini, "Integrated Resonant Tunnel Diode," in *Proc. of the 20th Int. Conf. on IR and Millimeter Waves*, Florida, Dec. 1995.

[4] G. M. Rebeiz, "Millimeter-Wave and Terahertz Integrated Circuit Antennae," *Proc. IEEE*, vol. 80, no. 11, pp. 1748-1770, Nov. 1992.

[5] L. P. B. Katehi, "Novel Transmission Lines for the Submillimeter-Wave Region," *Proc. IEEE*, vol. 80, no. 11, pp. 1771-1787, Nov. 1992.

[6] C. E. Collins, R. D. Pollard, R. E. Miles, D. P. Steenson, G. M. Parkhurst, J. M. Chamberlain, N. J. Cronin, and J. W. Bowen, "The TINTIN Project and the Need for Integrated Antennae at Terahertz Frequencies," in *Proc. of 1996 Int. Symp. Antennae and Propagation*, pp. 1229-1232, Chiba, Japan, Sept. 1996.

[7] J. W. Bowen, L. S. Karatzas, J. M. Chamberlain, N. J. Cronin, R. E. Miles, R. D. Pollard, and D. P. Steenson, "A Quasi-Optical Measurement System for the Characterisation of Terahertz Integrated Component," in *Proc. of the 20th Int. Conf. on IR and Millimeter Waves*, Florida, Dec. 1995.

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