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X-BAND BURNOUT CHARACTERISTICS OF GaAs MESFETS

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Summary

X-Band microsecond pulse, millisecond pulse, and CW burnout data have been measured for GaAs MESFETs. Values of incident pulse power required to cause burnout are presented and discussed.

Introduction

Low noise gallium-arsenide (GaAs) Metal-Semiconductor Field-Effect Transistors (MESFETs) have been developed for use as RF amplifier stages in microwave receivers. One important application for these RF amplifier stages will be in transmit-receive radar systems which share a common antenna. Transmit-receive radar systems usually have protection devices to limit the microwave power incident upon the GaAs MESFET. Since the protection devices cannot respond instantaneously, there is a short duration of time (1 to 10 nsec) during which the protection device cannot limit the microwave power incident upon the GaAs MESFET. During this short duration of time, the MESFET may be burned out.[1-4] When limiting occurs (e.g. after 10 nsec) there is still leakage of the order of 100 mW through the limiter which can cause GaAs MESFET degradation or burnout.[3] There are also some applications in which it may be desired to omit a limiter in order to reduce weight, cost, or the degradation in system noise figure caused by the limiter insertion loss which may be in the range 0.2 to 0.8 dB. The reliability of such radar systems will depend upon the burnout properties of the GaAs MESFET. Information on this subject is still rather sparse.[1-4] For this reason an experimental investigation has been carried out to obtain X-Band microsecond pulse, millisecond pulse, and CW burnout data for GaAs MESFETs.

Experimental Procedures

For the MESFET burnout investigation two commercially available GaAs MESFETs with 1 micron gate lengths were selected. One has an Al gate metallization, and the other has a Ti/Pt/Au gate metallization. The GaAs MESFET dice were bonded using silver epoxy to 50 ohm microstrip circuits, and 0.7 mil gold bond wires were attached using thermocompression bonding techniques. Next the dc characteristics and X-Band S-parameters were measured. Then microwave matching networks which consisted of sections of low impedance line located close to the MESFET were used for input and output matching. Single stage noise figures were in the 2.5 to 4.0 dB range with associated power gains in the 5 to 10 dB range at 9.35 GHz.

After the GaAs MESFET noise figure and power gain were measured, it was exposed to one of the four types of X-Band signal described in Table 1. Initially, the incident pulse peak power was set at 0.1 W. (Ocassionally, an initial level as low as 0.01 W was used.) If the GaAs MESFET was exposed to a pulse signal (Types 1, 2, or 3 in Table 1), it was first exposed to a single pulse. If the MESFET did not burnout, the single pulse was repeated. If 10 single pulses did not cause burnout, the GaAs MESFET was exposed to a pulse drain with the lowest duty factor listed in Table 1 for several minutes. If burnout did not occur, the duty factor was increased to the next higher value given in Table 1, then the GaAs MESFET was exposed to a pulse train with the higher duty factor for several minutes. If burnout did not occur, the procedure was continued until the highest duty factor listed in Table 1 was used. If the GaAs MESFET was exposed to a CW signal (Type 4 in Table 1), the exposure time was typically 10 to 15 minutes. After exposure to an X-Band signal with a 0.1 W power level, the GaAs MESFET noise figure and power gain at 9.35 GHz were measured again. If no significant change in noise figure occurred, the incident pulse power was increased and the test procedure was repeated. A typical sequence of incident power levels used in the experiment is given in Table 2. The test procedure was repeated at increasing incident power levels until a significant reduction in MESFET noise figure was observed.

Experimental Results

The most significant observations will be presented and discussed. One observation is that a gradual degradation in noise figure did not occur. Instead the GaAs MESFETs failed catastrophically. A second observation is that for the types of signals listed in Table 1, the only failure mode observed was a gate-to-source short-circuit. Furthermore, the amount of damage (the damage area) increased as the pulse duration increased. The damage site also depended upon the pulse duration. Another observation is that the pulse duty factor did not affect the incident power level at which a GaAs MESFET failed. Several GaAs MESFETs that did not fail at an incident power level P_I when overstressed with an X-Band pulse train with a high duty factor failed on a single pulse when the incident power P_I was increased to the next level listed in Table 2 (usually 1 or 2 dB higher). Many cases were observed in which failure was caused by a single pulse. Shown in Figure 1 is a copy of a photograph which illustrates a single pulse failure in which failure occurred during the pulse. Failure during a microwave pulse was most clearly indicated by an abrupt increase in the power reflected by the MESFET.[5] The incident power levels at which GaAs MESFET failure occurred are plotted versus pulse duration in Figure 2. The data plotted are for GaAs MESFETs that failed for all the types of signals listed in Table 1. Also shown are nanosecond pulse burnout data reported previously.[2] The data in Figure 2 suggest the existence of an incident power threshold level at pulse durations longer than 0.2 microsecond. The incident power threshold level for burnout is in the range 3 to 6 W for the Type A MESFETs which have a Ti/Pt/Au gate metallization and in the range 1.5 to 3 W for the Type C MESFETs which have an Al gate metallization.

Optical Characteristics of Overstressed MESFETs

Following burnout each MESFET was examined using an optical microscope at magnifications up to 500X. For pulse durations 0.2 μsec, 5 μsec, and 5 msec and CW overstressing, only one type of failure mode, called metal migration, was observed. The metal migration failure mode caused a gate-to-source short-circuit. For a 0.2 μsec pulse duration the failure site had one of two locations. One location was in the channel at a point close to where the gate metallization divided into two branches. The other location was at the point where the gate metallization divided into two branches. For pulse durations 5 μsec and longer (including CW), the failure site was always located where the gate metallization divided into two branches. The size of the damage site increased as the pulse duration increased and was largest for CW overstressing. The explanation appears straight-forward. The data shown in Figure 2 indicate that the level of the incident pulse power required to cause burnout is essentially independent of pulse duration for pulse duration 0.2 μsec and longer. However, the absorbed pulse energy is determined either by the entire pulse duration or by the part of the pulsed duration prior to failure when failure occurs during the pulse. (See Figure 1.) In either case, as the pulse duration increased, the absorbed pulse energy increased causing the size of the damage site to increase.

Conclusion

Microwave μsec pulse, msec pulse, and CW burnout data have been measured for two commercially available 1 micron gate MESFETs. Gradual degradation in noise figure and power gain were not observed. All failures were catastrophic and were associated with metal migration that caused a gate-source short-circuit. The data indicate the existence of an incident power threshold level for pulse durations 0.2 μsec or longer and for CW. The incident power threshold level for burnout is in the range 3 to 6 W for Type A MESFETs which have a Ti/Pt/Au gate metallization and in the range 1.5 to 3 W for Type C MESFETs which have an Al gate metallization.

TABLE 1

TYPES OF X-BAND SIGNAL USED TO OVERSTRESS GaAs MESFETs

Pulse Duration	Pulse Duty Factor (Pulse Duration ÷ Pulse Period)	Exposure: Number or Time
0.2 μsec	Single Pulse - Repeated	10
	.000031, .00036, .0032, .036, .33	5 to 10 min.
5.0 μsec	Single Pulse - Repeated	10
	.00028, .0031, .030, .30	5 to 10 min.
5 msec	Single Pulse - Repeated	10
	.077, .33	5 to 10 min.
CW		10 to 15 min.

TABLE 2

TYPICAL SEQUENCE OF X-BAND INCIDENT POWER LEVELS USED TO OVERSTRESS GaAs MESFETs

Incident Power

dBm	W	dBm	W
20	0.10	33	2.0
23	0.20	34	2.5
26	0.40	35	3.2
28	0.63	36	4.0
30	1.00	37	5.0
32	1.58	38	6.3

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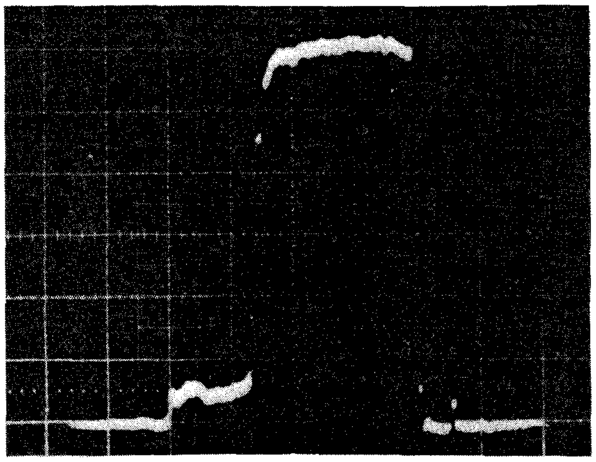

Figure 1

Photograph of CRO trace corresponding to rectified waveform of microwave pulse reflected from MESFET. The abrupt increase in amplitude of the reflected pulse indicates the time of failure. The pulse duration was 0.2 microsecond. The time of failure is 0.07 microsecond.

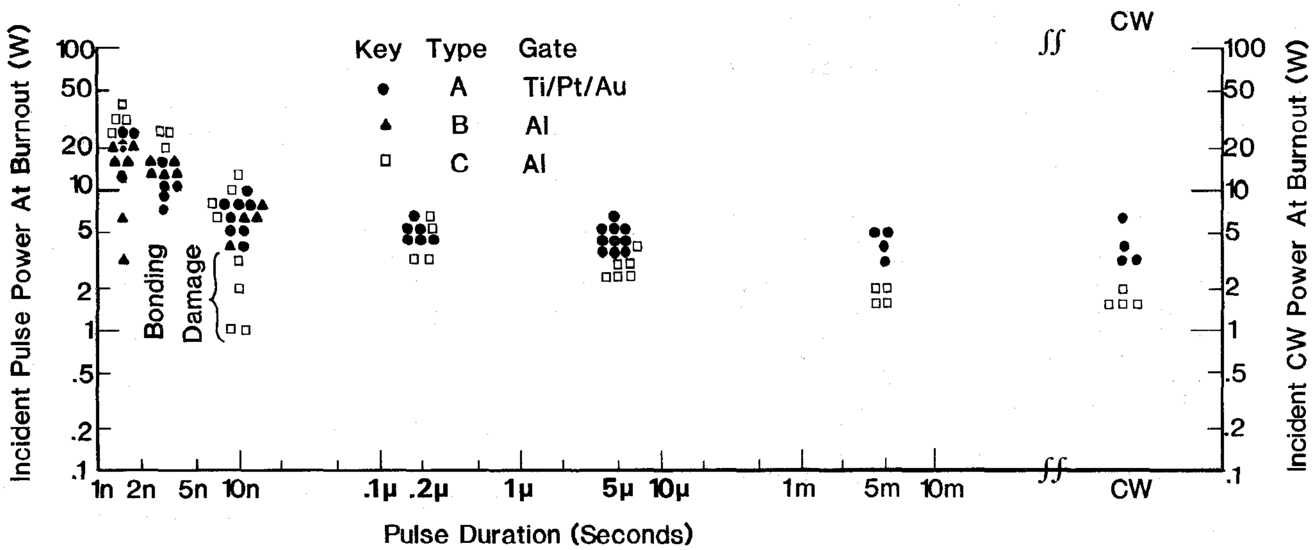

Figure 2. Values of Incident Pulse Power Required to Cause Burnout. Note CW Values are given at Far Right.