HIGH POWER PULSED IMPATT OSCILLATOR NEAR 140 GHz

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ABSTRACT

IMPATT diodes with a double drift p^+-p-n-n^+ doping profile were fabricated and tested for high power pulsed operation. Using a pulse width of 100 ns and a 0.5% duty factor, a peak output power of 3.0W with 2.8% conversion efficiency has been measured at 140 GHz.

Introduction

The need for high power pulsed IMPATT diodes at millimeter wavelengths for radar applications has been recognized for some time. Apart from much of the activities which are currently being pursued around 94 GHz, there is a growing requirement for developing radar systems that will operate at even higher frequencies to increase resolution and to reduce aperture size. Recently, pulsed IMPATT diodes capable of generating 13 watts peak power at 94 GHz was reported.[1] This paper describes the results of an experiment in which a peak output power of 3.0W at the 140 GHz atmospheric window frequency was achieved using double drift IMPATT diodes.

Diode and Circuit Design

The double drift IMPATT profile was first formed by growing an n-layer on an n^+ arsenic doped substrate wafer. The lightly doped p region is fabricated by overcompensating with implanted boron ions.[2] Finally, the thin p^+ contact layer was formed by a low temperature boron diffusion. After profile formation, an array of inverted mesa diodes is fabricated from the wafer and is individually bonded on copper heatsinking disk.

For narrow pulse widths and low duty operation, the diode is no longer thermally limited. The operating current density can therefore be much higher than that for CW diodes. Based on a careful analysis of the transient thermal behavior of a pulsed diode, we choose 10^5 Amp/cm^2 as the operating current density. Furthermore, in order to obtain optimum diode performance, the total epitaxial layer thickness must be carefully controlled so that the active layer thickness is equal to the total depletion width at the operating current and junction temperature. At high current density and elevated junction temperature, the depletion width will widen due to space charge effects[3] and thermal effects. This increase in depletion width is considerably larger in pulsed diodes than in CW diodes; consequently a thicker epi layer is required for pulsed diodes. The profile has an approximately symmetrical p^+-p-n-n^+ structure with a 3×10^{17} cm^{-3} net doping density in the lightly doped region. The total active layer thickness is about 0.35 μm. The diode breakdown voltage is between 9.5 and 10 volts.

At 140 GHz the diode package parasitics become important elements of device/circuit matching. The package configuration in the vicinity of the diode chip must transform the relatively low diode impedance (1-2 ohms) to match the much higher characteristic impedance of the waveguide cavity. This is accomplished by mounting the chip in a double-quartz-standoff package. In this structure, two quartz standoffs are bonded next to the diode mesa on the copper heatsinking disk. A ribbon lead is bonded between the diode back contact and the top of the standoffs. A silver button is bonded on top of each standoff to protect the ribbon. A scanning electron micrograph of this package configuration is shown in Figure 1.

The test circuit consists of a 0.010" reduced height waveguide cavity with a tapered waveguide height transition to the WR-7 waveguide output. Tuning was achieved by a sliding back short. A relatively large bias pin with diameter between 0.027" and 0.035" was used in the cavity. A bias pin of this size inside a 0.010" reduced height waveguide can no longer be regarded as a thin inductive post, but rather a close approximation to a step transformer whose lower face provides additional impedance transformation between the IMPATT diode and the reduced height waveguide load. A schematic cross-section of the bias pin arrangement is shown in Figure 2.

Oscillator Performance

Power measurements were made using a dry calorimeter (Hitachi model E3904) which, in spite of its slow response time, is generally much less sensitive to frequency than a thermistor mount. Since the calorimeter is constructed in WR12 waveguide, a transition from WR12 to WR7 was used in the measurements. The sensitivity was found to be 60.9 μV/mW at 60 GHz. Because the calorimeter has a relatively flat frequency response, this sensitivity also holds at 140 GHz. This assumption constitutes a conservative measurement in power because it is likely that the sensitivity decreases at high frequencies.

Frequency detection and measurement were made by a point contact detector and a frequency meter, respectively. A low loss isolator was used with the IMPATT oscillator to provide 20 dB of isolation. Further isolation or padding was obtained by an attenuator which was placed between the isolator and the frequency meter.

All rf measurements were made using a pulse repetition frequency of 50 KHz. The width of the input current pulse is adjustable between 80 ns and 130 ns. Many diodes with different junction capacitances were tested, and the optimum capacitance which yields the highest output power and the best rf tuning characteristics was found to be somewhat between 2.0 pf and 2.5 pf. Figure 3 shows a typical input current pulse (top trace) and the corresponding rf video pulse (bottom trace) for one of the high power diodes. The peak power was 3.0W and the rf pulse width was 100 ns. The frequency chirp caused by transient thermal heating of the diode was from 139.0 GHz to 142.0 GHz. The conversion efficiency was 2.8%. A summary of these tuning characteristics as a function of bias current is shown in Figure 4.

Conclusion

High power pulse operation at 140 GHz was demonstrated with IMPATT diodes in which the doping concentration and epi layer thickness were carefully designed and controlled. As the diodes were not thermally limited, they may have been driven harder than usual in order to obtain high power, which resulted in some sacrifice in efficiency. We believe that with more work done on diode and circuit optimization, it should be possible to achieve even higher power and efficiency.

Acknowledgments

The authors wish to thank Dr. T.T. Fong for helpful discussions, A.E. Martin for device fabrication, and H.H. Luckey, D.P. Williams and G.M. Hayashibara for technical assistance.

This work is sponsored in part by the U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground under Contract No. DAAK 11-77-C-0040.

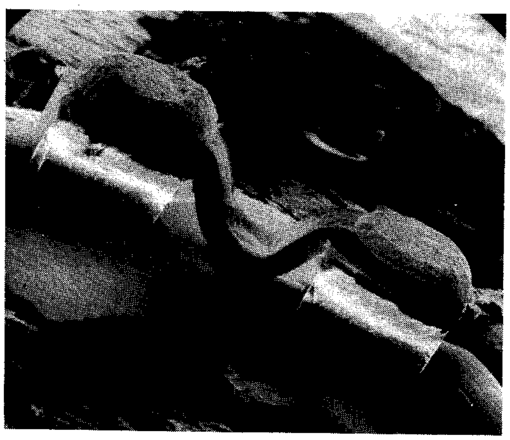

FIGURE 1: SCANNING ELECTRON MICROGRAPH OF THE DOUBLE-QUARTZ-STANDOFF STRUCTURE.

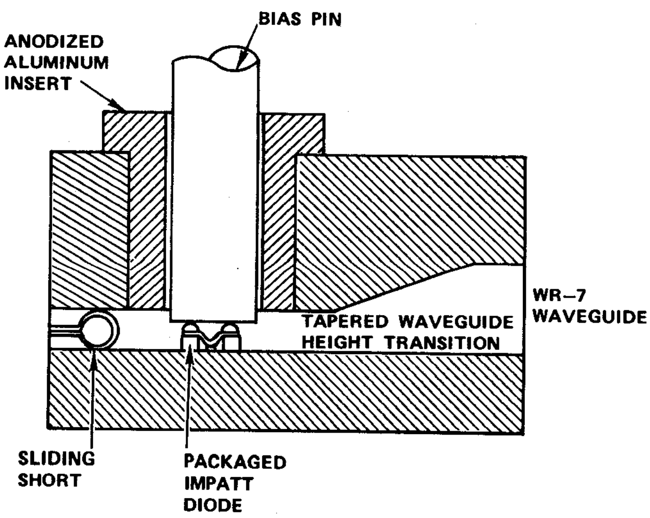

FIGURE 2: BIAS-PIN TRANSFORMER WAVEGUIDE CIRCUIT CONFIGURATION.

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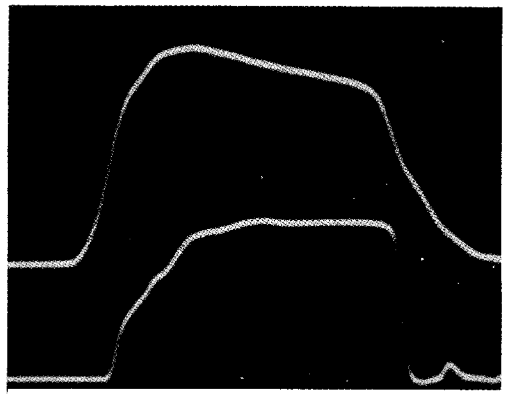

FIGURE 3: A TYPICAL INPUT CURRENT PULSE (TOP TRACE) AND VIDEO OUTPUT PULSE (BOTTOM TRACE).

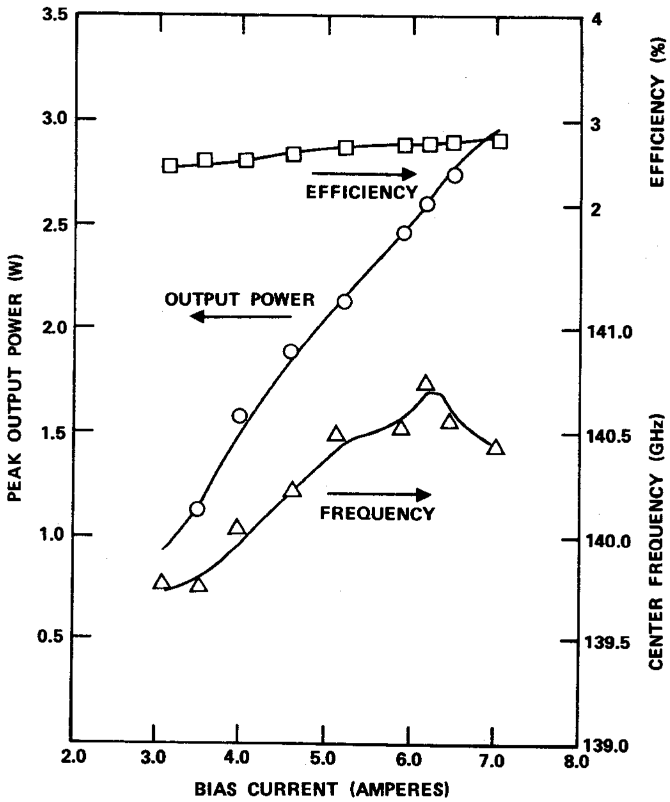

FIGURE 4: 140 GHz PULSE IMPATT OUTPUT POWER, FREQUENCY AND EFFICIENCY AS A FUNCTION OF BIAS CURRENT.