MONOLITHIC SCHOTTKY DIODE IMAGING ARRAYS AT 94 GHZ

Zeev Rav-Noy, Chung-en Zah, Uri Shreter,
David B. Rutledge
California Institute of Technology
Pasadena, CA 91125

Tai-Chi Wang and S. E. Schwarz
Dept. of Electrical Engineering and
Computer Science
University of California, Berkeley, CA 94720

Thomas F. Kuech
IBM Thomas J. Watson Laboratories
Yorktown Heights, NY 10598

Abstract

Monolithic GaAs Schottky diode imaging arrays have been demonstrated at 69 and 94 GHz. In the 94 GHz experiments, the diodes are fabricated by a self-aligning technique on semi-insulating GaAs and are isolated by a combination of a mesa-etch process and proton-bombardment. The series resistance is 20 Ω and the estimated capacitance is 15-20 fF. The antennas are planar bow-ties, and power is coupled in through a quartz lens placed on the back of the GaAs substrate. The wafer is lapped to 90 μm thick to eliminate losses to substrate modes. The measured system responsivity is 330 V/W. The 69 GHz diodes are made by a non-self-aligned process, and a silicon substrate lens is used.

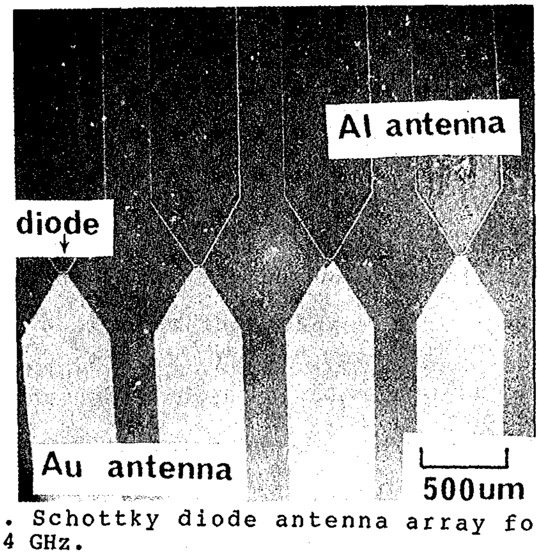
Millimeter Wave Arrays

Millimeter-wave systems are less affected by smoke, fog, and dust than infrared imagers, and have the potential for better resolution than microwave radars. Since atmospheric absorption is relatively low at 94 GHz, radars and receivers at this frequency should fill a gap between microwave radars and infrared imagers [1]. Murphy et al. [2,3] made an important step in this direction by combining a planar low-capacitance Schottky diode on semi-insulating GaAs with a slot antenna. They made an excellent mixer by mounting this device in a hollow-metal waveguide. Without the waveguide, the responsivity was reduced (possibly because of coupling to unwanted substrate modes) to 40 V/W at 75 GHz [2]. Neikirk et al [4] demonstrated another antenna approach where power is coupled through a substrate lens onto an array of planar bow-tie antennas. The lens eliminates the losses to substrate modes, and 50% of the available power is coupled into the array.

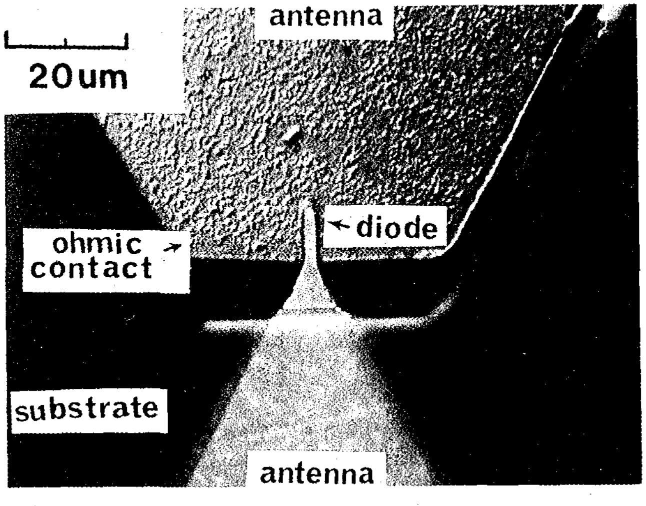
In this work we have combined the two approaches, integrating monolithic Schottky diodes with planar antennas and substrate lenses. Fig. 1 is a photomicrograph of the 94 GHz array. The diodes are at the apex of the bows, and the antennas extend to form the low-frequency leads. The GaAs wafer has been lapped to a thickness 90 μm to eliminate substrate modes. The GaAs wafer acts as an assymmetric dielectric waveguide, with air on one side and the quartz substrate lens on the other. Assymmetric guides are different from symmetric guides in that all modes have a cutoff thickness. The spacing between the antennas is set to half the wavelength in quartz, 0.75 mm, to achieve the potential resolution of the optics [4].

Schottky Diodes

Fig. 2 is a photograph of one diode in the array. The Schottky contacts are aluminum evaporated on a lightly doped n region, while the ohmic contacts are a thin sheet of Au-Ge alloy underneath a thicker sheet of Au, deposited on a n+ region. The goal of the fabrication process is to have the n+ layer as thick as possible, while maintaining a planar structure. The diodes and antennas are isolated from each other



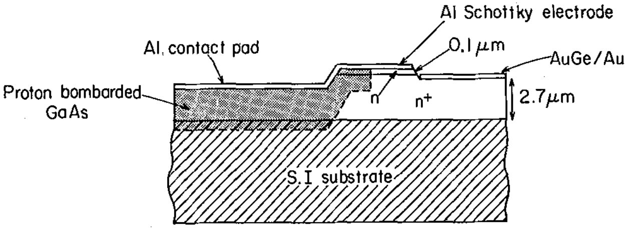
1. Schottky diode antenna array for 94 GHz.



2. Top view of a Schottky Diode in the array.

by two steps: an etch removing part of the n+ layer and a proton bombardment converting the rest to semi-insulating material. Diodes were made from semi-insulating wafers with epitaxial layers grown both by metal-organic chemical vapor-phase deposition (MOCVD) and liquid-phase epitaxy (LPE), but we describe only the fabrication process for the MOCVD wafers.

Fig. 3 shows cross-section of the diode and the epitaxial layers. The bottom n+ layer for the ohmic contact is 2.7 µm thick, with a doping of $1\text{x}10^{18}\text{cm}^{-3}$. The top n layer for the Schottky contact is 0.1 µm thick, with a doping of 10^{17}cm^{-3}. The Schottky contact area and the ohmic contact area (see Fig. 2) are masked with photoresist, and the wafer is dipped in a sulfuric acid-hydrogen peroxide etch (1:8:8 H_2SO_4:H_2O_2:H_2O) to remove the n layer and a micron of the n+ layer. Next an 80 nm layer of Si_3N_4 is deposited and the diode area is masked against the proton bombardment with a layer of photoresist 3.5 µm thick. The wafer is bombarded with 240 keV protons at a dose of $5\text{x}10^{14}\text{cm}^{-2}$ to convert the rest of the exposed n+ layer to semi-insulating material. The wafer is thoroughly cleaned to remove the photoresist and the silicon nitride, leaving a clean GaAs surface to evaporate 300 nm of Al for the Schottky contact.



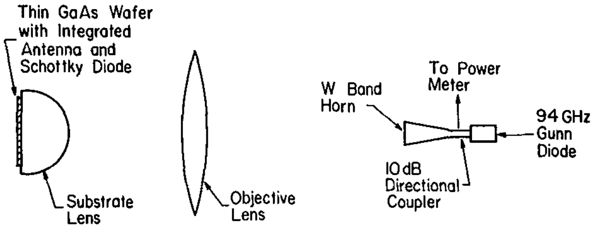
3. Cross-section of the Schottky diode

The diode active area (2.5 µm x 8 µm) is defined by a single photoresist pattern. First the aluminum layer and then a portion of the n layer etched away from the ohmic contact area, and then the ohmic contact is made by liftoff. The wafer is heated to 420°C for 30 seconds to alloy the contacts. Now the diodes are finished, and the wafer is lapped from a thickness of 350 µm to 90 µm. The chip is glued to a quartz substrate, and the low-frequency wire bonds are attached. The estimated zero-bias capacitance is 15-20 fF, the measured series resistance is 20 Ω, and the ideality factor is 1.3. The estimated cutoff frequencies are in the range 500-700 GHz. Breakdown voltages of -6V and 3 nA leakage currents at -2V are typical.

The 69-GHz devices are made by a conventional non-self-aligned method on materaial with a 1-micron-thick n+ buried layer. The resulting diodes have ideality factors approaching 1.0 and reverse breakdown voltages greater than ten volts.

94 GHz Measurements

Fig. 4 shows the set-up for measuring the video responsivity. The signal is generated by a Gunn diode that is square-wave modulated at 1 kHz, and the power is measured by an HP432A power meter with a Hughes 45776H thermistor mount. The signal radiates from a Hughes 24-dB standard-gain horn, and the receiver is in the far field 2 m away. An objective lens (TPX plastic with a 50mm focal length and a 48mm aperture) focuses the signal onto the array through the quartz substrate lens. The power incident on the lens is calculated from standard antenna formulas. The diodes are biased to 30 µA. The best system responsivity measured was 330 V/W. The noise-equivalent power (NEP) is $6\text{x}10^{-11}$ W/Hz$^{1/2}$ at a modulation frequency of 100kHz.



4. Quasi-optical set-up for 94 GHz measurements.

Acknowledgements

We appreciate the support of the Army Research Office under grants DAAG29-82-K-0165 and DAAG29-82-K-0166, Department of Energy, and U.S. Army MERADCOM. Zeev Rav-Noy acknowledges the support of a Bantrell Fellowship. Drs. Dean Neikirk and C.C. Chang, and D. D'Avanzo made valuable suggestions, and Prof. William Bridges at Caltech and Prof. Neville Luhmann at UCLA have been exceedingly generous in loaning us equipment. Hewlett-Packard Corp. generously provided epitaxial GaAs material.

References

[1] G.A. Gordon, R.C. Hartmann, P.W. Kruse, "Imaging-Mode Operation of Active NMMW System," in Infrared and Millimeter Wave, K.J. Button, ed., Academic Press, N.Y.

[2] R.A. Murphy, C.O. Bozler, C.D. Parker, H.R. Fetterman, P.E. Tannenwald, B.J. Clifton, Y.P. Donnelly and W. Lindley, "Submillimeter Heterodyne Detection with Planar GaAs Schottky diodes," **IEEE Trans. Microwave Theory,** vol. MTT-23, no. 6, June 1977.

[3] B.Y. Clifton, G.D. Alley, R.A. Murphy and I. H. Mroczkowski, "High Performance Quasi-Optical Monolithic Mixer at 100 GHz," **IEEE Trans. Electron Dev.** ED-28, no. 2, pp. 155-157, Feb. 1981.

[4] D.P. Neikirk, D.B. Rutledge, M.S. Muha, "Far Infrared Imaging Arrays," **Appl. Phys. Lett.,** 40(3), Feb. 1982.