Simulation of the Heterodyne Method for Measurement of the Second Derivative of the Current-Voltage Characteristic

Nikita I. Lysenko[1,2], Vladimir G. Polovinkin[1,2]
[1]A.V. Rzhanov Institute of Semiconductor Physics SB RAS, Novosibirsk, RF
[2]Novosibirsk State Technical University, Novosibirsk, RF

Abstract – **The analysis and simulation of the heterodyne method for measurement of the second derivative of the current-voltage characteristic is given. The model current-voltage characteristic of a silicon diode, its first and second derivatives by heterodyne method are obtained. The derived characteristics are in good agreement with the results of numerical differentiation of the current-voltage characteristic, which indicates the availability of the heterodyne method for measuring the current-voltage characteristic's first and second derivatives.**

Index Terms – **Nonlinearity, second derivative, current-voltage characteristic, heterodyne method.**

I. INTRODUCTION

RESEARCHING of the nonlinearity of various devices' and structures' characteristics allow to take additional information about physic processes in this objects and allow to extract additional parameters for researching devices. Nonlinearity measurement is active used in the inelastic tunneling spectroscopy [1-4].

II. PROBLEM STATEMENT

The nonlinearity of the current-voltage characteristic for a given potential value is determined by the value of the second derivative at this value. The traditional method for measuring the second derivative is the second harmonic method [1-4]. The second harmonic method has a disadvantage: the first harmonic of the input signal can be found in the output signal and can influence the measurement result, since the ratio of the frequency of the input signal to the output signal is fixed and equal to two. When using the heterodyne method, the input signal consists of the sum of two high-frequency (HF) signals, and the output signal is measured at a frequency equal to the difference of these HF components. Thus, the measured signal can differ significantly with respect to frequencies ratio from the input signal, so it is possible that the measured signal is better isolated from the input signal, in contrast to the second harmonic method.

Since the heterodyne method for measuring the second derivative was not previously used, its simulation was previously realized.

III. MATHEMATICAL DESCRIPTION OF METHODS OF MEASUREMENT OF THE SECOND DERIVATIVE

Expanding the current-voltage characteristic (CVC) of some device in a Taylor series near the value of some constant bias - V_0, we get

$$I(V) \approx I(V_0) + \left.\frac{dI}{dV}\right|_{V=V_0} \delta V + \frac{1}{2}\cdot\left.\frac{\partial^2 I}{\partial V^2}\right|_{V=V_0} \delta V^2, \quad (1)$$

where the modulation signal has the form:

$$\delta V = A\cdot\sin(\omega_1 t) + A\cdot\sin(\omega_2 t). \quad (2)$$

Those, sum of two signals with different frequencies, from which it follows that:

$$\begin{aligned} \delta V^2 &= A^2\cdot\left(\sin(\omega_1 t)+\sin(\omega_2 t)\right)^2 = \\ &= A^2\cdot\left(\sin^2(\omega_1 t) + \right. \\ &\left. +2\sin(\omega_1 t)\cdot\sin(\omega_2 t)+\sin^2(\omega_2 t)\right) = \\ &= A^2\cdot\left(1-\frac{\cos(2\omega_1 t)}{2}-\frac{\cos(2\omega_2 t)}{2}+\right. \\ &\left. +\cos(\omega_1 t-\omega_2 t)-\cos(\omega_1 t+\omega_2 t)\right). \end{aligned} \quad (3)$$

As a result, it can be concluded that the magnitude of the nonlinear term of the CVC is determined by the second harmonics, the difference and total frequencies of the signals from which the modulation signal consists. Because the modulation signal is the result of the addition of two HF signals, and the measurement can be made at the difference frequency of these high-frequency components, then the described method can be called heterodyne [5].

If in the modulation signal (2) is adopted $\omega_1 = \omega_2 = \omega$, i.e. $\delta V = 2A\cdot\sin(\omega t)$, then we get

$$\delta V^2 = 8A^2\cdot\left(1-\cos(2\omega t)\right). \quad (4)$$

The amplitude of the second harmonic of the modulation signal is proportional to nonlinear term of the Taylor series.

The measurement of the second harmonic is often used in inelastic tunnel spectroscopy.

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