Y-BAND (170-260 GHz) TUNABLE CW IMPATT DIODE OSCILLATORS

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Abstract

This paper describes circuit, packaging, and device techniques used in the development of tunable CW IMPATT diode oscillators in the 170-260 GHz range.

Introduction

Recently significant progress in output power and conversion efficiency has been achieved with IMPATT diode oscillators in both the CW and pulsed modes of operation at frequencies above 200 GHz. A CW output power of 50 mW at 202 GHz with a 1.3 percent conversion efficiency and a peak pulsed power of 520 mW at 214 GHz with a 2.6 percent conversion efficiency have been reported separately by different research groups[1,2]. At these frequencies, because of the very short wavelength involved, chip-level circuit design is required. This paper describes the application of such a design approach to the development of CW IMPATT oscillators at Y-band (170-260 GHz) frequencies. Circuit and package development, as well as diode design and characterization and RF tuning characteristics of the oscillators are described.

Circuit Design

At Y-band frequencies, several problems which are encountered commonly at lower millimeter-wave frequencies are amplified. First, the physical dimensions of the waveguide become inconveniently small. This feature makes the diode mounting and oscillator assembly difficult. In addition, because of the very short wavelength involved, the dimensions of the diode package become comparable to a wavelength. This fact makes impedance matching between the diode and the circuit more critically dependent on the package parameters which can limit the performance of the diode if not properly chosen. In order to overcome this performance limitation and to match the device and circuit impedances properly, the package design must be considered as an important part of the overall circuit design. This chip-level circuit design requires a new type of cavity to facilitate diode mounting and packaging.

The circuit used for the IMPATT oscillator is a reduced height waveguide cavity which consists of three major sections as shown in Figure 1(a): A tapered waveguide section which transforms from full height to reduced height waveguide, a reduced height waveguide wafer section which contains the IMPATT diode and a mechanical tuning short section. The cavity design resembles Sharpless wafer-type circuits used for mixer diode applications. The wafer is sandwiched between the other two sections to form the complete waveguide cavity.

The wafer-mounted IMPATT diode modular cavity design permits variation of the circuit configuration at the chip level. Figure 1(b) shows the details of the wafer module. The IMPATT diode is soldered to a heat sink slab which forms the lower wall of the waveguide slot. A bias pin is used to contact the diode which can be either packaged or unpackaged. The bias pin is inserted through a choke in the top of the wafer. In order to eliminate any low-frequency instabilities there are two sections of lossy material (Eccosorb) in the bias choke. This bias network design for eliminating instabilities is important for LO applications of the oscillator.

Package Development

In order to properly transform the relatively high circuit impedance to the low device impedance, package parasitics must have optimum values. In addition, one particular important design factor for any solid-state source in CW operation is the efficient removal of heat due to the power dissipation in the diode. The operation of IMPATT diodes at these frequencies is largely thermally limited in output power and efficiency.

In order to develop a package configuration with optimum parasitics and good thermal properties, two approaches have been used. In the first approach, bias contact is made directly to the diode with a wire welded on the end of the bias pin thus eliminating the need for a quartz standoff and the associated package parasitics. Two versions of the wire configuration have been developed utilizing single- and double-welded wire contacts. Figure 2 shows a diode contacted by a single-welded wire on a bias pin of 7 mil diameter. The direct contact scheme results in low parasitics. Moreover, the spring action of the wire provides adequate compensation for the thermal expansion and contraction which occur as the device temperature is varied between the ambient and operating values. Unfortunately, this technique requires rigid mechanical tolerances.

In a second approach, the conventional quartz standoff package previously used successfully up to 170 GHz has been improved for operation at Y-band frequencies. A miniaturized version has been developed. Diodes with this type of package give consistently good RF performance with wide tunability. This feature indicates that the parasitics of this package configuration have reasonably optimized values.

Diode Characterization

The diodes used in the present work have an ion-implanted double-drift-region (p^+-p-n-n^+) doping profile. The breakdown voltages range between 8 V and 10 V. At the high frequencies of operation the resistive losses in the diode substrate can become quite significant. For this reason the substrates of these diodes are reduced in thickness to a few microns.

Because of very high frequency of operation, the total active region of the IMPATT diode is only about 0.25 micron long. The realization of the desired

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doping profile and the elimination of the positive resistance associated with the unswept epitaxial region at the device operating level are difficult even with state-of-the-art technology. The accuracy required for determining the diode doping profile almost exceeds the resolution of the capacitance-voltage (C-V) method commonly used in profiling the diode. C-V data has been taken on some completed devices in order to obtain information on the doping profile. For a double-drift-region device the C-V method can only be used to measure an effective profile N_E given by

$$\frac{1}{N_E} = \frac{1}{N_D} + \frac{1}{N_A} \qquad (1)$$

where N_D and N_A are respectively the donor and acceptor concentrations at the edges of the depletion region formed by the application of the specified voltage. No information on N_D or N_A individually can be deduced from C-V measurements. Figure 3 shows double-drift-region doping profile of a Y-band diode as obtained from measurements on the epitaxial layer doping and an estimation of the implanted p-type profile. Figure 4 shows a plot of N_E (the "calculated" curve) based on the profile in Figure 3 and Equation (1). The plotted points in Figure 4 are values of N_E obtained from the measured C-V data. The agreement is quite good.

Thermal resistance for the diodes has been measured. The results are plotted as a function of diode diameter in Figure 5. Also plotted is a curve of calculated thermal resistance. The calculation is based on a simple model consisting of a silicon diode chip mounted on a two-layer (Au and Cu) semi-infinite heat sink. (Because of the very small diode diameters, it is not possible to ignore the presence of the Au bonding layer which is about 4 μm thick.) The total thermal resistance R_T is given as

$$R_T = R_{Si} + R_{HS}$$

where R_{Si} is the contribution due to the silicon between the junction and the heat sink and R_{HS} is the contribution from the two-layer heat sink. The latter contribution was evaluated using an expression given by Board.[3] As can be seen, the correlation between measurement and calculation is very good.

RF Performance

Oscillators with the circuit and package designs described above have been evaluated extensively in Y-band with the silicon double-drift-region IMPATT diode at a junction temperature of approximately 250°C above ambient. CW powers of 23 mW at 207 GHz, 10 mW at 230 GHz and 1.9 mW at 250 GHz have been achieved.

Particular emphasis is placed on the tunability of the oscillator for system applications. Figure 6 shows the RF performance of a mechanically-tuned oscillator with a quartz standoff packaged IMPATT diode as a function of bias current. The frequency of oscillation increases monotonically from approximately 190 to 220 GHz as the bias current is varied from 150 to 440 mA. It is interesting to point out that there are no low-frequency instabilities observed even though there is low-frequency negative resistance induced by the combination of RF rectification effects and space charge effects at the high current levels. The stability can be attributed to the special bias network used.

Acknowledgments

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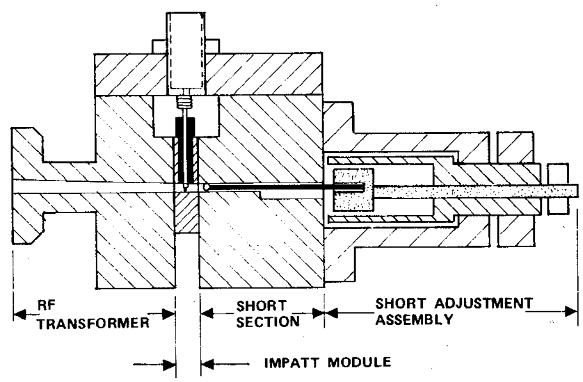

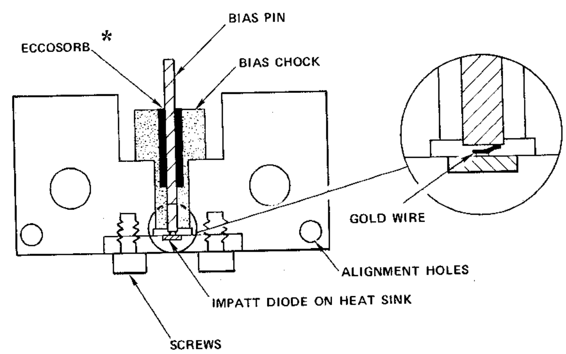

Fig. 1-Y-band IMPATT diode oscillator circuit.

(a) Cross-section of entire circuit assembly
(b) Details of wafer-mounted IMPATT module

*Manufactured by Emerson & Cuming, Inc.

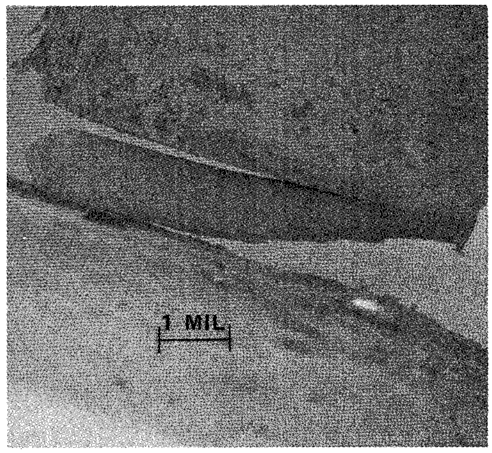

Fig. 2-Single-welded wire contacted diode.

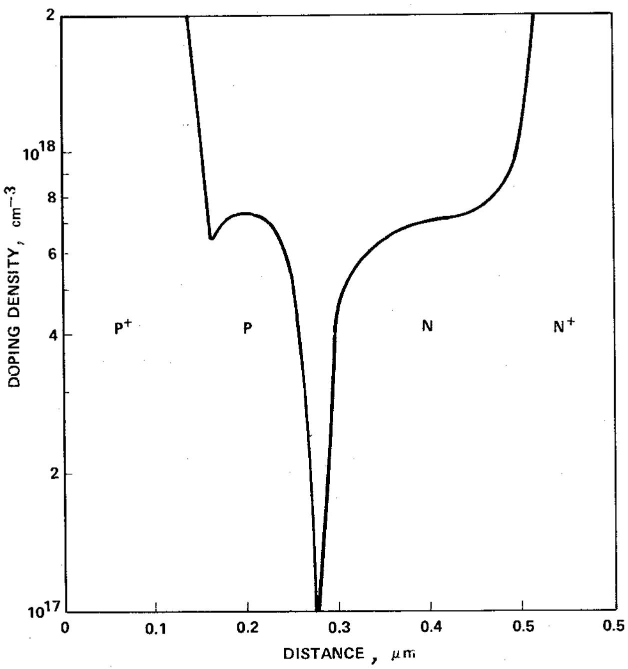

Fig. 3-Diode doping profile.

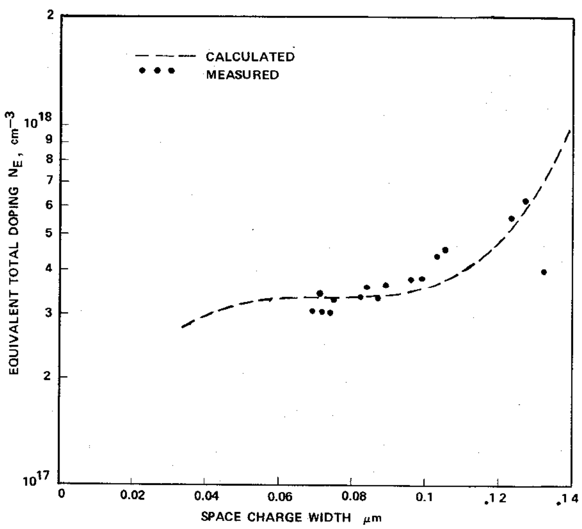

Fig. 4-Calculated and measured equivalent total doping vs. space charge width of the Y-band diodes.

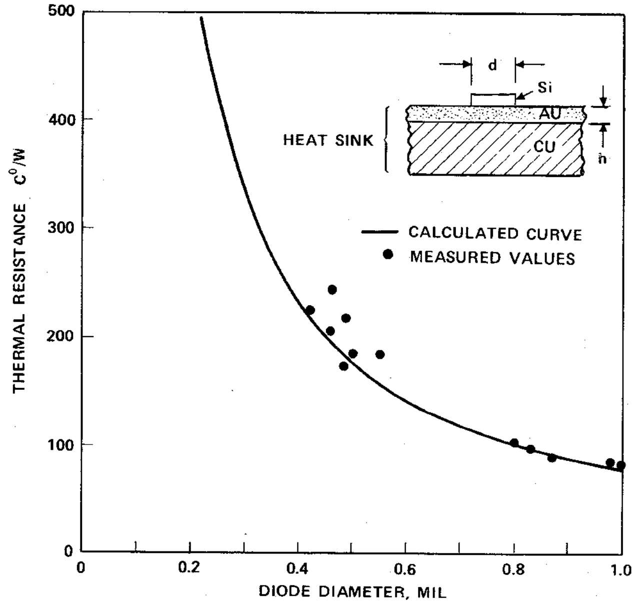

Fig. 5-Thermal Resistance vs. Diode Diameter for Y-band diodes.

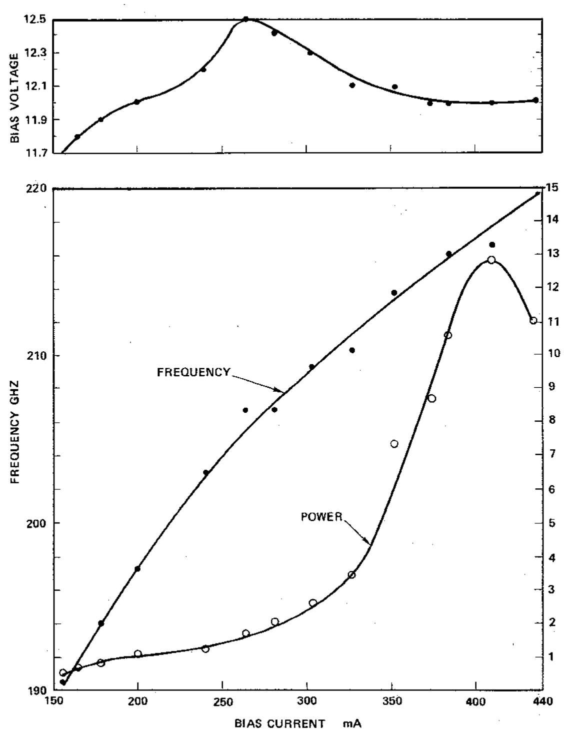

Fig. 6-Tuning characteristics of a Y-band IMPATT oscillator.