CHARACTERIZATION OF PLANAR RESONATORS BY MEANS OF INTEGRATED SCHOTTKY DIODES

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Abstract

In this paper a method is presented to examine the suitability of planar structures to work as a resonator for IMPATT diodes in a frequency range above 70 GHz. The IMPATT diode is replaced by a SCHOTTKY diode previously characterized by impedance. It is suggested to test the suitability of the resonator for an IMPATT diode by employing the radiation characteristics of the structure. This set-up allows the determination of the detector's sensitivity depending on the frequency. The sensitivity corresponds to the matching of the resonator and the SCHOTTKY diode. Thus, for maximum sensitivity the equation $Z_{SCHOTTKY} \approx - Z^*_{IMPATT}$ allows to assess the suitability of the planar structure to function as a resonator for an IMPATT diode.

1. Introduction

The demand for monolithic integrated systems led to the fusion of active element and resonator to form an oscillator [1]. This device does not need connection lines between separate compounds thus resulting in reduced space requirements. At the given frequency of 76 GHz IMPATT diodes are suitable as active elements on silicon substrates, but demand a resonator resistance below 3 Ω. To build an oscillator the input impedance of the resonator has to be known precisely [2].

To determine the input impedance of the resonator at 76 GHz only coplanar on-wafer probing can be used. The required equipment for this type of measurement is available but the probing tips interact with the field radiated by the resonator resulting in a changed input impedance. The use of additional coplanar lines to transfer the location of the probing-tips away from the resonator has the same effect - a changed input impedance.

We suggest to test the suitability of the resonator for an IMPATT diode by employing the radiation characteristics of the set-up. Therefore the IMPATT diode is replaced by a SCHOTTKY diode changing the former oscillator structure into a detector. The characterization of the resonator uses the fact that for frequencies above 70 GHz the relation $Z_{SCHOTTKY} \approx - Z^*_{IMPATT}$ is valid. This relation has been found by on-wafer measurements of the small-signal-parameters of the diodes. For a given input impedance of the SCHOTTKY diode it is possible to estimate the resonator's input impedance for the frequency range above 70 GHz by evaluating the measured sensitivity.

2. Formulation of the Problem

2.1 Small-Signal-Impedance of IMPATT-Diode and SCHOTTKY Diode

By on-wafer-measurements of IMPATT- and SCHOTTKY diodes in the frequency range of 1-60 GHz the linear equivalent circuits have been derived [3]. The impedance for each type of diode is depicted in Fig. 1.

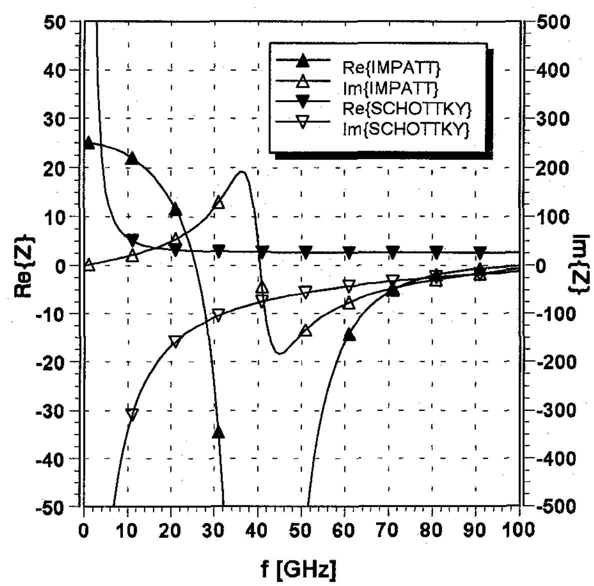

Fig. 1 Impedance of IMPATT- and SCHOTTKY diodes, measured: 1-60 GHz; extrapolated: 60-100 GHz

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The linear equivalent circuits of IMPATT- and SCHOTTKY diode are shown in Fig. 2 and Fig. 3, respectively.

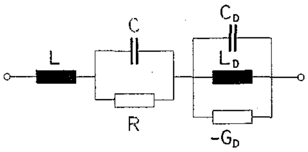

Fig. 2 Equivalent circuit for IMPATT diodes

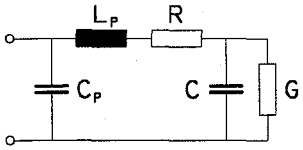

Fig. 3 Equivalent circuit for SCHOTTKY diodes

In the frequency range above 70 GHz the relation between the two impedances can be approximately noted as follows:

$$Z_{Schottky} \approx -Z^*_{IMPATT} \quad \Rightarrow \quad \begin{matrix} R_{Schottky} \approx -R_{IMPATT} \,; \\ X_{Schottky} \approx X_{IMPATT} \end{matrix} \qquad (1)$$

In this paper a resonator with an input impedance Z_R is examined. For the purpose of signal generation an IMPATT diode is integrated into the resonator. The condition for oscillation is given by:

$$Z_R + Z_{IMPATT} = 0 \qquad (2)$$

When the IMPATT diode is replaced by a SCHOTTKY diode, due to the radiated field the configuration works as a receiver. The impedance is characterized by:

$$Z_R - Z^*_{Schottky} = 0 \quad \rightarrow \quad Z_R = Z^*_{Schottky} \qquad (3)$$

Power matching between resonator and SCHOTTKY diode is achieved only while the oscillation condition is satisfied, resulting in maximum sensitivity. This interrelation is the basis for the analysis below.

2.2 Matching Plane

The approach to determine the resonators impedance is made by evaluating the detectable power.

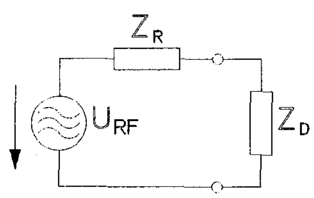

Fig. 4 Small-signal RF circuit

Z_R and Z_D as depicted in Fig. 4 describe the impedance of the resonator and the impedance of the detecting diode, respectively.

$$\begin{aligned} Z_R &= R_R + j\,X_R \\ Z_D &= R_D + j\,X_D \end{aligned} \qquad (4)$$

The real power dissipated by the power source is given by:

$$\begin{aligned} P_W &= U_{RF}^2 \frac{R_D}{(R_D + R_R)^2 + (X_D + X_R)^2} \\ P_{W\max} &= \frac{U_{RF}^2}{4\,R_D} \Bigg|_{Z_R = Z_D^*} \end{aligned} \qquad (5)$$

For $Z_R = Z^*_D$ the real power P_W reaches its maximum value P_{Wmax}. By substituting the impedance of the resonator the ratio of the received real power to the maximum real power is given by

$$M(f,\Delta Z) = \frac{P_W}{P_{Wmax}} = 4\,\frac{1 + \frac{\Delta R}{R_D}}{\left(2 + \frac{\Delta R}{R_D}\right)^2 + \left(\frac{\Delta X}{R_D}\right)^2} \qquad (6)$$

$$\begin{aligned} Z_R &= Z_D^* + \Delta Z \\ \rightarrow Z_R &= R_D + \Delta R + j(-X_D + \Delta X)\,, \end{aligned}$$

where ΔZ is a mismatch parameter. $M(f,\Delta Z)$ is a mismatch function between the resonator impedance and the diode impedance ($0 \leq M(f) \leq 1$). Fig. 5 shows $M(f,\Delta Z)$ as a function of the normalized mismatch parameter $\Delta Z/R_D$.

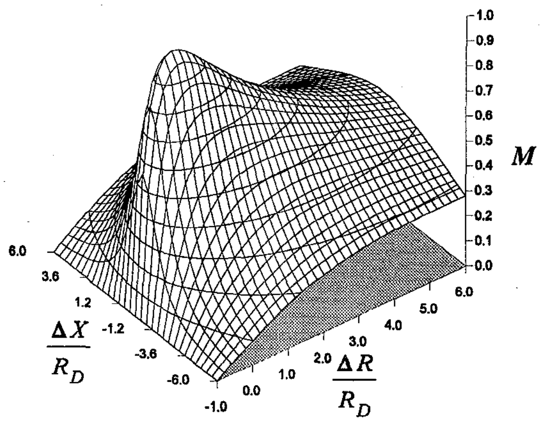

Fig. 5 Matching plane, unit 100%

Note the sharp decline of M($f,\Delta Z$) when the resistance of the resonator exceeds the impedance of the SCHOTTKY diode.

The detected RF-power at the diode is sensitive to slight changes of the resonator impedance, because of the low impedance level of the SCHOTTKY diode ($Z_D \approx (3 + j30)\,\Omega$). At maximum sensitivity precise determination of the resonator impedance is possible.

2.3 Characterization of the Input-Impedance of the Resonator

Due to the non-linear I-V-characteristic of the SCHOTTKY junction RF-oscillations are immediately rectified. For a constant bias current the output voltage at the diode varies with the RF power. The equivalent circuit illustrated in Fig. 3 was verified by on-wafer measurements in the frequency range of 1-60 GHz. G, C and R represent the active SCHOTTKY contact, the junction barrier capacitance and the bulk resistance, respectively, while parasitic elements are described by C_P and L_P. In general, the input admittance $Y_D = G_D + j B_D$ is referred to as :

$$G_D = \frac{G + RG + \omega^2 C^2 R}{(1 + RG - \omega^2 L_P C)^2 + (\omega L_P G + \omega C R)^2}$$

$$B_D = \omega C_P + \frac{\omega C + \omega^3 C^2 L_P + \omega L_P G^2}{(1 + RG - \omega^2 L_P C)^2 + (\omega L_P G + \omega C R)^2} \quad (7)$$

The available RF real power at the varistor is $P_W = M(f,\Delta Z) \cdot P_{W max}$ while the conductance G at the SCHOTTKY junction absorbs the power P_G:

$$\frac{P_G}{M(f,\Delta Z)\cdot P_{W\,max}} = \frac{\frac{G}{G^2 + \omega^2 C^2}}{\frac{G_D}{G_D^2 + B_D^2}} \quad (8)$$

Due to the square-law rectification of the RF power at G the deviation of the bias current ΔI_0 is evaluated by

$$\Delta I_0 = \frac{e}{2kT}\,\frac{1}{1 + GR + GR_M}\,P_G = \frac{e}{2kT}\,\frac{G\,(G_D^2 + B_D^2)}{(1 + GR + GR_M)\,G_D\,(G^2 + \omega^2 C^2)} \cdot M(f,\Delta Z)\cdot P_{W\max} \quad (9)$$

Therefore, the current sensitivity β and the voltage sensitivity γ of the detector are determined by:

$$\beta = \frac{\Delta I_0}{P_{W\max}}\;; \qquad \gamma = \beta\, R_M = \frac{\Delta I_0\, R_M}{P_{W\max}} \quad (10)$$

The maximum sensitivity γ_{max} is derived from the equivalent circuit of the SCHOTTKY diode under the assumption of ideal power matching $M(f,\Delta Z) = 1$. The relation between γ and γ_{max} is given by:

$$\gamma = \gamma_{max}\, M(f,\Delta Z) \quad (11)$$

3. Experimental Results

The measurements were carried out according to the measurement set-up shown in Fig. 6.

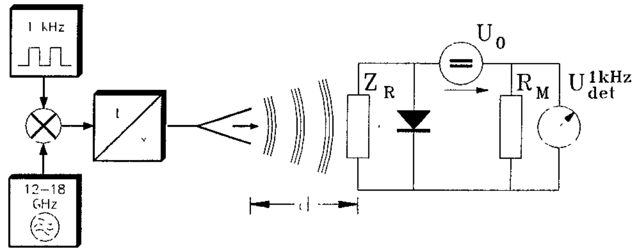

Fig. 6 Measurement set-up

The RF-power is generated by amplitude modulation of the synthesizer. The modulation frequency is 1 kHz. The antenna gain and the attenuation of free space are taken into account in the calculation of the radiation density S at the location of the antenna as functions of frequency. The voltage at the diode and the resistance R_M is measured by a selective voltmeter. This measurement set-up enables the determination of the area sensitivity γ_A of the detector as function of frequency.

The extrapolated diode impedance and the input impedance of the antenna, which was derived by a two-dimensional full wave analysis, were used in the calculation of the sensitivity γ. The unit of the calculated sensitivity γ is power. Although the detected voltage U_{det} is based on power density, due to the test set-up, a qualitative prediction of power matching between diode impedance and resonator impedance can be made.

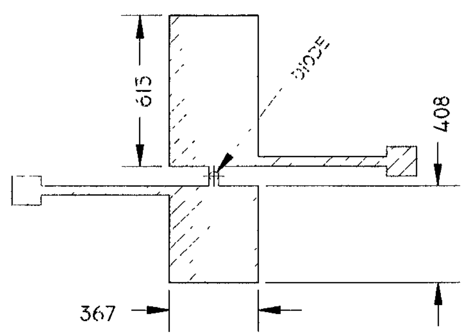

Fig. 7 Examined resonator, unit µm

The active element of the resonator depicted in Fig. 7 is a SCHOTTKY diode. Measured and calculated γ_A, γ and γ_{max} characteristics for this configuration are compared in Fig. 8.

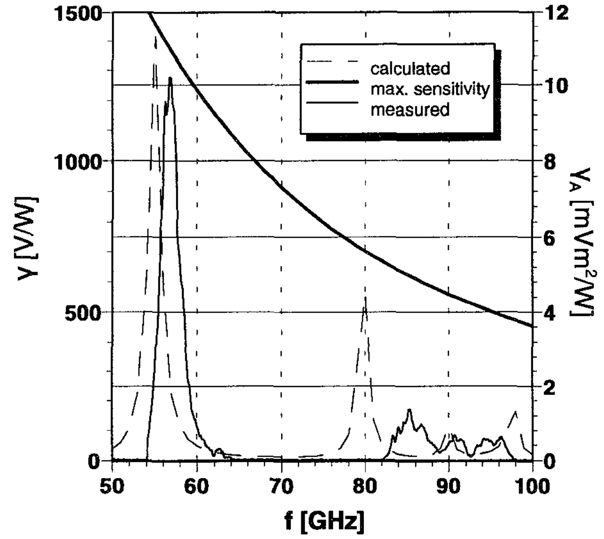

Fig. 8 Measured and calculated sensitivity

While the calculated and measured curves show good agreement in the V band, in the W band power matching could only be verified at 90 GHz. We suppose that problems in contacting the structure deteriorate the accuracy of the measurement around 80 GHz. Currently an optimized measurement set-up is under test.

4. Conclusion

The interrelation between the impedance characteristic of IMPATT diodes and SCHOTTKY diodes was demonstrated by calculation and by measurement. Due to the frequency dependence of the power matching between SCHOTTKY diode and resonator impedance, the impedance of the resonator can be characterized by the sensitivity of the detector. Calculated and measured sensitivities show good agreement. Minor deviations in the lower W band are probably related to contact problems in the test set-up. The presented method allows the characterization of the resonator impedance in the frequency range of 60-100 GHz.

Acknowledgement

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