HIGH POWER GaAs IMPATT AMPLIFIERS

KAZUO NISHITANI, HIROSHI SAWANO, TAKASHI ISHII and SHIGERU MITSUI
Central Research Laboratory, Mitsubishi Electric Corporation,
4-1 Mizuhara, Itami, Hyogo, Japan

and

EIJI KAJI and AKIRA AMANO
Communication Equipment Works, Mitsubishi Electric Corporation,
80 Nakano, Minami Shimizu, Amagasaki, Hyogo, Japan

Abstract

10 Watts P-N junction GaAs IMPATT diodes with MTTF more than 10^6 hours have been developed. Using these diodes, amplifiers of 5 Watts output power, 10-dB gain, 17 per cent efficiency, 150 MHz bandwidth and 80-dB thermal noise (S/N) have been constructed.

Introduction

In low power receivers or transmitters of which handling power is less than one Watt, solid-state microwave devices are actively used. However, at present high power solid-state microwave sources are not available and consequently high power transmitters of more than several Watts can not help depending on TWT's. For the high power solid-state microwave sources, works until now have been mainly concentrated on the GaAs IMPATT diode with a Pt Schottky barrier. Experimentally, excellent results of output power more than 10 Watts[1,2] and efficiency of 37 per cent[3] have been obtained. Practically, however, applications of these Schottky barrier type GaAs IMPATT diodes were so limited. It is because the Schottky barrier type GaAs IMPATT diodes are less reliable[4] due to the rapid interdiffusion[5] of Pt with GaAs by the temperature raise under operation.

We have noted from the very beginning that a P-N junction type is more stable than the Schottky barrier type especially at elevated temperatures and have made efforts to develop the P-N junction type GaAs IMPATT diodes of high powers and high efficiencies and apply them to high power solid-state amplifiers.

Recently, we have developed 10 Watts GaAs IMPATT diodes having the P-N junction Hi-Lo structure with MTTF longer than 10^6 hours. In this paper, characteristics of the P-N junction type GaAs Hi-Lo IMPATT diodes for J-band and operation characteristics of the high power GaAs IMPATT amplifiers using these high power IMPATT diodes in the corresponding frequency band are described.

GaAs IMPATT diode

The GaAs IMPATT diodes have the Hi-Lo structure. They are fabricated from epitaxial P^+-N-N^--N^+ on N^{++} GaAs wafers successively grown by LPE. The P^+ region is doped with Ge and 1 μm thick. The N region, the avalanche region, is Sn doped with a net carrier concentration of 1×10^{17} cm^{-3} and is 0.3 μm thick. In order to obtain high efficiencies, avalanche region is intended to increase its carrier concentration and to narrow the width compared to a conventional Hi-Lo structure[1,2]. In the N^- region, the drift region, the carrier concentration is notably lowered to 6×10^{14} cm^{-3} to operate the diodes with high efficiencies at low current densities. Thus designed and fabricated diodes show the maximum efficiency at the current density as low as 300 A/cm^2, which is much lower than the so far reported value[1]. Shortage of output power due to the optimum oscillation at such the low input power level is compensated by combining the power of multi-chips. For a 10 Watts output power, four 300 μm square chips are bonded in a package.

Diodes are mounted in a J-band waveguide cavity with a "hat" for frequency determination. Their characteristics are measured by a WRJ-7 test circuit under the optimum tuning to obtain the maximum output power. The highest efficiency is obtained by a one-chip diode and is 26.6 per cent at 7.3 GHz. The highest output power is obtained by a four-chips diode and is 11 Watts at 5.7 GHz. Figure 1 shows the typical oscillation characteristics of the four-chips diodes. Because of the reduced thermal resistance and the improved thermal homogeneity due to the multi-chips structure, the temperature raise and the thermal inhomogeneity of the diodes are believed to be kept minimum. Output powers of 10 Watts with efficiency of more than 20 per cent are reproducibly obtained at junction temperatures less than 200 °C.

Reliability of the diodes have been evaluated by accelerated life tests and D.C bias tests. Figure 2 shows the mean time to failure (MTTF) of the diodes as a function of temperature. At the junction temperature of 200 °C, MTTF more than 10^6 hours is deduced by extrapolating the Arrhenius plots with the activation energy of 1.8 eV. The MTTF of 10^6 hours is well satisfied compared to the life of the Pt Schottky barrier type GaAs IMPATT diodes or TWT's. It is one order magnitude longer than the Pt Schottky barrier type GaAs IMPATT diode's[4] and is 50 times longer than the TWT's.

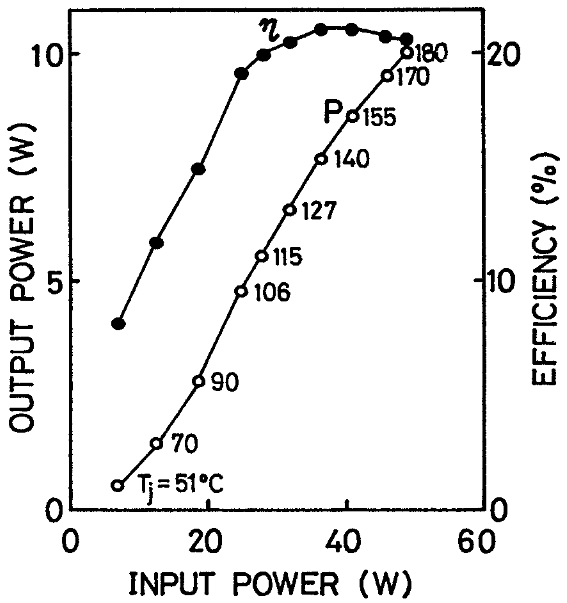

Fig. 1 Typical oscillation characteristics of the four-chips P-N junction GaAs IMPATT diodes. Oscillation frequency is 5.9 GHz. Output power of 10 Watts is obtained at the junction temperature of 180 °C.

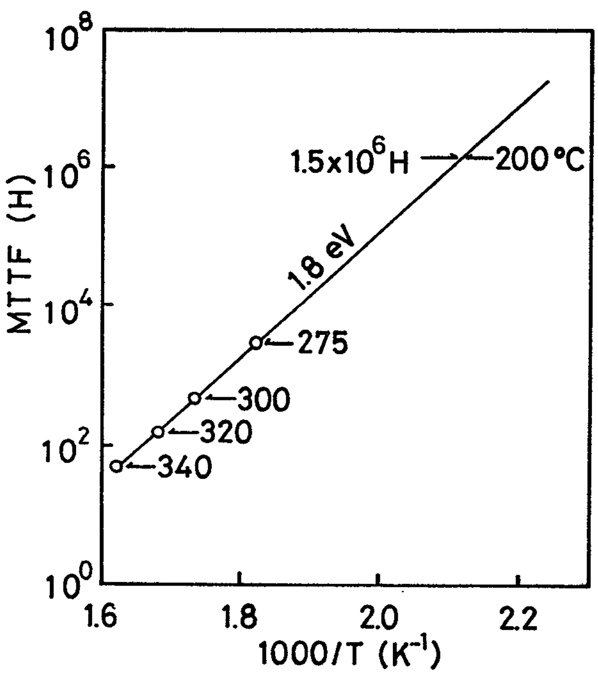

Fig. 2 Mean time to failure (MTTF) of the P-N junction GaAs IMPATT diodes as a function of reciprocal temperature.

GaAs IMPATT amplifier

Using the high power and high reliability P-N junction type GaAs IMPATT diodes, 5 Watts one-stage amplifiers are constructed for 6/7 GHz multi-channels microwave radio equipments. The block-diagram of the amplifier and the diode cavity are shown in Fig. 3 . The diode cavity is waveguide-coaxial type and has a low Q(Q~10). Impedance matching between the diode and the load is accomplished by a coaxial 1/4 wave-length transformer . The center frequency is varied by changing the length of the transformer. Output power from a high power 0.5 Watt Gunn modulator is amplified by the IMPATT amplifier.

In Table 1, the typical characteristics of the amplifiers are summarized. Output powers over 5 Watts are reproducibly obtained with gain more than 10-dB and junction temperatures less than 200 °C. Efficiency, locking bandwidth and thermal noise(S/N) are more than 15 per cent, 150 MHz and 80-dB, respectively. The highest output power is 6.5 Watts with the junction temperature less than 200 °C and the efficiency of 17 per cent, where the diode is expected to have MTTF more than 10^6 hours. In Fig. 4, characteristics of the amplifier are shown against the D.C input power of the GaAs IMPATT diode. With the increase of the D.C input power, the locking bandwidth decreases but the locking bandwidth is still more than 150 MHz, which is large enough for transmitting 1800 telephone-channels at the output power of 6.5 Watts. The thermal noise characteristics(S/N) of the amplifier is shown in Fig. 5. It is more than 80-dB and is satisfactory enough for practical microwave radio equipments. Figure 6 shows the temperature dependences of the output power of the amplifiers. In every case, against the temperature deviation from 0 to 50 °C, the deviation of the output power is less than 1-dB.

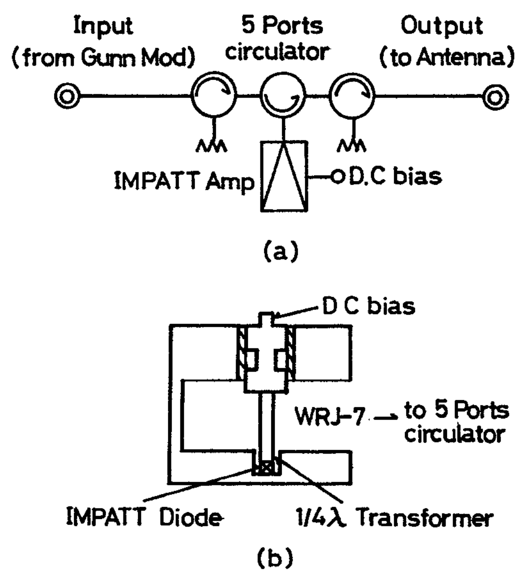

Fig. 3 Block-diagram of the GaAs IMPATT amplifier (a) and the diode cavity (b).

Table 1 Characteristics of the GaAs IMPATT amplifiers

Amp. No.	P_{out} (W)	Gain (dB)	Eff. (%)	S/N (dB)	Δf (MHz)	f (GHz)	T_j (°C)
A-1	6.5	11.1	17.1	>80	>150	7.47	195
A-2	5.1	10.1	16.0	>80	>150	7.73	170
A-3	6.0	10.8	17.7	>80	>150	7.59	177
A-4	5.5	10.4	15.7	>80	>150	7.57	187
A-5	5.8	10.6	17.5	>80	>150	7.57	173

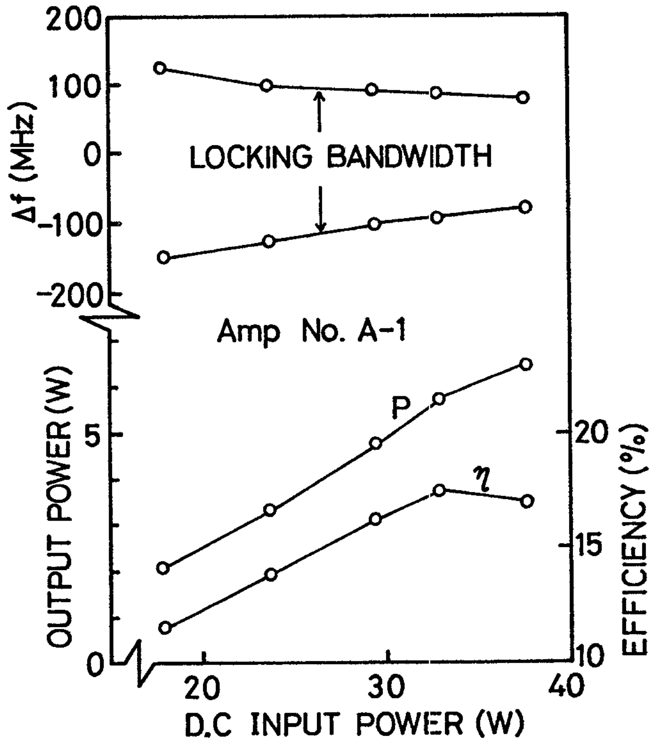

Fig. 4 Characteristics of the GaAs IMPATT amplifier against D.C input power of the diode.

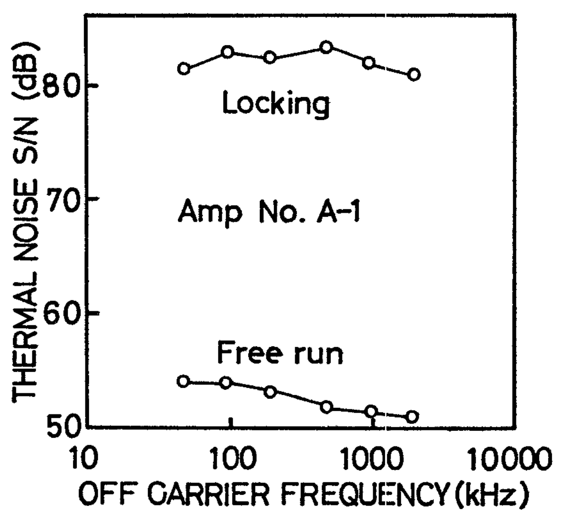

Fig. 5 Thermal noise characteristics of the GaAs IMPATT amplifier. Deviation is 200 kHz r.m.s and bandwidth is 3.1 kHz.

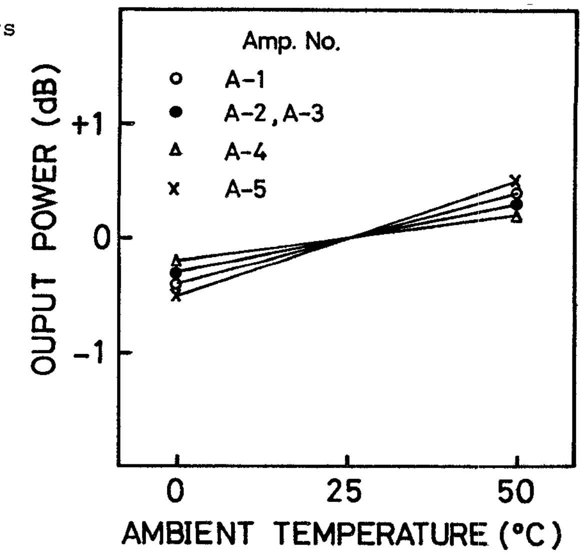

Fig. 6 Temperature dependences of the output power of the GaAs IMPATT amplifiers.

Conclusion

From this work, it is concluded:

(1) 10 Watts P-N junction GaAs IMPATT diodes with efficiency over 20 per cent and MTTF more than 10^6 hours have been developed in J-band.

(2) Applying these high power P-N junction GaAs IMPATT diodes to J-band amplifiers, output powers over 5 Watts have been obtained with 10-dB gain and 17 per cent efficiency. Locking bandwidth and thermal noise(S/N) are more than 150 MHz and 80-dB, respectively.

(3) Because of the excellent thermal stability and the excellent reliability, the 5 Watts GaAs IMPATT amplifiers can be used for practical high power solid-state microwave radio equipments.

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