COMPUTER-AIDED CHARACTERIZATION OF MILLIMETER-WAVE SEMICONDUCTOR DEVICES

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ABSTRACT - A new, improved characterization technique for evaluating semiconductor devices at millimeter-wave frequencies is described. By this technique both passive and active parameters of the device (e.g., series resistance, junction capacitance, negative resistance), and also the circuit parasitics can be characterized accurately.

INTRODUCTION

The development and applications of various types of semiconductor devices at millimeter frequency ranges have been increasing at a rapid rate in recent years. In order to evaluate the qualities of a device of interest and to design an optinum circuit in which the device is to be used, the device must be characterized in terms of an equivalent circuit.

At the lower microwave frequency ranges through X-band, the device characterization can be carried out in a relatively simple manner in conjunction with a network analyzer.[1,2] At the higher frequency ranges such as millimeter-wave ranges, however, characterization must be performed in a waveguide. A method for measuring the cutoff frequency of a millimeter-wave varactor diode mounted in a Sharpless package[3] and a technique for characterizing an oscillating IMPATT diode[4] have recently been reported. These measurement techniques which employ the resonant characteristics of the test circuit with the device require variable frequency sources. Furthermore in these methods, which utilize reduced height waveguide sections, it is generally assumed that the extraneous parasitics due to the impedance transformer, bias feed through, device mounting, and waveguide short are small and will not affect the measurement significantly. However, the contributions of these parasitics which are very sensitive to frequency have significantly increased effects on the measurement accuracy, particularly at millimeter-wave frequencies.

In the new characterization technique described in this paper, both the device parameters and the associated circuit parasitics are characterized. This technique, which does not depend on resonant characterisitcs, can be carried out at a single frequency. Simply stated, the device parameters and the circuit parasitics which all treated as unknowns are evaluated from the measured VSWR and phase-shift variations as a function of the position of the micrometer-driven movable short by means of a computer-aided curve fitting method.

CHARACTERIZATION METHOD

Depicted in Figure 1 are the experimental test circuit used for the measurement and its complete equivalent circuit. The device is embedded in a reduced height waveguide section under a bias pin, and the matching to regular height waveguide is accomplished by a pair of multiple-step quarter-wavelength transformers. A micrometer-driven short is also provided in the regular height waveguide section behind the device. The electrical distance from the device plane to the probe in this slotted-line section and that from the device plane to the movalbe short are presented by θ_1 and θ_2, respectively. Y_o denotes the characteristic admittance of the reduced height waveguide section. The complex impedance due to the movable short Z_{SHT} may include a small loss. Z_1 and Z_2 are the series impedance elements which arise from the bias pin and the bias feedthrough. The coupling network between the device and the waveguide circuit can take many different forms depending on the geometries of the device package and the bias feedthrough. It is perfectly general, however, to represent the coupling network by a T network which can be identified closely with the physical circuit components.

The input impedance of the entire circuit varies as a function of the position of the movable short. Thus VSWR and relative phase-shift can be measured as a function of relative position of the movable short. The exact values of θ_1 and θ_2 which are very difficult to measure, are not necessary. Figure 2 shows an example of such data. From this data all the quantities in the equivalent circuit which are treated as unknowns can be evaluated by means of an iterative curve fitting process with a computer. In the computing process a minimum-mean-square-error solutions are obtained since an exact solution may not always exist due to possible measurement errors. The accuracy of the measurement technique and the computer program were examined by comparing the passive and active parameters of an IMPATT diode measured by this technique at X-band frequencies with those of the same diode measured by a network analyzer technique. The comparison of the parameters measured by the two techniques showed excellent agreement with smaller than 10% differences. In the following, characterization of a millimeter-wave IMPATT diode is described as an example.

IMPATT DIODE CHARACTERIZATION

Figure 3a shows the diode structure and an equivalent circuit of a millimeter-wave IMPATT diode consisting of a silicon p-n junction diode chip bonded to a copper heat sink, and connected to a small quartz standoff by a gold ribbon. The steps employed for the measurement of the passive parameters (R_s and C_j) and the parasitics (L_s and C_p) of the diode are depicted in Figure 3b. In order to measure the active parameters ($-G_n$ and L_a), the circuit must be stabilized. However, the characteristic admittance Y_o of a practically realizable reduced height waveguide circuit is in general much smaller than the negative conductance of typical millimeter-wave IMPATT diode. A stabilization method developed is shown in Figure 3c. The stabilization is accomplished by means of an impedance trasnformer in the form of a reactive element connected in series with the device. The series reactive element is provided by a coaxial section as shown in the Figure. Figure 4 shows the passive parameters and the frequency dependent active parameters measured by this technique. The characteristics of an IMPATT amplifier theoretically calculated based on the measured diode characteristics and the corresponding experimentally measured amplifier characterisitcs are shown in Figure 5, where gain and gain-bandwidth product are plotted as a function of frequency for various positions of the movable short. The comparison of the theoretical curves and the experimental curves shows excellent agreement.

CONCLUSIONS

In summary, this paper presents a new, improved characterization technique for millimeter-wave semiconductor devices. By this technique both the device parameters and the circuit parasitics which are sensitive to frequency can be accurately characterized over a broad frequency range. Consequently, significant improvements can be achieved in the evaluation of devices and the design of solid-state circuits in the millimeter-wave frequency range.

REFERENCES

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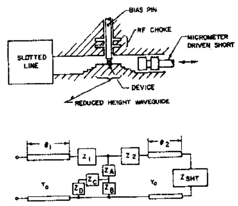

Figure 1 Test circuit structure and an equivalent circuit.

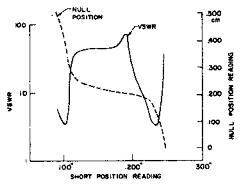

Figure 2 Typical variation of VSWR and phase-shift as a function of the position of the movable.

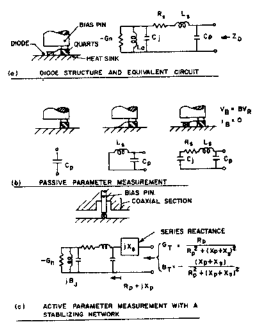

Figure 3 Characterization procedure for a millimeter-wave IMPATT diode.

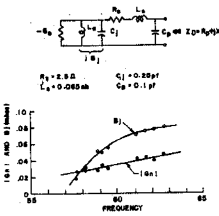

Figure 4 Measured parameters of a millimeter-wave IMPATT diode.

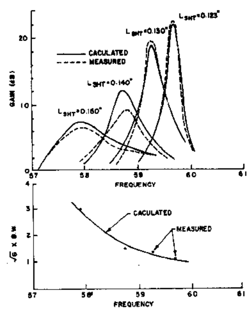

Figure 5 Comparision of experimental results with theoretically calculated amplifier characteristics based on the measured diode parameters.