CALCULATED AND MEASURED SILICON PIN LIMITER SHORT-PULSE DAMAGE THRESHOLDS

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ABSTRACT

Limiters, used to protect sensitive electronics from high levels of rf radiation, are themselves subject to damage. A combined theoretical and experimental study has been made of damage thresholds of silicon PIN limiters with intrinsic region widths of 0.5 to 10 μm, using frequencies from 1.5 to 9.4 GHz and pulse lengths from 10 to 1000 ns.

INTRODUCTION

Limiters are used to protect sensitive electronics from damage due to exposure to high levels of rf radiation. However, limiters are themselves subject to such damage. Manufacturers seldom give damage thresholds for exposure to short pulses in the microsecond range, and there are almost no available data in the nanosecond range. This paper provides analytic scaling relations for this pulse length region that have been confirmed by measurements.

On-going analytic and experimental studies of the transient characteristics and the damage thresholds of silicon PIN limiters are being made at Harry Diamond Laboratories. Measurements are compared with the results from the computer program DIODE (1). The range of measurements and calculations include diodes with intrinsic region widths from 0.5 to 10 μm, frequencies from 1.5 to 9.4 GHz, and pulse lengths from 10 to 1000 ns.

VOLTAGE WAVEFORMS

Since usually only single diodes were damaged for a given set of parameters (frequency, pulse width, etc), voltage transients were measured so that additional comparisons with calculations could be made. Figure 1 shows an example of the fit of a calculated and measured turn-on transient. Forward and reverse half cycles must be calculated in separate runs with the DIODE program. The stored charge distributions from the forward half cycle are used as initial conditions for the reverse half cycle. Greater stored charges reduces the maximum reverse voltage in the following half cycle. This is illustrated in figure 1, where the second calculated

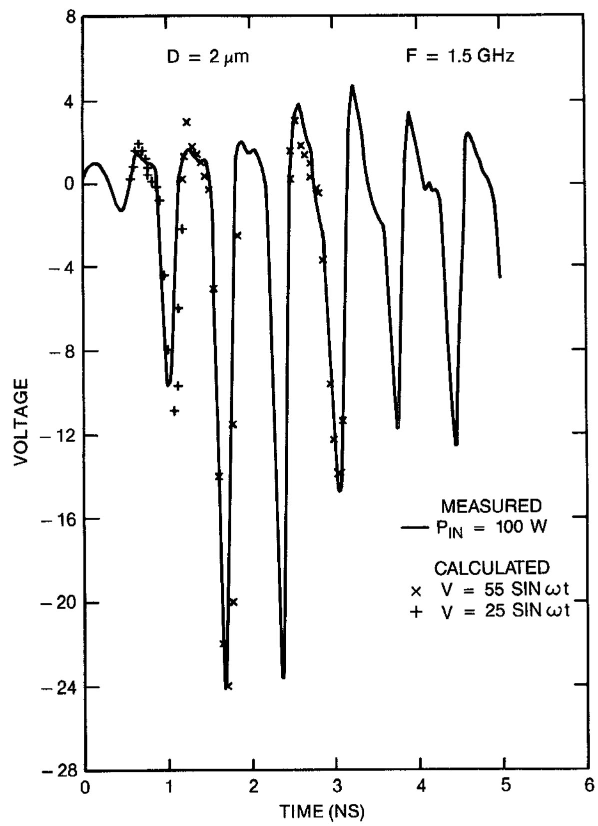

Figure 1. Comparison of calculated and measured turn-on transient.

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reverse waveform with 55 V applied has an order of magnitude greater stored charge. Different applied peak voltage values are required to simulate the rise time of the rf pulse.

Similar diodes with different lead inductances showed quite different output voltage waveforms, both as measured and calculated.

DAMAGE CALCULATIONS

The calculated threshold for damage was obtained from the heating rate at the specified power in order to reduce computation time. An average temperature rise of 350 K had previously been found to correspond with dc breakdown (1) for the 1N4148. However, PIN diodes have little negative resistance and a rise of 500 K was usually chosen for the damage point in this paper. Calculations of heating caused by video (dc) pulses were used to compare with the rf calculations of dissipated power. Relaxation oscillations were calculated above the avalanche breakdown voltage. Figure 2 shows an example of these calculations. The 1-μm diode showed the strongest oscillations of the various diode widths used in the calculations.

Calculations for video pulse exposures show that the damage (heating within the device) energy threshold is essentially constant between 10 ns and 1 us. However, the applied energy, including the energy dissipated across a 50 Ω load resistor, increases strongly as the pulse length decreases and the current increases.

Since the calculations are made for a constant voltage circuit, and the measurements with a constant power input, it becomes difficult to assign an input power for the calculations as the diode turns on (from very high to very low impedance compared to 50 Ω). With this uncertainty in the input power, calculated rf damage (heating) thresholds show a marked energy increase for pulses shorter than 1 μs, and are in rough agreement with the dc applied power in the range of tens of nanoseconds, as seen in figure 3 for a 1-μm diode. The variation of the threshold with frequency between 0.5 and 2 GHz is small.

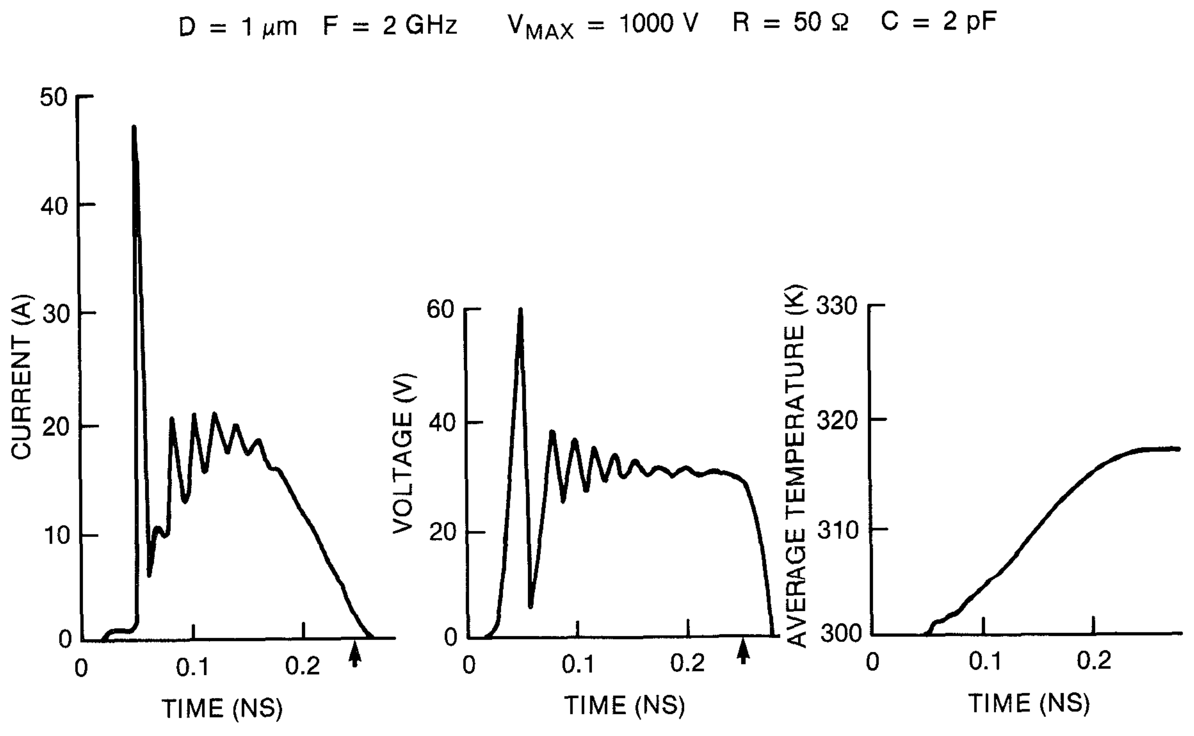

Figure 2. Relaxation oscillations and heating curve for reverse half cycle. Arrows indicate end of applied voltage half cycle.

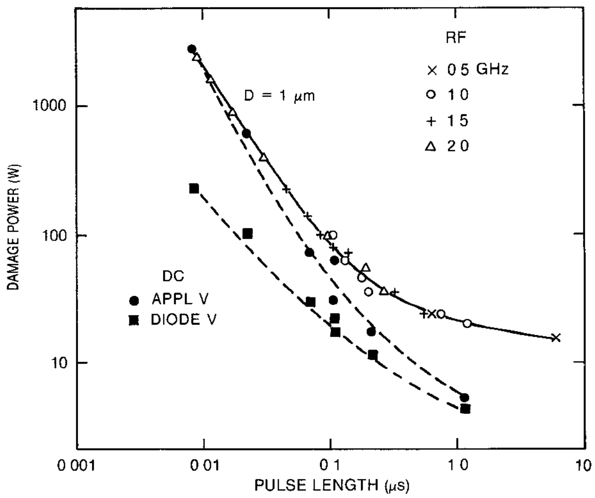

Figure 3. Calculated damage thresholds for 1-μm diode.

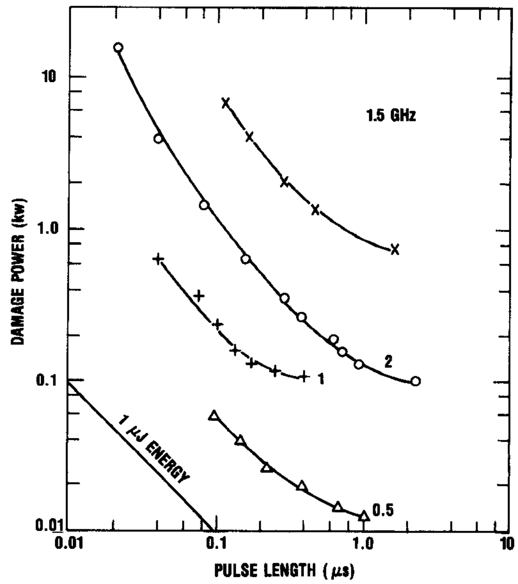

Figure 4. Calculated damage thresholds for diodes of various widths. Parameter is diode width in μm. A constant energy curve is also shown.

VARIATION IN DIODE WIDTH

Measured threshold damage power levels have shown a strong dependence on the width of the intrinsic region of the PIN diode. Results of calculated damage thresholds for diodes of 0.5-, 1-, 2- and 5-μm widths, as a function of pulse length (time to reach 500 K) are shown in figure 4. The rf frequency is 1.5 GHz. A slightly different formula for obtaining the input rf power from the applied voltage was used in figure 3 from that used in figure 4. Also a temperature rise of 350 K was used in figure 3 only.

Figure 4 shows that the threshold power decreases less than linearly with pulse length at the longer pulse lengths, but decreases faster than linearly for pulses less than 1 μs. In other words, the damage energy increases for both shorter and longer pulse widths of approximately 0.1 μs. A constant energy curve is shown in figure 4 for comparison. The computer program does not include heat conduction so that calculations beyond about 1 μs are questionable, depending upon the thermal time constant of the device. Heating rates of less than 1 K per nanosecond were set equal to zero. This is thought to approximately compensate for the neglect of heat conduction. The increase in energy for the shorter pulses is mainly attributed to greater reflected power from the higher conducting diodes.

The damage threshold power for a 0.1 μs pulse length is plotted as a function of diode width in figure 5. The slope of the straight line is 2.2, showing an increase with width slightly greater than the increase in volume. The areas of the devices were made proportional to the widths, keeping the junction capacitance constant. The calculated damage power is nearly an order of magnitude lower than the measured threshold for 10 ns pulses but the slope is in good agreement. The major reason for this discrepancy is believed to be the difference in the pulse length between the measured and calculated data. Figure 4 shows a large increase in energy as 10 ns is approached. Another important error in the calculations is believed to be related to an insufficient amount of stored charges accumulated during the forward half cycle calculation. No provision was made to accumulate charges from cycle to cycle, even though some calculations indicate such accumulation would occur.

COMPARISON WITH MEASUREMENTS

The measured damage threshold was obtained by step stressing the diode, either doubling the power at a constant pulse length or doubling the pulse

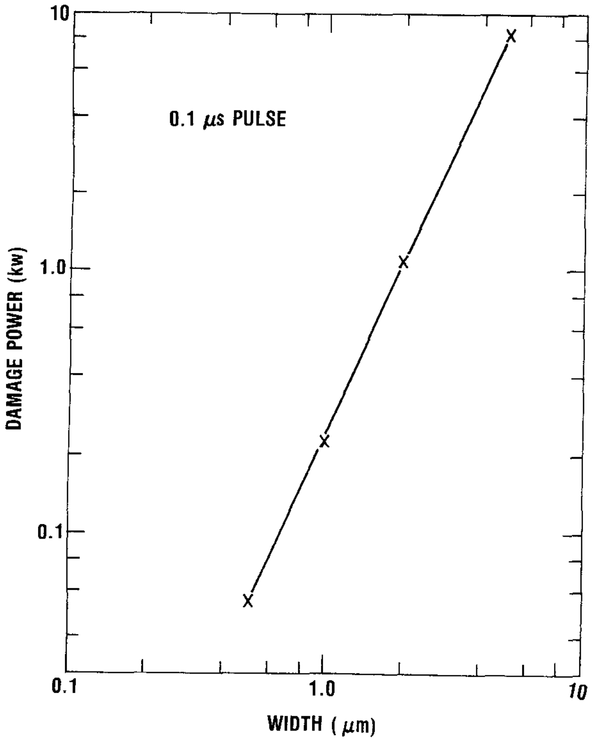

Figure 5 Calculated variation of damage thresholds as a function of diode width for 0.1-μs pulses.

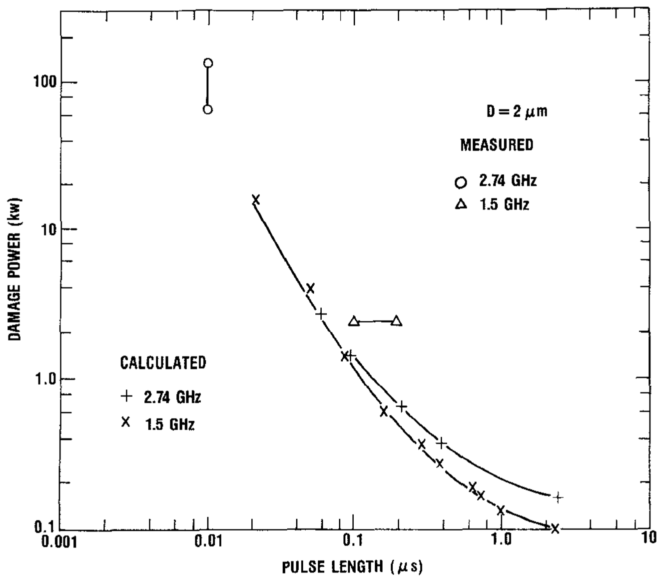

Figure 6. Comparison of measured and calculated damage thresholds for 2-μm diode. Experimental no-damage and damage points are shown.

length at a constant power. The criterion of damage was a definite lowering of the diode reverse-breakdown voltage. The measured damage for two 2-μm diodes is shown in figure 6. Two points are shown for each diode. The diodes survived the lower energy but failed at the higher energy. Also shown in this figure are the results of the calculations for a 2 μm diode at the same frequencies. For this wider 2-μm diode, there is appreciable frequency dependence at the longer pulse lengths, i.e, near the avalanche threshold. The formative time for the avalanche necessitates a higher breakdown voltage at higher frequencies, a transit time effect that is more evident for wider diodes. The agreement shown in Figure 6, between the measured and calculated thresholds, is satisfactory.

SUMMARY

Comparison of measured and calculated voltage transients of PIN diodes during turn-on has produced detailed qualitative agreement but not exact quantitative agreement. This study has contributed to the goal of understanding damage thresholds. It is also useful in designing dual diode limiters to reduce spike leakage and to increase the damage threshold.

1. A.L. Ward, "Calculations of Second Breakdown," IEEE Trans. Nucl. Sci., Vol. NS-24, pp 2257-2260, December 1977.