AN EVALUATION OF POINT CONTACT TUNNEL DIODES AS MICROWAVE CIRCUIT ELEMENTS*

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Introduction. The point contact geometry tunnel diode is recognized as an excellent low level detector. A recent analysis[1] indicates that the tunnel diode, under certain conditions, has a figure of merit greater than any other known diode. In diodes designed for operation in the millimeter wave region, it is found that a number of factors arise which determine the performances of the devices that are not significant in diodes designed for the lower frequencies (less than 20 GHz). This paper reports some measurements carried out on point contact tunnel diodes in the millimeter wave region and evaluates the performances of these diodes in various applications.

The diodes under discussion are fabricated in the package shown in Figure 1. The nickel pin, capped with the diode, is then inserted into the appropriate measurement circuit. The diodes are pulsed formed using indium wire with n-type germanium (dopant level $\approx 2 \times 10^{19}/\text{cm}^3$) and tin wire with p-type gallium arsenide (dopant level $\approx 6 \times 10^{19}/\text{cm}^3$). Peak to valley ratios are typically 3:1, and the peak currents range up to 2 ma for the diodes tested.

Equivalent Circuit Measurements. To characterize our diodes, equivalent circuit parameters were measured as a function of bias and frequency using a General Radio 1607 Immittance Bridge. Because of the small values of the junction capacitances, extreme care must be taken to insure that a proper reference plane is established. A procedure for establishing this plane will be described. Because the calculated parameters of the equivalent circuits were found to vary in a consistent manner with the peak currents, the peak currents were used to characterize the diodes.

The junction capacitances of these tunnel diodes were found to be strongly dependent on bias and frequency below the peak voltage as shown in Figure 2. DeAndrade[2] and Arizumi[3] have observed a similar dependence on bias and proposed models based on free carrier contributions to the junction capacitance. We have attributed the frequency dependence to delayed release of tunnelling carriers from trapping levels in the depletion region. Analytical results, based on an average trapping time of 1.3×10^{-8} sec. have shown good agreement with the experimental results. These measurements indicate that small signal equivalent circuit measurements at bias voltages less than the peak voltage have to be carefully interpreted to avoid making erroneous predictions of the performances. Additional evidence for the existence and importance of these traps have been observed in noise measurements.

Using the equivalent circuit parameters, the various cut-off frequencies were calculated. For our purposes, we are concerned with the resistive cut-off frequency, f_{co}, at which the real part of the admittance is zero, and the detector cut-off frequency, f_{DET}, at which the spreading resistance equals the magnitude of the junction impedance. The latter frequency, f_{DET}, is essentially a measure of the highest frequency at which the diode acts as an efficient detector. For reasons discussed later, f_{DET} is of interest only for the region near zero bias. These frequencies are plotted as a function of peak current in Figure 3. It is observed that our diodes will function efficiently as detectors at 70 GHz if their peak currents are less than 400 μa. The maximum power output of an oscillator using one of the diodes as a function of frequency can be determined from the static characteristic and Figure 3. The results are shown in Figure 4.

The analytical results predicted on the basis of the equivalent circuit have been verified by measurements at millimeter wave frequencies. In general, the measured performances approach the predicted performances as an upper limit, as expected.

Microwave Measurements. The diodes were evaluated as low-level detectors by measuring the minimum detectable signal (MDS). This quantity is 8 db smaller than the tangential sensitivity defined by others.[1] Sensitivity measurements were made in the 25-40 GHz and 70 GHz frequency ranges. At 25 GHz, the best MDS for a commercial unit was -64 dbm (Sylvania IN26) compared to -73 dbm for one of our units. At 70 GHz a Sylvania IN78 had a sensitivity of -48 dbm compared to -65 dbm for our unit. The best sensitivity obtained by a standard laboratory "run in" type of silicon diode with a tungsten catwhisker was -63 dbm. This best case was very unstable. The high performance of similar tunnel diodes as detectors has been previously shown by Burrus.[4, 5]

Some improvement (1-2 db) in sensitivity can be obtained by biasing the tunnel diode slightly. Further increases in bias result in lower sensitivities because of 1/f noise. The zero biased diode has the lowest 1/f noise, and our diodes are generally operated at this point. The reasons for the increased noise of millimeter wave diodes will be discussed.

Several diodes whose predicted f_{DET} fell in the Ka band region were evaluated. Measurements of MDS versus frequency showed breaks at approximately the predicted frequencies. Additional frequency dependences were attributed to the microwave circuit.

MDS measurements carried out on a large number of diodes with varying peak currents showed a relatively smooth dependence. This indicates, again, the consistency at which the diodes can be fabricated. Some scatter could be attributed to differences in the individual packages.

A microwave oscillator was fabricated for K band. As shown in Figure 4 power outputs less than a microwatt could be expected. Power outputs that were observed were usually less than 0.2 μw with a maximum value of 0.75 μw in agreement with Figure 4.

Noise Measurements. Measurements of the noise of a few diodes have been made using standard techniques. Considerable 1/f noise which increases rapidly with bias was observed. The noise spectrum only approximately fits a 1/f dependence and shows variation from diode to diode. Abrupt increases in noise in the negative resistance region are attributed to defect levels in the tunnelling region. Occasionally, a "hump" appears in the static characteristic at this point. Recent results will be summarized.

Conclusions. The point contact geometry tunnel diode has been found to be an excellent low-level detector in the millimeter wave region. Its performance can be predicted on the basis of a small signal equivalent circuit if care is taken to correctly interpret the results in terms of trapping levels that may be present.

It was found that 1/f noise is a significant factor in limiting the sensitivity of the device under biasing. The power output of oscillators made from these diodes have low power output in agreement with analytical results.

Using the small signal equivalent circuit, the restrictions on device performance by the semiconductor properties can be discussed. The usefulness of tunnel diodes as microwave devices above 20 GHz are summarized on this basis.

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Figure 1. Diode Package

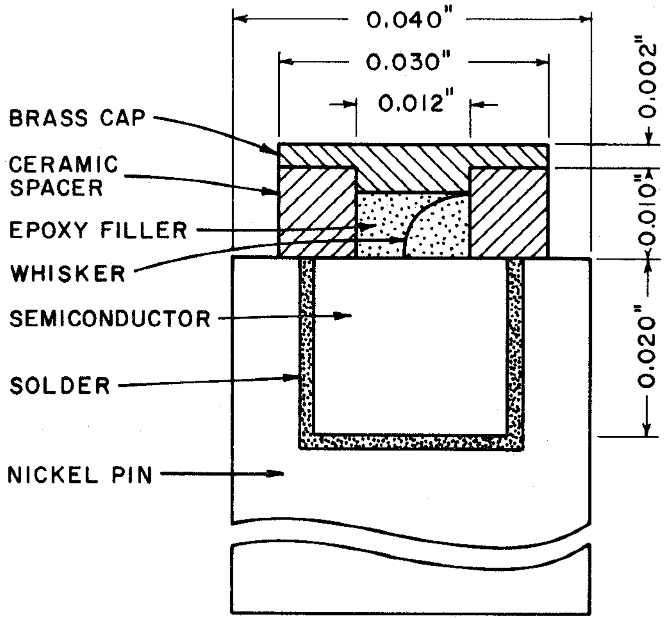

Figure 2. Junction Capacitance as a Function of Bias Voltage and Frequency

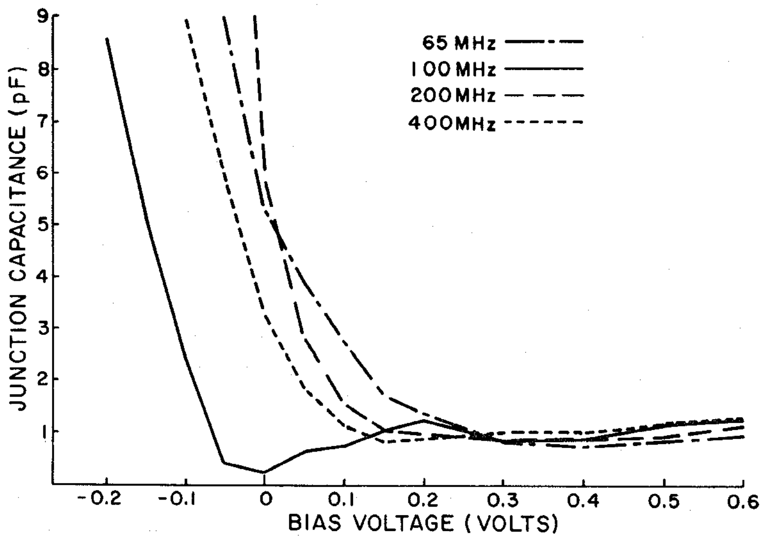

Figure 3. Resistive Cut-off Frequency and Detector Cut-off Frequency vs. Peak Current

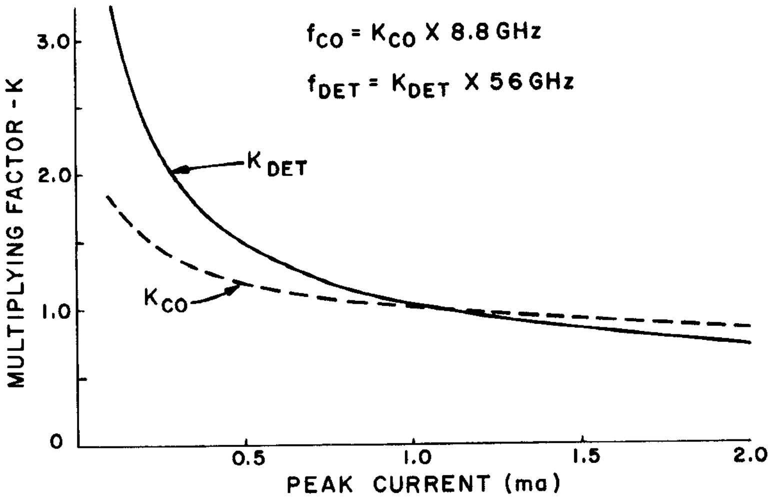

Figure 4. Peak Output Power vs. Frequency