GaAs IMPATT DIODES PULSED AT 40 GHz*

M. G. Adlerstein and S. L. G. CHu

Raytheon Research Division
Lexington, Massachusetts 02173

Abstract

Gallium arsenide double-drift Read IMPATT diodes are under development for use at 40 GHz. Such diodes have offered higher efficiency and average power than silicon diodes. The advantage may be ascribed to both the intrinsic properties of GaAs and the more complex doping structures used. In this paper, we describe diodes which give 16 W peak power at efficiencies up to 15%. Duty cycles between 5% and 30% have been employed at various peak power levels.

The techniques used to design the double Read doping profiles and their resulting microwave properties are discussed. The characteristics of the Kurokawa test circuit are described in terms of measured S-parameters.

Introduction

GaAs double-drift IMPATT diodes are presently under development for use in the millimeter wave region. CW diodes on diamond heat sinks at 44 GHz have given efficiencies up to 18% with power levels as high as 2.8 W. Higher powers are available, but junction temperatures have been held to 250°C or less to enhance the reliability of the devices.

In pulse operation, where the average temperature rise is reduced by the duty cycle of the pulse, one can expect considerably higher peak power. In this paper, we describe diodes which gave 16 W peak power at efficiencies up to 15% at 40 GHz.

Diode Design

The devices used in our work were beam lead single mesa chips mounted on copper heat sink puck packages. The doping profiles were double-drift Read structures (1). The total active region is about 0.8 micron wide.

In an oscillating diode biased at high current density (around 18 KA/cm^2), the static electric field distribution is modified by time dependent space charge. However, the doping profile is still found to play a crucial role in determining device efficiency, η. We studied the doping profiles of diodes we tested to choose that which gave the best efficiency.

A clear correlation of efficiency with doping profile emerges when the diodes are categorized by operating voltage. The operating voltages are higher than the room temperature voltages due to the combined effects of heating and space charge resistance (2). In lower operating voltage diodes, below 22 V, significant portions of the drift zones remained undepleted, yielding excess parasitic series resistance rather than active volume for generation of microwave power.

At operating voltages above 25 V, efficiency again decreased since the excess dc voltage was not accompanied by a corresponding increase in maximum rf terminal voltage, (1) $(V_{rf})_{max}$.

Diodes were tested to their avalanche resonance limited input power. The condition of avalanche resonance as a function of bias current density is defined as that current density where the microwave admittance of the IMPATT at the test frequencies vanishes. At this current density, the inductive and capacitive susceptances of the avalanche zone cancel (2).

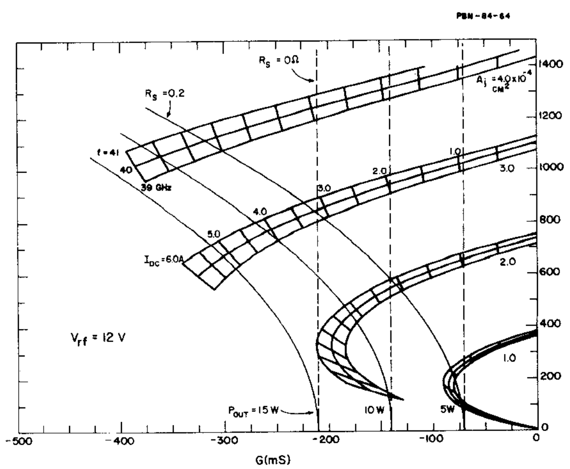

Figure 1. Calculated admittance and power contours for diodes under study.

The effect is seen clearly in Figure 1. Here, an analytical model (1,3) is used to calculate device admittance Y = G + jB as a function of bias current for various junction areas with $(V_{rf})_{max}$ = 12 V.

0149-645X/84/0000-0187 $01.00 © 1984 IEEE

The power available at the chip is given by

$$P = \frac{1}{2}\left(|G| - R_s B^2\right)\left[(V_{rf})_{max}\right]^2 \quad (1)$$

where R_s is the parasitic series resistance (1,4), Loci of constant power for two values of R_s are superimposed on the admittance contours. Avalanche resonance is seen clearly for the smallest area (1×10^{-4} cm^2) device. The maximum peak power available from a device with area 2×10^{-4} cm^2, even with $R_s = 0$, is 15 W with 4.5 A input. It can be shown that stable operation beyond this current is not possible since the derivative $(\partial|G|/\partial V_{rf}) > 0$. Hence, the current density limit of a pulsed IMPATT is about 55% of its avalanche resonance value. Higher powers must be obtained by increasing the junction area of the device.

TABLE 1

PERFORMANCE OF GaAs PULSED IMPATTs AT 40 GHz

Diode	A_j	P_{rf}	P_{av}	I_{dc}	η	θ	D
5B-66D-40	0.93	5.1	1.5	1.7	10.7	17.8	30
5B-666-111	1.28	7.6	1.9	2.8	10.3	13.7	25
33612B-18	1.45	10.5	1.1	2.8	14.2	14.3	10
33612C-31	1.76	12.5	1.3	3.9	11.9	13.2	10
91-92-2B-10	2.95	15.9	0.7	5.9	10.5	11.2	4
91-1583-01D-17	3.46	16.0	0.8	4.7	14.8	10.5	5
Units	$10^{-4}cm^2$	W	W	A	%	°C/W	%

Table 1 shows the experimental relationship between junction area, maximum power input, and power output. The diodes on copper heatsinks were taken from different lots with slightly different doping profiles. Each diode was tested to maximum power output using a Kurokawa circuit, to be described below. The duty cycle, D, was adjusted to maintain roughly constant peak and average temperature. Pulse lengths were between 100 and 300 nS. The trends in the table are consistent with those predicted in Figure 1. Differences arise because of variations in $(V_{rf})_{max}$ and R_s. Note that two of the lots tested produced significantly higher efficiencies.

Circuit Design

Device testing was conducted using an iris coupled waveguide Kurokawa circuit (5). A coaxial line, terminated with a matched load on one end and the diode at the other, passes along the sidewall of a waveguide cavity. The cavity is formed by waveguide terminated by a sliding short on one end and an iris on the other. The matched load properly terminates the diode away from the cavity resonance frequency, but also absorbs some available power. The circuit efficiency is the ratio of output at the iris to available power at the diode.

The circuit efficiency is given by

$$\eta_c = \frac{|S_{12}|^2}{1 - |S_{22}|^2} \quad (2)$$

The S-parameters were measured as a function of frequency for various irises using an automatic network analyzer. Equation (2) was then used to determine $\eta_c \approx 80\%$ around cavity resonance. The power values quoted in this paper are referred to the coaxial circuit input using Equation (2). Thus, the measurements give the diode's available power and permit separate optimization of the diode and the circuit.

S_{22} may be transformed along the 50 Ω coaxial line to give the impedance at the waveguide cavity midplane. Once this and the package and mount parasitic reactances are known, appropriate coaxial diode matching transformers can be designed.

In operation, the device lines of Figure 1 are a function of temperature during the pulse. The resulting shift in frequency in the free running oscillator was found experimentally to be about 140 MHz for a 200 nS pulse with about 10 W output. The spectrum is improved considerably by injection locking (6).

Acknowledgement

The authors acknowledge the contributions of their many colleagues to this work and especially that of Dr. B. Lauterwasser, who provided GaAs epitaxial wafers. The support of Raytheon Company Missile Systems Division is gratefully acknowledged.

References

(1) M.G. Adlerstein and E.L. Moore, "Microwave Properties of GaAs IMPATT Diodes at 33 GHz," Proc. 8th Biennial Cornell Electrical Engineering Conference, Ithaca, NY p. 375-384 (August 1981).

(2) S.M. Sze, Physics of Semicondutor Devices, John Wiley and Son, (1969).

(3) L.H. Holway, Private Communication.

(4) M.G. Adlerstein, L.H. Holway and S.L.G. Chu, "Measurements of Series Resistance in IMPATT Diodes" IEEE Transactions on Electron Devices, ED-30 2 Feb 1983, p. 179-182.

(5) K. Kurokawa and F.M. Magelhaes, "An X-Band 10 W Multiple IMPATT Oscillator, Proc. IEEE 59, p. 102, (January 1971).

(6) K. Kurokawa, "Injection Locking of Microwave Solid-State Oscillators," IEEE Proc 61, 10 p. 1386-1410 (1973).

*This work was supported, in part, by the U.S. Air Force Avionics Laboratory, Wright-Patterson Air Force Base, Ohio under Contract No. F33615-81-C-1470.