TRANSIENT RESPONSE OF PIN LIMITER DIODES

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ABSTRACT

Results of experimental and theoretical studies have determined which physical parameters of PIN diode junctions control their dynamic responses as limiters to fast risetime microwave pulses. Both rf and dc dynamic impedance measurements were made and compared, with good agreement, to theoretical calculations which model both the junction and intrinsic regions of the PIN diode.

INTRODUCTION

PIN diode limiters are used to prevent transient rf pulses from damaging sensitive, low-noise microwave receiver components. The performance of the limiters in response time and recovery time is dependent on dynamic mechanisms taking place inside the PIN diode. We have made detailed measurements and theoretical calculations of PIN diodes to ascertain which device and circuit parameters control these response times.

A series of experimental and analytic analyses of the transient response of PIN diodes has been completed, consisting of measuring the responses to fast-rising microwave pulses and video pulses. These studies have yielded the impedance of the diode during the turn-on period. This transient impedance is needed to predict the performance of the PIN diode in a circuit for the "optimum" limiter performance during these periods. Measurements of this type were first performed on thick PIN diodes in the 1960's at 10 MHz (Ref. 1).

EXPERIMENTAL RF PULSE MEASUREMENTS

RF pulse measurements were performed on packaged (pill-prong microwave package) Si PIN devices mounted in series in a modified air line (shown in fig. 1). The input waveform was generated by using a matched tee to combine a dc pulse (generated using a charged line) and a sinusoidal signal. The 1-GHz rf pulse measurements were made with the use of a 6-GHz digitizing oscilloscope. A 1-GHz scope was used for the 300-, 550-, and 800-MHz rf pulse measurements. Typical forward current and voltage responses are shown in figure 2 for a 10-um device. The magnitude of the impedance was taken from the current voltage response and plotted as a function of time, as shown in figure 3. The maximum estimated error in this process is on the order of 20%. These measurements include the parasitic capacitance and inductance of both the diode pill-prong microwave package and the sample holder. The inductance of the diode package was measured using a shorted diode package. The capacitance of the probe and diode package is less than 1 pF, and the combined circuit and package inductance was estimated using a network analyzer to be 3 nH.

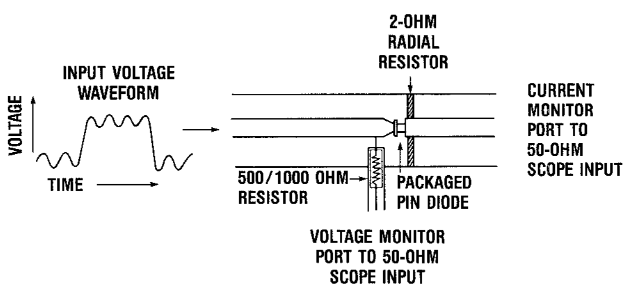

Figure 1. Modified 50-ohm air line used to make the voltage and current measurements on the PIN diode.

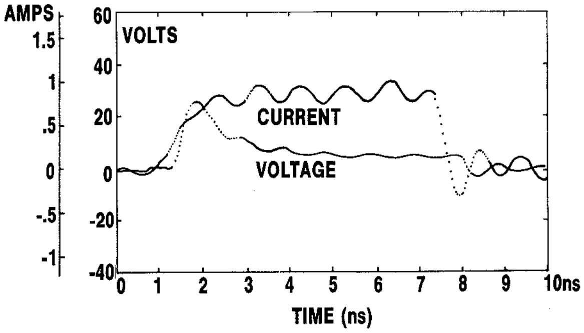

Figure 2. Typical oscilloscope traces of the forward current and voltage response for a 10-μm PIN diode.

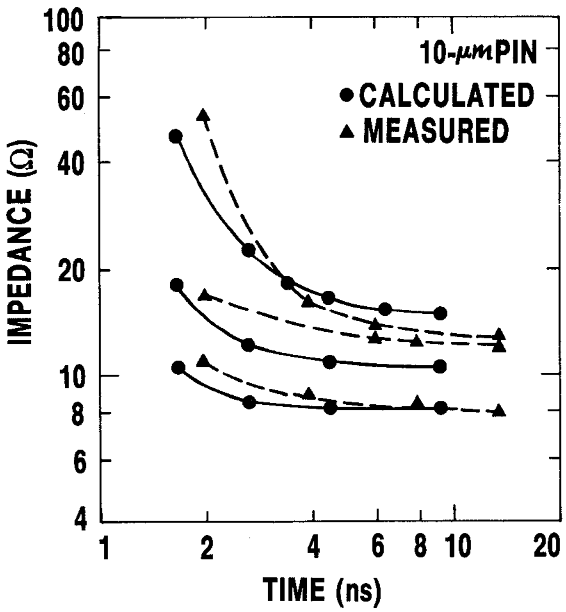

Figure 3. Measured and calculated rf impedance during forward turn-on for 10-μm diode at 1.0 GHz. Average current levels from top to bottom are 160, 330, and 710 mA, respectively, for the calculated data, and 154, 404, and 640 mA, respectively, for the measured data.

THEORETICAL CALCULATIONS OF RF IMPEDANCE TRANSIENTS

RF turn-on impedance transients were computed with the DIODE program (Ref. 2). This computer program models both the junction and intrinsic regions of the PIN diode. Simpler analytic models incorrectly represent the nonlinear dependence of the mobility, recombination times, and space charge effects in the high field regions.

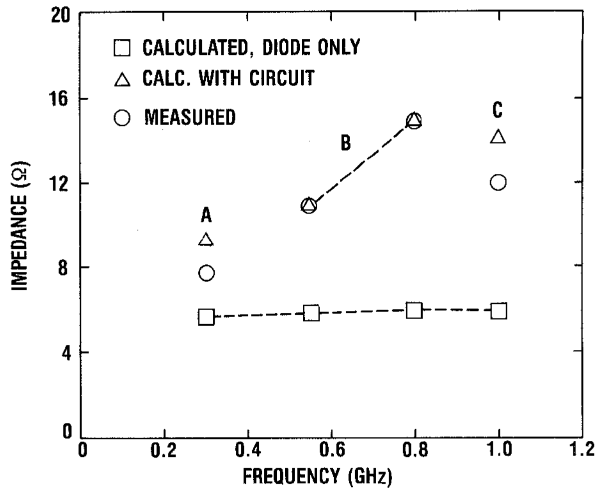

Figure 4. Measured and calculated quasi-equilibrium forward biased rf impedances for 10-μm diode as a function of frequency. Average current levels are (A) 170 mA, (B) 300 mA, and (C) 400 mA.

Failure to include these considerations results in poor agreement with experiments, especially for "thin" (50 um or less) intrinsic regions. An example of the agreement between the calculated and measured rf turn-on impedance transients is shown in figure 3.

Measurements were also made on another 10-μm diode at lower frequencies, and the variation of the quasi-equilibrium impedance at approximately the same current level is seen in figure 4. Also shown on the same figure are results of calculations. The impedance of the diode itself is essentially independent of frequency over this range, but with the addition of 2 nH for the diode package and sample holder inductance and 2 ohms for the current measuring resistance, the calculated impedance is in good agreement with the measured values. For a fixed current, the calculations show that the total impedance varies linearly with frequency from 0.1 to 5 GHz. In order to fit the experimental data, a recombination rate of 5 times that of ideal intrinsic material was needed. Increased recombination increases the rf impedance.

Extending the calculations to 50 μm at 1 GHz and 10 μm at 5 GHz yields the results in figure 5 for both turn-on and recovery responses of the diodes. In this figure the impedance versus time

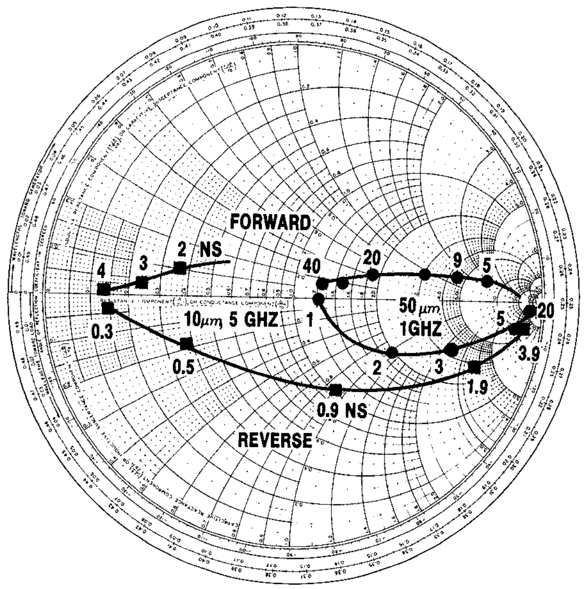

Figure 5. Transient impedances calculated for 10-µm and 50-µm diodes at 5 and 1 GHz, respectively. The times are given in nanoseconds.

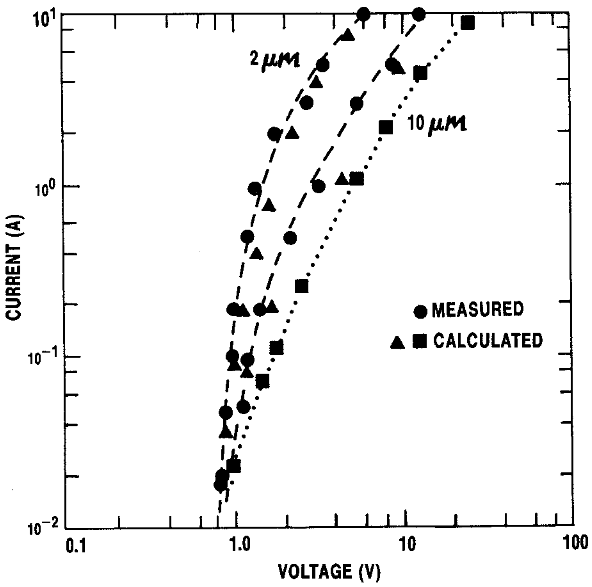

Figure 6. Comparison of measured forward-bias current voltage characteristics with calculated characteristics for 2- and 10-µm diodes. For the 10-µm diode, squares indicate an ideal PIN, while triangles indicate the measured profile.

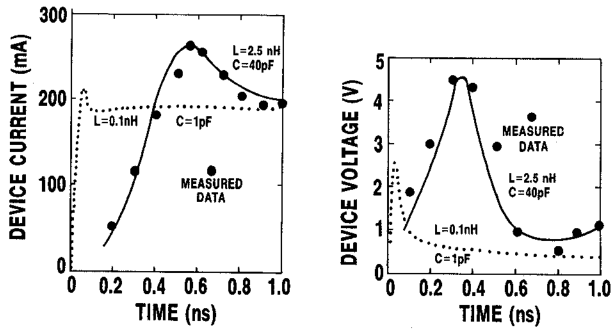

Figure 7. Comparison of measured and calculated forward turn-on transients for 2-µm diode.

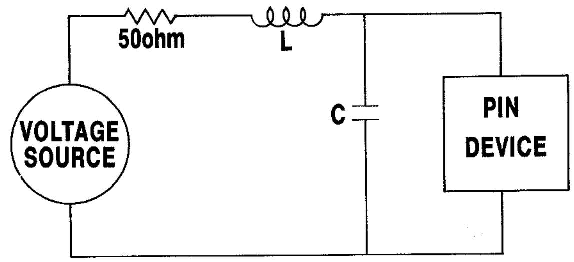

Figure 8. Circuit used for diode calculations.

(in nanoseconds) is plotted. To build a very fast PIN limiter, consideration must be given to this impedance time profile. Note that the response of the 10-µm device is about 10 times faster than the 50-µm device in a 50-ohm circuit.

VIDEO PULSE MEASUREMENTS AND CALCULATIONS

Video pulse measurements of the PIN devices have also continued (Ref. 3) because they provide a ready technique for evaluating PIN performance. Video turn-on measurements and calculations have been made for various diode thicknesses. Figure 6 shows a comparison of quasi-equilibrium current voltage characteristics for 2- and 10-µm diodes. For the 10-µm diode the calculations were made for both a flat-profile PIN diode and the sloped doping profile obtained by the manufacturer from his capacitance versus voltage measurements. The latter profile was also required to fit the rf impedance data. Comparison of the experimental and analytic turn-on response of a 10-µm diode is shown in figure 7. The measurements were

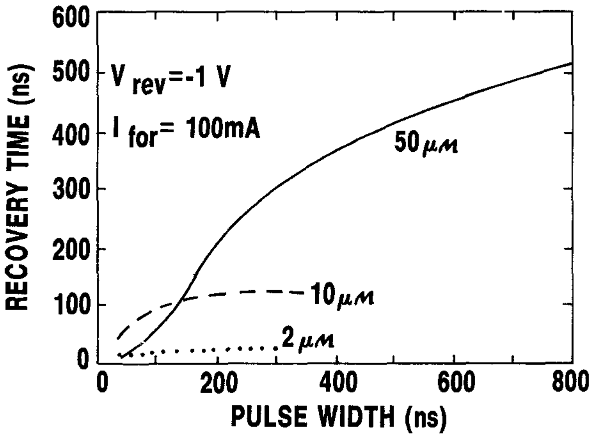

Figure 9. Measured recovery time versus forward current pulse width for constant current amplitude and reverse bias voltage.

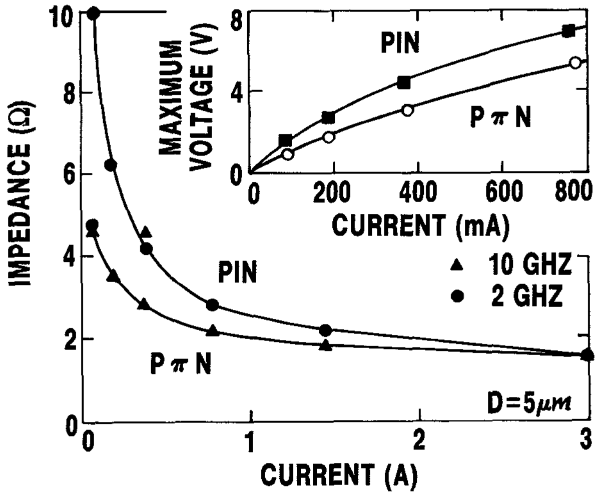

Figure 10. Comparison of quasi-equilibrium forward-biased impedances of 5-μm PIN and PπN diodes. The π doping is $1X10^{15}$ cm^{-3}. The inset compares the maximum turn-on voltage of the two diodes.

performed in a coaxial insertion unit similar to figure 1. In order to represent the 0.5-ns risetime and ringing of the incident pulse (because of the scope and probe) in the computer calculations, it was necessary to use L = 2.5 nH and C = 40 pF in the simple equivalent circuit shown in figure 8. The experimental and analytic agreement obtained with these values is evident in figure 7. If the PIN diode were measured with very-fast-risetime pulse and oscilloscope (equivalent to L = 0.1 nH, C = 1 pF), the response calculated in figure 7 would be obtained. The DIODE program predicted that the recovery time for a PIN diode is a function of the forward current and pulse width. The video measurements shown in figure 9 confirmed this prediction. Measurements were made with a 100-ma forward current pulse of varying length and a reverse bias voltage of 1 volt for 2-, 10-, and 50-μm diodes. The recovery time can be reduced with additional reverse bias.

DISCUSSION AND FUTURE WORK

The combination of the experimental and analytic investigations of PIN diodes has yielded confidence in the DIODE program's ability to represent the actual device responses. One interesting analytic result is that a low level of P doping in the intrinsic region reduces the transient turn-on response time and reduces the turn-on peak voltage. Figure 10 shows how a low level of P doping reduces the impedance, and turn-on peak voltage as a function of current. The holes in the intrinsic region help compensate for the lower hole mobility in Si. Also, because of the hole mobility, the DIODE program does not predict a faster response for GaAs PIN devices. Experimental verification of these two analytic results is ongoing as part of HDL's program. Future work will include building and evaluating "optimum" response limiters and two-diode limiters for high-power applications.

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2. A. L. Ward, "Calculations of Second Breakdown in Silicon Diodes," HDL-TR-1978, August 1982 (see sect. 2).

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