HIGH POWER PULSED UHF AND L-BAND P^+-N-N^+
SILICON TRAPATT DIODE OSCILLATORS*

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Abstract

TRAPATT oscillators utilizing highly graded p^+-n-n^+ silicon junction devices with large p-region width to total depletion region width ratios have produced more than 500 W pulsed power output with a minimum efficiency of 25% in the UHF and L-band ranges.

Introduction

One of the important potential applications of silicon TRAPATT diodes is as solid-state sources for fuses. The requirements for such applications necessitate the design and development of high pulse power, high efficiency TRAPATT devices and the associated circuits. This paper will describe high pulse power generation from lumped-element TRAPATT oscillators utilizing p^+-n-n^+ silicon devices having graded junctions with varying portions of the depletion width extending into the p-side of the junction.

The feasibility of an all lumped-element high performance TRAPATT circuit having no significant electrical length separating one element from another or from the diode has been demonstrated by Clorfeine, et al.[1,2] However, to achieve a cost effective, all lumped-element TRAPATT circuit module for production purposes, many factors controlling the performance of a practical circuit module should be explored. Some of these factors will be discussed.

Diode Fabrication

The diodes used in this work are deep diffused p^+-n-n^+ silicon junction devices fabricated by the pill processing technique. Junctions are formed by diffusing boron into arsenic-doped silicon epitaxial layers on n^+-substrates. Epitaxial growth and diffusions are carried out in such a way as to minimize process-induced damage. Low boron surface concentrations are obtained to reduce stresses in the lattice. The electrical dc junction properties have sharp breakdown with no low-current oscillation or burn-out. Computer calculations are used to determine the doping and electric field properties. The width ratio (p-region width/total depletion region width), W_p/W_T, is varied by properly controlling the material parameters and diffusion conditions.

Circuit Design

An effective and simple modeling technique – the lumped modeling approach[3,4] – has been employed to design TRAPATT oscillator circuits by correlating the diode behavior to that of the external circuit. A time-domain device-physics lumped-model of a given TRAPATT diode structure is obtained by dividing the diode active region into "lumps" and applying the continuity and Poisson's equations to each lump. By also describing the external circuit in time domain, a simple simultaneous solution of the device-external circuit complex is obtained. For a specified terminal current, the solution predicts the circuit element values required to yield proper harmonic impedances for the efficient trapping of harmonics of the fundamental power and for the maximum coupling of the fundamental power to the load.

The criteria adopted in the circuit design are: maximum power capability consistent with near optimum efficiency, a wide range of tunability with adaptability to diodes of different characteristics, and simplicity. Figure 1 shows the schematic of the lumped-element oscillator circuit designed to meet the above criteria. The circuit consists of inductors, chip capacitors and tunable capacitors. L_1 (2 nH), L_2 (4.3 nH), L_3 (32 nH) form the series inductances for optimum circuit operation. C_1, C_2 and C_3 (1-10 pF each) are the variable capacitors used to provide the tuning necessary for harmonic loading and circuit adaptability to diodes of different characteristics. C_{B1} (43 pF), L_{B1} (51 nH) and C_{B2} (68 pF) and L_{B2} (100 nH) form a low pass filter to prevent RF power leakage into the pulse circuit. C_{op} (300 pF) is the blocking capacitor to prevent any bias-pulse from being wasted in the load.

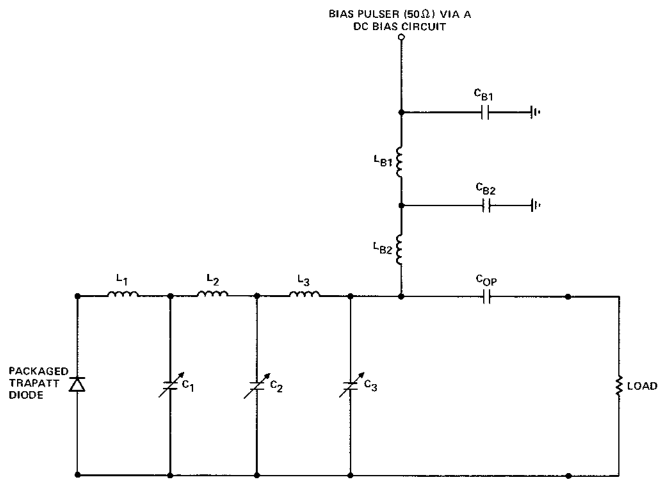

Figure 1 Schematic of lumped-element circuit.

RF Performance

Experiments are carried out to determine the maximum possible power capability of the diodes using pulses 200 ns to 1 μsec long. Peak power outputs of at least 500 Watts and minimum efficiencies of 25% at 1% duty have been consistently achieved from single devices with width ratios greater than 0.40. Figure 2 shows the oscillator RF performance for diodes from six

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different wafers. Each of the diodes has a diameter of 33 mil, breakdown voltage of 200 Volts, depletion region width of approximately 9 microns and varying width ratio, W_P/W_T. It is seen that the power capability of deep diffusion junction TRAPATT devices increases with the increase in the p-region width. The efficiency does not exhibit the same trend as the power, but the oscillation frequency shows a discernible increase for width ratios greater than 0.5. The maximum and minimum efficiencies observed for the power levels shown in Figure 2 are 38% and 25% respectively. Most of the power levels achieved are believed to be state-of the art.

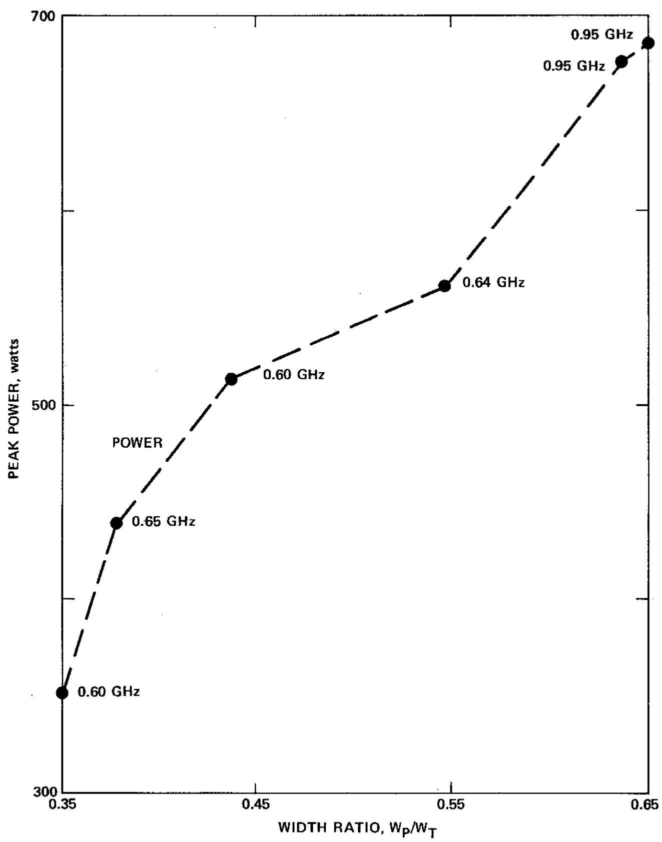

Figure 2 RF performance for varying p-region width to total depletion region width ratio.

Frequency tunability of the oscillator circuit and its diode frequency adaptability are shown in Figure 3 for a typical UHF diode (f_{opt} = 0.7 GHz, V_B = 200 Volts, diameter = 33 mils, I_{bias} = 12 Amps) and a typical L-band diode (f_{opt} = 1.1 GHz, V_B = 185 Volts, diameter = 17 mils, I_{bias} = 7 Amps). It is evident from the figure that the circuit has a broad tuning frequency range for a given diode and offers a wide range of adaptability to diodes of different characteristics.

Some of the experimentally observed factors controlling the circuit performance may be summarized as follows:

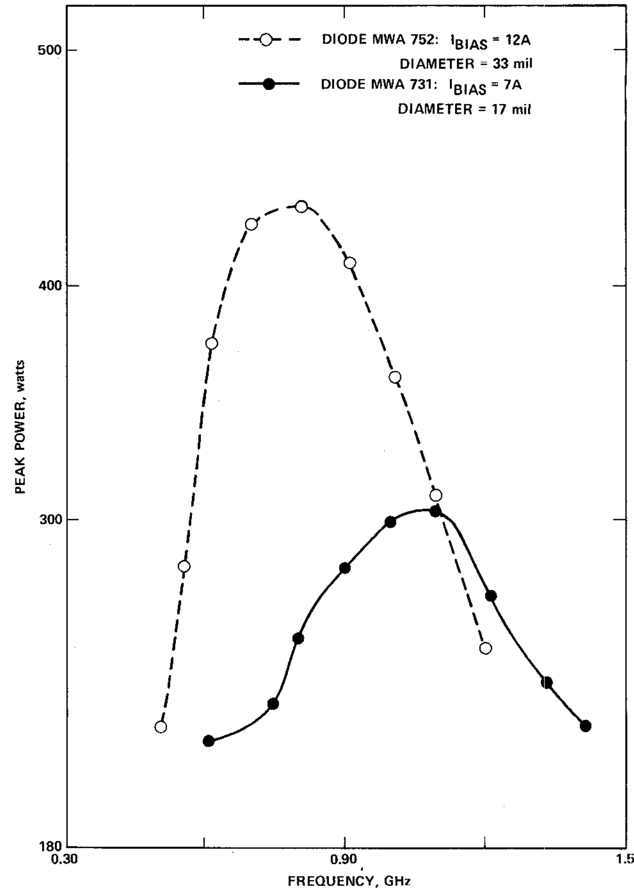

Figure 3 Frequency tunability and diode adaptability of oscillator circuit.

i) For a given lumped-element circuit with fixed element values, the package inductance controls the diode performance.[4]

ii) For a given diode and circuit configuration, the dc bias circuit between the pulser and the diode and the output loading conditions have a strong influence on the oscillator RF noise, mode break-up and jitter.

References

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