TUNABLE MILLIMETER-WAVE PACKAGED IMPATT DIODE OSCILLATORS

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Abstract

Broadband mechanically tunable V-band (50-75 GHz) and W-band (75-110 GHz) IMPATT oscillators have been developed using packaged silicon p^+n junction diodes. A tuning bandwidth of 20% with minimum output of over 50 mW is obtained in V-band and 6% bandwidth with minimum output over 25 mW is obtained in W-band. Higher power but more limited tuning bandwidth results from using other diode structures.

Introduction

Recently the need for reliable solid state millimeter-wave sources in systems applications has been growing rapidly. For systems applications it is generally required that the electronic devices be passivated or hermetically sealed for protection against the outside environment. It is also desirable that an rf source can readily be mechanically tuned to a specific frequency. For test applications, a tunable low-voltage solid state source can be used to replace the more expensive klystron with bulky high voltage power supply.

In this paper we discuss the development and performance of tunable IMPATT oscillators developed to satisfy this need in V-band (50-75 GHz) and W-band (75-110 GHz). In this work particular attention has been given to providing a rugged package capable of hermetically sealing the IMPATT diode. In the circuit development, emphasis has been placed on broadband mechanical tunability.

Diode Fabrication and Packaging

The IMPATT diodes used for this work are single-drift p^+n silicon diffused junction diodes with breakdown in the range 12 to 17 volts. The junction is formed in epitaxial material grown on arsenic-doped substrates through the pyrolysis of silane. The epitaxial material doping profile is flat with an abrupt n^+n transition. A shallow, low-temperature diffusion of boron is used to form the p^+n junction of approximately 0.15 μm from the wafer surface.

Diodes are formed on a large-area-bonded integral copper heat sink. This is accomplished by bonding an entire silicon wafer to a polished copper disk. An array of mesa diodes is formed using standard masking and etching techniques, and the diodes are separated by punching a disk-shaped base under each diode out of the larger copper disk. The copper disk under the diode forms the base of the diode package as shown in Fig. 1.

The packaging scheme developed to hermetically seal the diode while maintaining sufficiently low package parasitics is shown in Fig. 1. A quartz ring is brazed onto the copper base completely encompassing the diode. A ribbon is bonded between the top of the ring and the diode's back contact and a lid is soldered over the quartz ring to completely seal the diode. The shunt capacitance of the quartz ring is about 0.1 pF. The effective series lead inductance of the package can be increased by using a half-strap lead instead of the full-strap depicted in Fig. 1. The lead inductance can also be varied to some extent by changing the cross-sectional geometry of the ribbon. Providing the correct impedance transformation through the package is important in operating the diodes with the microwave circuit. Using a full-strap ribbon of 0.003 inch width, this packaging configuration has been successfully used up to 110 GHz.

Oscillator Circuit

The waveguide circuit developed for the oscillator is shown schematically in Fig. 2. The circuit was designed with the goal of achieving a broad mechanical frequency tuning while maintaining a reasonable output over the tuning range. A single quarter-wavelength impedance transformer is used to reduce the waveguide impedance near the diode position. An inductive post contact is used to provide the required dc bias current to the diode. The mechanical tuning is achieved by simply moving a sliding short in the reduced height section behind the diode. The frequency range for smooth mechanical tuning is primarily determined by the package and bias post parameters. The frequency of oscillation is determined by the position of the tuning short. A waveguide height reduction ratio of 3 to 5 was used for both V and W-band oscillators.

Microwave Performance

The mechanical tunability of the oscillators is dependent on the IMPATT diode structure as well as the circuit. In V-band, the broadest mechanical tuning range has been achieved with relatively-heavily-doped, low-voltage diodes. Some typical power-vs-frequency characteristics of the V-band oscillators are plotted in Fig. 3. No "holes" or discontinuous jumps in power were detected over the frequency range indicated for any of these oscillators. Curves A and B were obtained with 12-13 volt diodes. A tuning bandwidth of 10 GHz or greater can be readily obtained from these diodes over any segment of V-band. Curve C was generated from a 17 volt breakdown diode. Operation of this lot was limited to the lower position of V-band where wide tuning range is also achieved. Higher power output has been generated at some sacrifice in tuning bandwidth. Curve D shows the performance of a relatively high power diode. A minimum power of 125 mW is generated over the range 59-65 GHz with a maximum power of 250 mW near 62 GHz.

Diodes having smaller junction area from the lower voltage lots used in V-band have also been operated in W-band. The tuning bandwidth achieved is not quite as large as V-band. Also, the power output is lower, due to both the smaller diode size and lower generation efficiency. The diodes used are not of optimum design for W-band. Improved performance should result from use of lower voltage diodes.

It should be noted that the performance achieved in both V and W-bands is obtained at a junction temperature of under 270°C in all cases. This is accomplished with only air cooling of the oscillator circuit. This insures reliable, long-life operation of the oscillator.

Conclusion

The significance of this work is that reliable IMPATT sources with broadband tuning capability which can readily be incorporated into systems and adapted to many applications have been developed for the 50-110 GHz range. The sealed quartz ring package provides a simple means of mechanical and atmospheric protection for the diodes. Sources of this type have passed vibration and shock tests under military standards.

Acknowledgements

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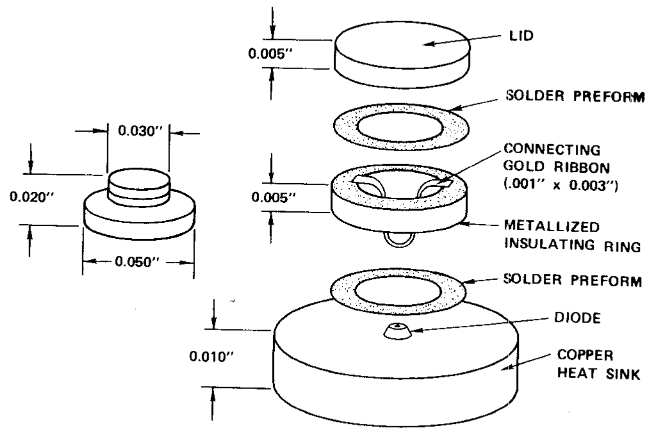

Fig. 1 Packaging scheme for sealing the millimeter-wave IMPATT diodes.

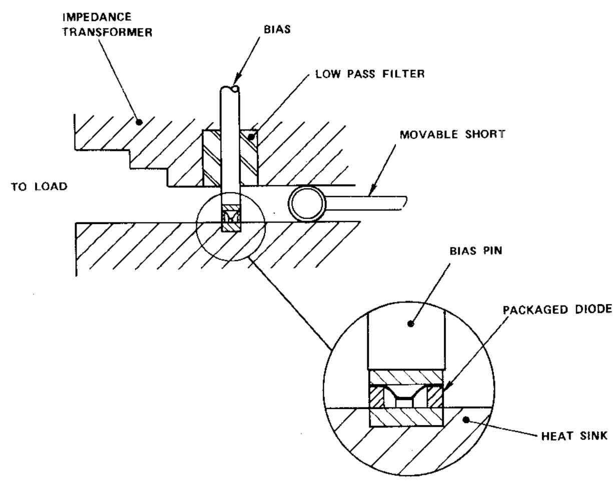

Fig. 2 Cross-sectional view of broadband tunable millimeter-wave oscillator circuit.

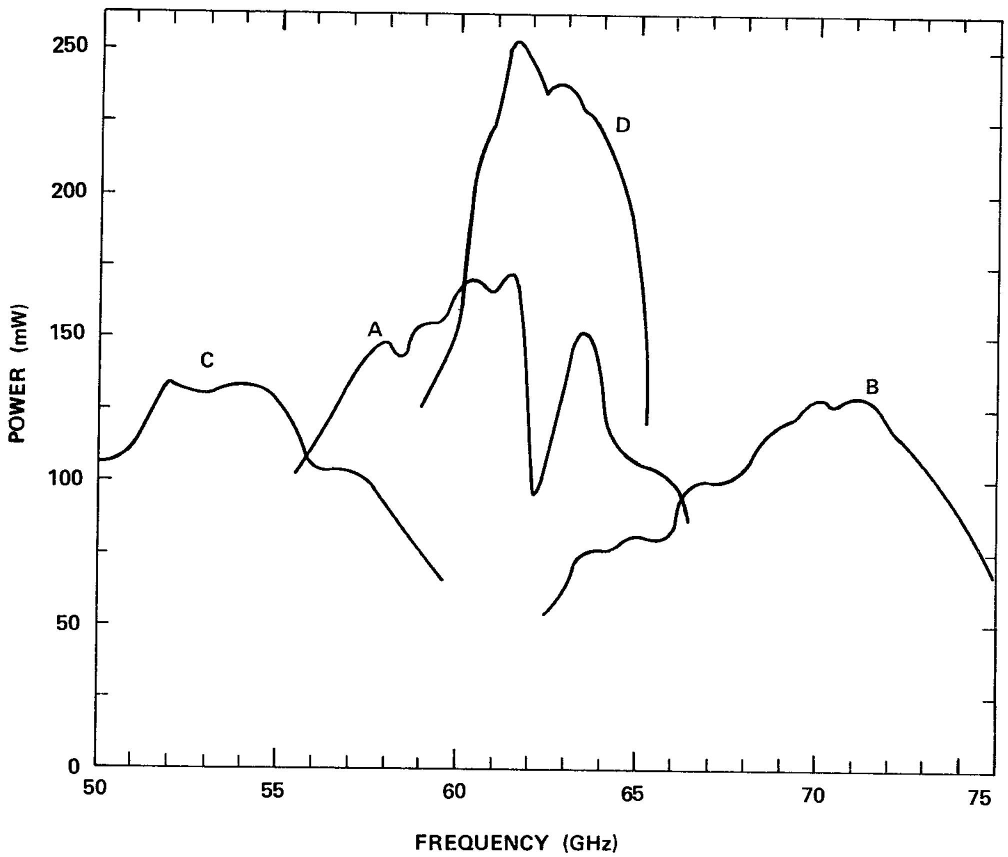

Fig. 3 Power output vs frequency characteristics of tunable oscillators

Curve	Current	Voltage	Junction Temperature
A	330 mA	16.2 V	250°C
B	330 mA	16.5 V	265°C
C	250 mA	21.5 V	230°C
D	340 mA	23.1 V	260°C

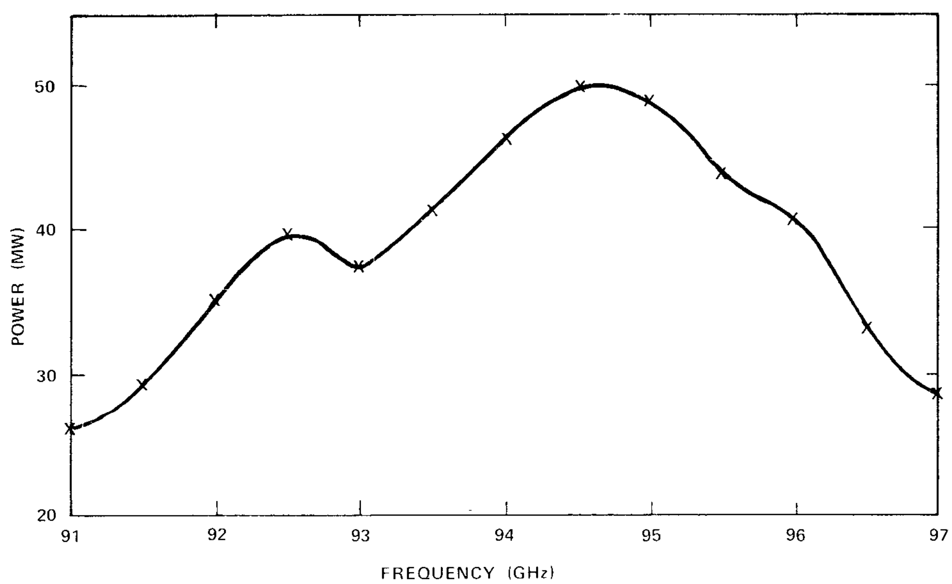

Fig. 4 Power output vs frequency for a W-band tunable oscillator with bias current of 300 mA at 15 volts. The operating junction temperature is 220°C.