THE EFFECT OF DISSIMILAR IMPATT DIODES ON POWER COMBINING EFFICIENCY*

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Abstract

Experimental results are presented which demonstrate that IMPATT diode preselection by growth wafer is unnecessary in order to achieve good power combining efficiency. With the possible exception of junction capacitance, tight tolerances ($<\pm10\%$) on DC or RF characteristics are also found to be unnecessary.

Introduction

As IMPATT diode power combining technology has developed, the quantity of devices combined in single structures has increased. The largest number of combined devices in our laboratory in a single structure is 60 diodes at X-band in a dual diode TM_{020} combiner.[1] As quantities increase, so does the importance of establishing device preselection criteria that can assure a designer that combining efficiency will not be significantly degraded as a result of device dissimilarities. Such criteria might include specifications on DC parameters such as junction capacitance, breakdown voltage, K-factor (breakdown voltage-junction temperature slope) and thermal resistance, or RF operating parameters such as frequency of operation in a fixed tuned circuit, diode DC to RF efficiency, and output power at a given junction temperature or operating current. Obviously, testing for all of these criteria is time consuming and expensive and results in reduction of quantities of qualified devices; no preselection, on the other hand, may result in inferior performance. An optimum set of specifications would be that which minimizes both preselection test time and performance degradation. This paper presents experimental evidence that very simple selection criteria at the device fabrication level may be sufficient.

Experiments

The devices used for this set of experiments are X-band GaAs double drift READ profile IMPATT diodes developed and fabricated by Raytheon's Research Division. All device wafers are grown to a standard doping profile specification and accepted or rejected for further processing based on measured compliance with the design profile ($\pm10\%$ doping level, $\pm5\%$ layer thickness). Devices that result from different acceptable growth wafers may vary by as much as $\pm10\%$ in room temperature breakdown voltage, thermal resistance, and K-factor, whereas devices from the same wafers typically vary by only $\pm3\%$ in the same parameters. The junction capacitance at breakdown was held to 4.5 pF $\pm$ .1pF for all devices used for these experiments.

All diodes that were combined had first been tested separately for RF performance in a circular cylindrical resonant TM_{010} mode cavity operating as a free running oscillator. In this test the pulsed operating voltage, current, average output power, frequency, and breakdown voltage at the end of the pulse are recorded and the peak diode output power, DC to RF efficiency and diode junction temperature are calculated.

Three combining experiments were performed in a 60 diode dual diode TM_{020} mode circular cylindrical resonant cavity described elsewhere[1] operating as an injection locked oscillator. No provisions for individual diode tuning are present in this configuration. In the first experiment, 60 devices from 9 different growth lots were combined. Each of the other two experiments consisted of combining 60 devices from a single wafer. In all of these experiments, each diode was operated at 270°C junction temperature; and the output power and the operating voltages and currents were recorded. The injected signal power level was 125 $\bar{W}$ and the output powers were 382$\bar{W}$ (1273$\hat{W}$), 391$\bar{W}$ (1303$\hat{W}$) and 351$\bar{W}$ (1190$\hat{W}$) for the three experiments, respectively. Assuming that the average diode DC to RF efficiency remains constant between the single diode tests and the combined tests, the average of the power produced per diode was calculated from the DC input power, and the combining efficiency was deduced from this information.

The combining efficiency is defined as the ratio of the power present at the output port to the sum of the power available at all of the diode ports. (By this definition, the single diode test cavity exhibits 70% combining efficiency.) Equation 1 relates this efficiency to the measured RF and input powers.

$$\sum_{i=1}^{N} P_i = \frac{P_{OUT} - P_{IN} \times \eta}{\eta} \qquad (1)$$

where

$\eta \triangleq$ Combining Efficiency

N = Number of Diodes

P_i = Power Generated per Diode

P_{IN} = RF Power at the Input Port

P_{OUT} = RF Power at the Output Port.

Results

Tables I, II, and III show the measured and calculated results of both the single diode tests and combining experiments 1, 2, and 3, respectively. Table I is broken down by wafer growth lot number to show the peak RF power generated, the average DC power into each diode, the diode junction temperatures, the thermal resistance from the junction to the liquid coolant, the diode DC to RF efficiency (a measured value of 70% cavity efficiency has been used for the single diode tests), the peak diode operating current, and finally the number of devices over which these averages have been taken. Tables II and III follow a similar format for diodes from a single growth lot. In addition, Figure 1 shows the distribution of room temperature breakdown voltages by diode growth lot. The computed cavity combining efficiency is shown to be 66.6%, 66.3% and 67.0% in combining experiments 1, 2, and 3, respectively.

Figure 2 shows the peak and average output power and gain for experiments 1 and 2.

These results demonstrate that the combining efficiency, as well as the gain/bandwidth characteristic of the combiner, is virtually unchanged as a result of using devices with a high degree of similarity in both DC and RF characteristics, compared with using devices that are dissimilar.

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Conclusions

Experimental data is presented showing that complicated device preselection procedures are unnecessary in order to achieve good power combining efficiencies in a circular cylindrical resonant cavity without provisions for individual diode tuning.

References

1. R. Laton, S. Simoes, L. Wagner, "A Dual Diode TM_{020} Cavity for IMPATT Diode Power Combining," 1982 IEEE MTT-S International Microwave Symposium Digest, pages 129-131.

TABLE I. Test data for diodes used in Experiment #1: 60 devices from 9 different growth lots were combined.

Single Diode Test Results

Lot	$P_{OUT}(\hat{W})$*	$P_{IN}(\bar{W})$**	$T_j(^oC)$	$\theta(^oC/W)$	$\eta(\%)$	$I(\hat{A})$	Quantity
4A-99	28.50	48.02	255	6.07	17.8	1.65	6
4A-218	29.79	52.40	269	5.82	16.9	1.66	14
4A-84	25.02	42.08	226	6.09	17.9	1.40	11
4A-103	29.84	50.09	236	5.36	17.9	1.69	10
4A-61	24.55	41.79	233	6.32	17.6	1.40	2
4A-52	25.20	42.84	254	6.75	17.6	1.40	1
4A-55	24.63	41.24	241	6.66	17.9	1.40	7
42316	22.47	40.82	225	6.15	16.5	1.40	6
42300	22.40	42.00	251	6.68	16.0	1.40	3
Weighted Averages	26.84	46.19	244	6.02	17.4	1.53	60

60 Diode Combiner Results (P_{IN} Adjusted for 270°C Junction Temperature)

Lot	$P_{OUT}(\hat{W})$*	$P_{IN}(\bar{W})$**	$T_j(^oC)$	$\theta(^oC/W)$	$\eta(\%)$	$I(\hat{A})$	Quantity
4A-99	27.80	46.84	270	6.61	17.8	1.63	6
4A-218	28.05	49.95	270	6.18	16.9	1.63	14
4A-84	27.88	46.89	270	6.61	17.9	1.54	11
4A-103	28.52	47.87	270	6.48	17.9	1.61	10
4A-61	29.08	49.50	270	6.24	17.6	1.65	2
4A-52	30.30	51.51	270	6.00	17.6	1.70	1
4A-55	27.44	45.95	270	6.75	17.9	1.53	7
42316	27.68	50.29	270	6.06	16.5	1.69	6
42300	24.48	45.90	270	6.60	16.0	1.55	3
Weighted Averages	27.86	47.90	270	6.43	17.4	1.60	60

Measured RF power output with 366$\hat{W}$ Input = 1273 $\hat{W}$
Cavity Efficiency from Eqn (1) = .666

TABLE II. Test data for diodes used in Experiment #2: 60 devices from Lot 4A-84 were combined.

Single Diode Test Results

$P_{OUT}(\hat{W})$*	$P_{IN}(\bar{W})$**	$T_j(^oC)$	$\theta(^oC/W)$	$\eta(\%)$	$I(\hat{A})$	Quantity
30.81	53.25	268.2	5.74	17.33	1.71	60

60 Diode Combiner Results (P_{IN} Adjusted for 270°C Junction Temperature)

$P_{OUT}(\hat{W})$*	$P_{IN}(\bar{W})$**	$T_j(^oC)$	$\theta(^oC/W)$	$\eta(\%)$	$I(\hat{A})$	Quantity
28.43	49.24	270.0	6.25	17.33	1.59	60

Measured RF power output with 392$\hat{W}$ Input = 1303$\hat{W}$
Cavity Efficiency from Eqn (1) = .663

*RF Quantity

**DC Quantity

TABLE III. Test data for diodes used in Experiment #3: 60 devices from Lot 42194 were combined.

Single Diode Test Results

	$P_{OUT}(\hat{W})$*	$P_{IN}(\bar{W})$**	$T_j(^oC)$	$\theta(^oC/W)$	$\eta(\%)$	$I(\hat{A})$	Quantity
	27.87	48.89	271	6.30	17.1	1.73	60
60 Diode Combiner Results (P_{IN} Adjusted for 270°C Junction Temperature)							
	25.27	44.33	270	6.93	17.1	1.62	60

Measured RF power output with 388$\hat{W}$ Input = 1190$\hat{W}$
Cavity Efficiency from Eqn (1) = .670

*RF Quantity
**DC Quantity

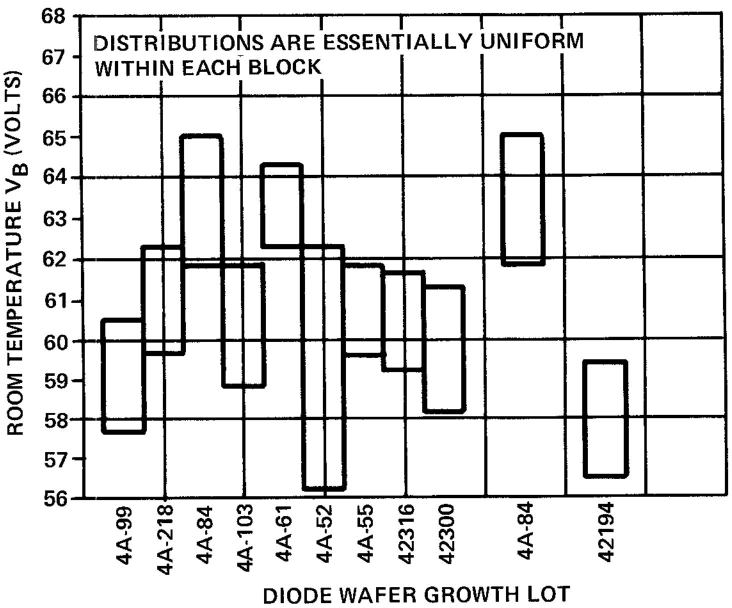

Figure 1. Distribution of Room Temperature Breakdown Voltage as a Function of Diode Growth Lot

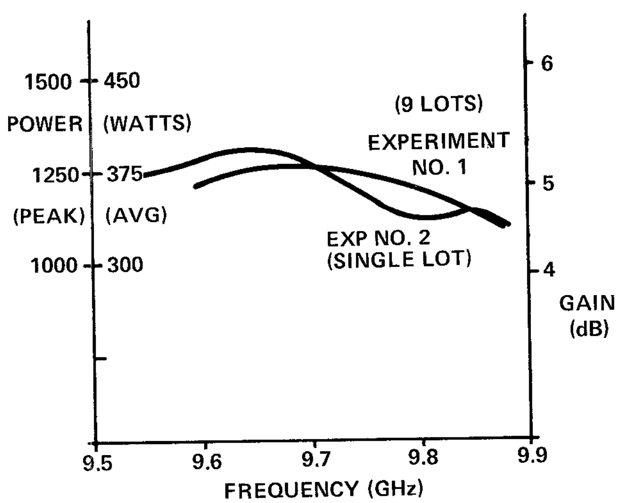

Figure 2. 60 Diode Combiner Performance