20 GHz GaAs IMPATT DIODE DEVELOPMENT FOR SOLID STATE TRANSMITTER*

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ABSTRACT

Double drift Read GaAs IMPATT diodes were fabricated for K Band from high quality MBE material. Single diode oscillator performance of 4.36W output and 19% efficiency were obtained at the flange of a reduced height cavity. A maximum power of 5.37W was obtained at a reduced efficiency.

INTRODUCTION

Efficient and reliable solid state components are required for future satellite communications applications. High efficiency and high output power IMPATT diodes are essential for the development of solid state power sources. GaAs IMPATT diodes have been designed, fabricated and evaluated for operation at 20 GHz. High quality double drift Read (DDR) profile GaAs layers were grown by molecular beam epitaxy (MBE). The profile design was evaluated by large signal computer simulation. Diodes were processed and packaged in 'pill' configuration. A reduced height cavity was used to evaluate the rf performance. The objectives of this program were 4.5 Watts of rf output power and an efficiency of 20%.

DIODE FABRICATION

At 20 GHz, a double drift Read doping profile provides the highest efficiencies in GaAs IMPATTs. Large signal computer simulation at TRW and elsewhere[1] have given efficiencies greater than 25%. These results do not include series resistance which when included reduce the predicted values to approximately η=20-22%. The 20 GHz DDR doping profile is shown in Figure 1. The complex eight layer structure is well suited for the MBE process. The sharp profile is essential for obtaining high efficiencies. The MBE epitaxial process inherently has low substrate temperature and slow growth rate. The Varian MBE 360 at TRW utilizes two Si sources for donors and two Be sources for acceptors. The multiple furnace configuration provides the sharp transitions in the LO-HI-LO profile that are necessary for high efficiency IMPATTs. A secondary ion mass spectroscropy (SIMS) scan of sample 302 can also be seen in Figure 1. The sharp, well defined features of the doping profile are easily seen in this figure. Microprocessor control of furnace shutters provides for exact and reproducible doping profiles. The MBE material was characterized by C-V profiling, SIMS analysis and Hall measurements. The net effective doping profile measured by C-V techniques provides a sensitive and convenient method of monitoring the doping levels and layer thicknesses. Across-the-wafer uniformity of better than five percent in breakdown voltage is routinely obtained. Electron and hole mobilities of the drift

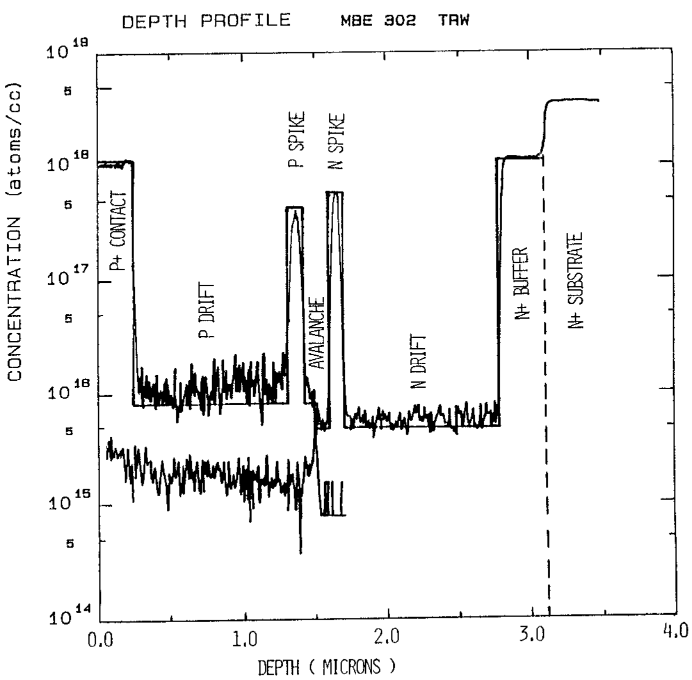

FIGURE 1 Doping profile and SIMS analysis of 20 GHz IMPATT diode.

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regions are at the theoretical level; μ_n=6500 cm^2/V-sec at T=300°K for N_D(Si)=1.5E16 cm^{-3}. A series of epilayers were grown around the simulated 'optimum' profile by varying the doping levels and layer thicknesses.

Diodes were fabricated by the standard TRW baseline GaAs IMPATT process. A Pt-TiW-Pt-Au p+ contact metallization was employed. This surface was TC bonded to a gold plated Type IIA diamond heatsink. The top metallization utilized a AuGe-Au ohmic contact. The single mesa diodes were packaged using the TRW 'pill' technique with ceramic rings and cross ribbons. A packaged diode is shown in Figure 2.

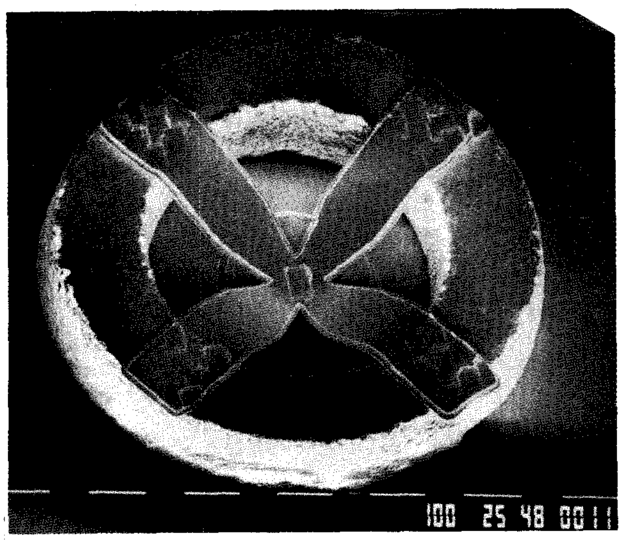

FIGURE 2. SEM photograph of IMPATT diode package.

RF CIRCUIT

To obtain maximum diode output power, a properly designed cavity is essential. One of the most important factors affecting the diode output power is the impedance match between the diode and the circuit. Because the IMPATT diodes developed at TRW are very low impedance devices (on the order of one ohm), the circuit must present a compatibly low coaxial impedance to implement the best match possible. Then the circuit must be designed so that it may transform this low impedance to the very high impedance (350-450 ohms) of the full height waveguide output.

The circuit used for RF evaluation of the 20 GHz GaAs diodes is the reduced height waveguide circuit shown in Figure 3. The diode is located in the center of the floor of the waveguide at the bottom of a coaxial well. The impedance transform is performed over two sections. First, a low coaxial impedance (~0.8 ohms) is presented to the diode in the coaxial section. To achieve this low impedance the center conductor was enlarged to a diameter just slightly smaller than that which would produce higher order modes of oscillation in the coaxial section. An extremely tight fit of the inner to outer conductor aided by a very thin dielectric insulator (<1 mil) allows this low impedance. The first impedance transform occurs in this coaxial well with the use of the transformer shims. With enlarged holes in the transform shims, gradually the impedance rises away from the diode. The second impedance transform occurs in the waveguide output section after the coaxial to waveguide transition. This impedance transformation is made up merely of two quarter wave waveguide sections stepped up in height to the WR-42 full height waveguide. Since the value of the characteristic impedance Z_0 is proportional to the waveguide height b, this quarter wave transformer gradually increases the impedance according to the height of the waveguide section. The bandwidth for this transformer was found to be sufficiently greater than 4 GHz using only 2 steps as shown in the figure.

An improvement incorporated into the circuit to increase the performance is the low pass filter located in the bias line above the top wall of the waveguide. This filter serves a variety of functions. It provides dc isolation for the bias line, it provides the proper harmonic terminating impedances, and most importantly it establishes an additional tuning element required to stabilize the diode at its operating frequency.

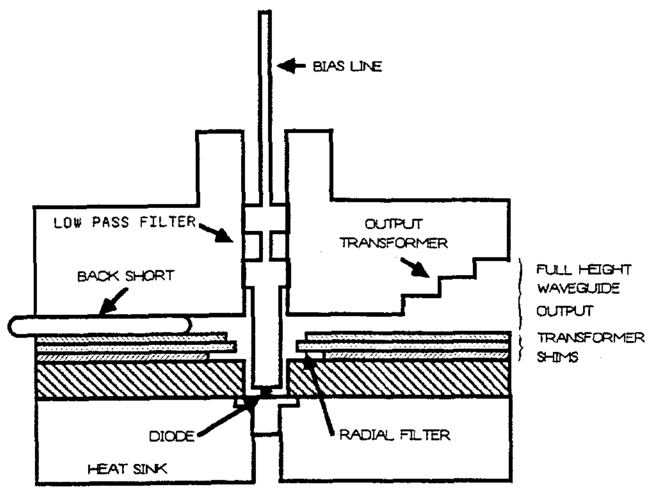

FIGURE 3. Reduced height wavequide cavity for 20 GHz GaAs IMPATT.

With the development of high power 20 GHz GaAs IMPATT diodes at TRW it became a common occurrence that the oscillator circuit using these devices would saturate in power at high bias levels. This is a phenomenon not well understood which manifests itself in a decrease in power output with an increase in bias drive after a sufficiently high bias has been achieved. It is suspected that this result is due to oscillations on the bias line or subharmonic oscillations in the circuit producing power at undesirable frequencies and thus sacrificing power output at the fundamental. In an effort to reduce the effects of this phenomenon we first attempted to diminish bias oscillation by using Brackett's method.[2] A dc pass, rf choke was put into the bias line but no change was observed in the power saturation. Next we focused on addressing the problem of generation of subharmonic oscillations in the circuit. In an effort to prevent oscillations at the first subharmonic frequency a radial filter was implemented in the coaxial well of the bias line beneath the floor of the waveguide. Unlike our attempt at using Brackett's method, this filter was placed as close as possible to the diode to stem the build up of subharmonic oscillations close to the diode plane. With the filter implemented the diode bias could be driven higher and power output increased as much as 2 db before power saturation occurred.

RF PERFORMANCE

With this reduced height circuit a maximum dc-to-rf conversion efficiency of 19.03% has been achieved with a power of 4.36 Watts using a single GaAs IMPATT diode. In addition, a maximum power output of 5.3 watts has been achieved. These results are reported as measured at the oscillator cavity waveguide output flange. The performance data is summarized in Figure 4.

Diode	Highest Efficiency(%)	Power (W)	Frequency (GHz)
DKR26M-1	19.03	4.36	18.08
DKR26C-5	18.3	3.80	18.09

Diode	Highest Power (W)	Efficiency(%)	Frequency (GHz)
DKR21F-4	5.37	15.5	18.28
DKR26C-15	4.78	16.1	19.93
DKR26B-4	4.67	14.1	19.10
DKR6M-1	4.67	18.3	18.12
DKR26C-5	4.57	15.2	20.99

FIGURE 4 Summary of rf performance at 20 GHz.

THERMAL RESISTANCE

The results reported herein were obtained with junction temperatures of less than 250°C. At TRW, we make thermal resistance measurements using three different methods. All involve pulsing the devices, measuring the voltage response as the junction heats or cools, and then comparing against a known reference. For these 20 GHz GaAs IMPATT diodes, thermal resistance values were measured as low as 7°C/W. Typical values for the better diodes evaluated are in the 10-15°C/W range.

1. R.K. Mains, et al., "Comparison of Theoretical and Experimental Results for Millimeter Wave GaAs IMPATTs." IEEE ED-31, p.1273, 1984.

2. C. A. Brackett, "The Elimination of Tuning-Induced Burnout and Bias Circuit Oscillation in IMPATT Diode Oscillators", Bell System Technical Journal, March 1973, Volume 52, Number 3.