Pergamon

0038-1101(94)00167-7

Solid-State Electronics Vol. 38, No. 3, pp. 739–741, 1995

0038-1101/95 $9.50 + 0.00

NOTE

A NEW TECHNIQUE FOR THE DETERMINATION OF BARRIER HEIGHT OF SCHOTTKY BARRIER DIODES

(Received 6 June 1994; in revised form 19 July 1994)

1. INTRODUCTION

The barrier height is an important parameter which controls the electrical conduction across Schottky barrier diodes. A convenient method to determine this parameter is to plot the logarithmic value of the current density as a function of voltage. The intercept of this plot on the current axis yields the saturation current density of the device, from which the barrier height can be extracted[1]. However, the method suffers from a limitation when a series resistance is present. The effect of series resistance has been considered in a number of publications in recent years[2,3]. For large values of the series resistance, the logarithmic current vs voltage characteristics become excessively nonlinear. This poses a serious problem in determining the saturation current density and hence, the extraction of the value of barrier height of the device. One therefore looks for a technique which is free from the above limitation. In this communication, a simple method based on the current–voltage characteristics is developed for the determination of the barrier height of Schottky barrier diodes. The method is used to determine the barrier height of Pt- and Co–nSi Schottky contacts.

2. DETERMINATION OF BARRIER HEIGHT

The current–voltage relation of Schottky barrier diode can be written in a functional form:

$$J = A^*T^2\exp(-qV_n/kT)\exp(-q\psi_s/kT) \qquad (1)$$

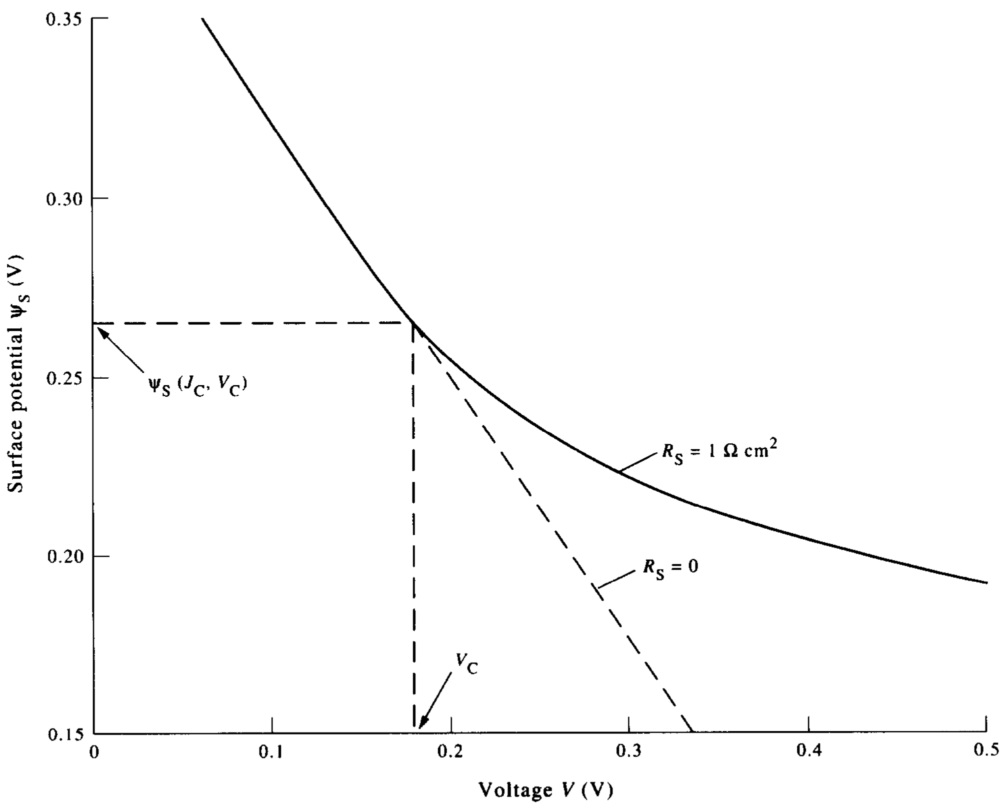

Fig. 1. Variation of surface potential with voltage. The dashed line shows the variation in absence of series resistance. The parameter V_c represents the critical voltage above which the variation of ψ_s is nonlinear. The value of the surface potential at the critical voltage is represented by ψ_s (V_c, I_c). Parameters: $\phi_b = 0.65$ eV, $C_2 = 0.78$ and $N_D = 10^{15}$ cm^{-3}.

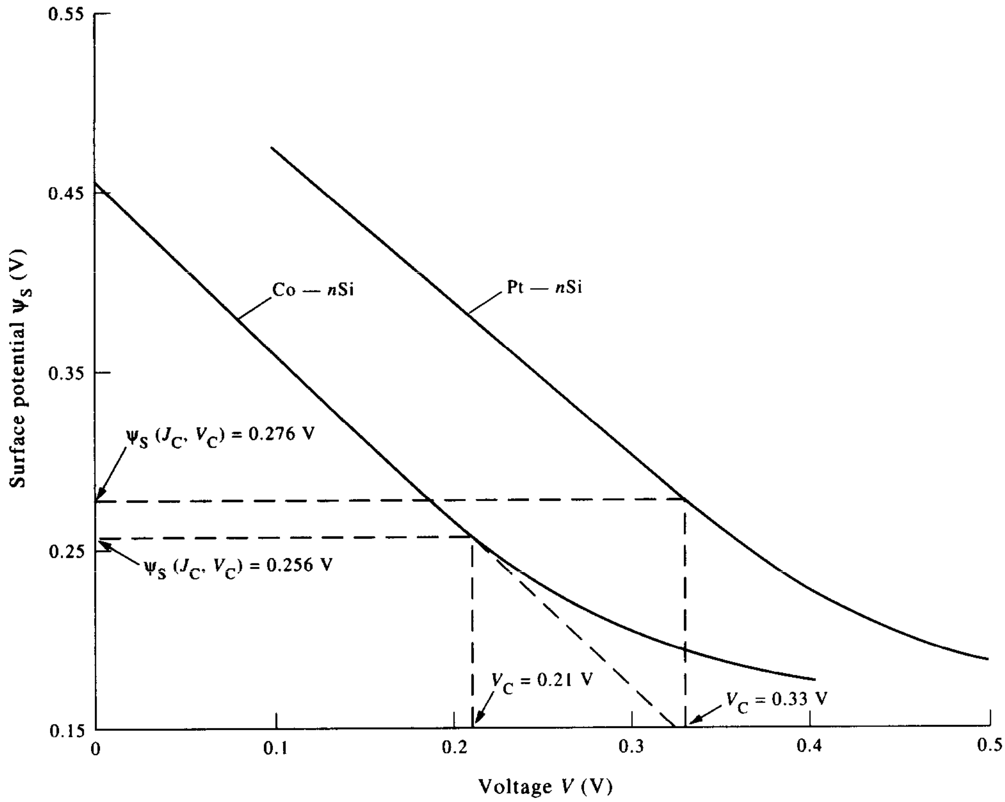

Fig. 2. Experimental ψ_s vs V plots of Co and Pt–nSi contacts. The dashed lines show the variation in absence of series resistance.

where A^* is the Richardson constant, T the temperature, qV_n the energy difference between the conduction band and and the Fermi level and ψ_s is the surface potential can be expressed implicitly as a function of current and voltage given by:

$$\psi_s = \psi_s(J, V). \tag{2}$$

It has been shown earlier that, for low and intermediate values of the doping concentration, the surface potential may be written as [3]:

$$\psi_s = \phi_b - V_n - C_2 V + C_2 J R_s, \tag{3}$$

where ϕ_b is the barrier height of the device, R_s the series resistance and C_2 is a parameter inverse of the diode ideality factor. Note that eqn (1) together with eqn (3) yields the conventional expression for current density obtained under thermionic emission model. Figure 1 shows the voltage dependence of ψ_s for given values of ϕ_b, R_s and C_2. It is seen from the figure that the surface potential decreases linearly with V until a critical voltage (V_c) is reached. The variation becomes excessively nonlinear as V exceeds V_c. It is possible to expand the surface potential in the neighbourhood of the point (J_c, V_c) in a Taylor series given by:

$$\psi_s(J, V) = \psi_s(J_c, V_c) + (J - J_c)\left(\frac{d\psi_s}{dJ}\right)_{J_c, V_c} + (V - V_c)\left(\frac{d\psi_s}{dV}\right)_{J_c, V_c}, \tag{4}$$

where the higher order terms are ignored. Comparing eqns (3) and (4), one obtains:

$$\psi_s(J_c, V_c) - J_c\left(\frac{d\psi_s}{dJ}\right)_{J_c, V_c} - V_c\left(\frac{d\psi_s}{dV}\right)_{J_c, V_c} = \phi_b - V_n \tag{5}$$

$$\left(\frac{d\psi_s}{dV}\right)_{J_c, V_c} = -C_2 \tag{6}$$

and

$$\left(\frac{d\psi_s}{dJ}\right)_{J_c, V_c} = C_2 R_s. \tag{7}$$

One obtains from eqns (1), (5)–(7):

$$\phi_b = \psi_s(J_c, V_c) + C_2 V_c + V_n - \frac{kT}{q}. \tag{8}$$

It is seen from eqn (8) that the barrier height can be obtained if the values of $\psi_s(J_c, V_c)$, V_c and C_c are known experimentally.

The accuracy of the technique may be tested with reference to a theoretical ψ_s vs V curve generated in Fig. 1 for

Table 1. Barrier heights and other related parameters of Pt and Co–nSi Schottky contacts measured using the present technique

Device	Ideality factor	V_c(V)	$\psi_s(J_c, V_c)$ (V)	Barrier height (V)
Co–nSi	1.15	0.21	0.256	0.673
Pt–nSi	1.06	0.33	0.276	0.78

a particular value of barrier height $\phi_b = 0.66$ V. Now, applying the proposed method, a value of $\phi_b = 0.65$ V is obtained from the above curve. Note that this value of barrier height differs by 10 mV which is less that 2% of the actual value of $\phi_b = 0.66$ V.

The proposed technique is applied to Pt and Co–nSi Schottky contacts fabricated on a substrate of doping concentration $2.3 \times 10^{15}\,cm^{-3}$ using vacuum evaporation method. The J–V characteristics of the above devices are measured using a picoammeter. The measured values of J are used to obtain the surface potential from eqn (1). Figure 2 shows the experimental ψ_s vs V plots for the above devices. The values of V_c and $\psi_s(J_c, V_c)$ are determined from the above figure and the barrier heights of the devices are calculated using eqn (8). The results are summarized in Table 1.

3. DISCUSSIONS

It is apparent from the above discussions that the proposed method may be used as an alternative to conventional techniques which determine barrier height of Schottky contacts. The method applied to devices having a series resistance and particularly, useful for evaluating barrier height at low temperature for which the J–V characteristics are considerably nonlinear[4,5]. It may be mentioned here that the determination of barrier height using the well known capacitance–voltage (C–V) technique become difficult when the $1/C^2$ vs V plot of the device is nonlinear[6,8]. Various reasons such as inhomoginity in doping concentration[9], interface states[10,11] and inversion layer[12] have been put forward to interpret the nonlinearity in the $1/C^2$ vs V characteristics. The use of the capacitance technique therefore require identification of the right mechanism responsible for the nonlinearity in the above characteristics and then use of a proper capacitance model for the estimation of barrier height. Clearly, the proposed technique has no such complicacy and can be applied by simply knowing the d.c. current–voltage characteristics of the device.

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