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IMPROVED CAPACITANCE TECHNIQUE FOR THE DETERMINATION OF SERIES RESISTANCE OF MS AND MIS-TYPE DEVICES FOR SOLAR CELL APPLICATIONS

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An improved capacitance technique for the determination of series resistance of MS and MIS-type devices suitable for photovoltaic applications is proposed. The method takes care of the possible effects of interface and bulk defects. The proposed method is examined for a known value of series resistance and the percentage error is calculated. It is seen that, the error in the determination of the series resistance can be minimized over wide range of doping concentration. The method is compared with other well known methods estimating the series resistance of the device.

1. Introduction

The determination of the series resistance is extremely important for metal-semiconductor (MS) and metal-insulator-semiconductor (MIS) solar cells. Various techniques have been so far developed for the estimation of the above parameter [1-6]. Among these, the techniques based on the analyses of the dc current and conductance data are well known [1-5]. Recently, a new technique for the determination of the series resistance from the capacitance-voltage characteristics has been proposed [6]. However, the technique suffers from some inherent limitations. Firstly, it assumes the surface potential to be linearly dependent on the applied voltage. Such an assumption is justified for low doping level and ultrathin interfacial layer [7]. As the doping increases, the surface potential can no longer be treated linearly dependent on the bias. The nonlinear dependence on voltage may be further enhanced as the thickness of the interfacial oxide layer is increased. In fact, in the case of MIS-solar cells where the series resistance plays an important role, the thickness of the interfacial I-layer is intentionally increased to enhance the open-circuit voltage [8] and the barrier height of the devices [9]. A second limitation of the above technique being the exclusion of the effects of the deep level impurities. These impurity levels may be present inherently during the growth of the crystal or may be introduced deliberately for specific purposes. The role of deep level

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npurities on the barrier height [10], the open-circuit voltage [11] and the capacitance oltage characteristics [12] has been discussed in several papers. Thus, looking at the bove two limitations and possible application in the characterization of Schottky barer and MIS-type devices and solar cells, an improved method for the determination the series resistance has been proposed in this work and compared with previously eveloped techniques.

2. Determination of series resistance

he determination of series resistance form the capacitance plots of Schottky contact nd related devices requires an in-depth analysis of the device capacitance. Frequently, e capacitance of Schottky contact has been found frequency dependent. Such freuency dependence mainly arises due to interface states which contribute an excess apacitance. Very recently, we have studied the capacitance of Schottky barrier diode onsidering the effect of deep level impurities [12]. A technique for the determination R_s may be developed considering the capacitance at high frequency for which the ontribution of the interface states and deep level impurities to the total capacitance is significant. The device capacitance C in such case can by described by [12]

$$C = \frac{C_{sc}}{1 + \frac{\delta}{\epsilon_i} C_{sc} + R_s qI/kT}, \tag{1}$$

here I is the current flowing over the device, R_s is the series resistance, δ is the ickness of the interfacial layer, ϵ_i is the permittivity of the interfacial layer and C_{sc} the depletion layer capacitance may be expressed as

$$C_{sc} = \left[\frac{q\epsilon_s(N_A + N_{TA})}{2\{\Psi_s - N_{TA}\Psi_{TA}/(N_A + N_{TA})\}}\right]^{1/2}, \tag{2}$$

here N_{TA} is the density of acceptor-like deep impurities, Ψ_{TA} the surface potential here Fermi-level intersects with the deep level and Ψ_s is the surface potential at $x = 0$. he potential at the point of intersection may be determined by the activation energy f the defect level and the Fermi level position [10]. The current tunneling across the terfacial layer has been estimated by Card and Rhoderick given by [13]

$$I = AA^* T^2 \exp(-\phi^{1/2}\delta) \exp[-q(\Psi_s + V_p)/kT] \tag{3}$$

here A is the area of the device, A^* the Richardson constant, T the temperature and xp$(-\phi^{1/2}\delta)$ represents tunneling attenuation factor and V_p is the depth of Fermi level elow the conduction band.

The capacitance-voltage characteristics obtained with the help of the eqns. (1) and 2) yields a peak due to series resistance effect and consequently, the plot of $1/C^2$ as function of V yields a minimum. Using the condition that $d(1/C^2)/dV = 0$ at the inimum, one obtains

$$\left(\frac{dC_{sc}}{dV}\right)_{V=V_m} + \frac{qR_s}{kT}\left(\frac{dI}{dV}\right)_{V=V_m} - \frac{(1 + \frac{\delta}{\epsilon_i} C_{sc} + qR_s I/kT)(dC_{sc}/dV)_{V=V_m}}{C_{sc}} = 0. \tag{4}$$

The quantity dI/dV can be estimated using equation (3) given by

$$\left(\frac{dI}{dV}\right)_{V=V_m} = -\frac{qI}{kT}\left(\frac{d\Psi_s}{dV}\right)_{V=V_m}. \tag{5}$$

Using eqn. (2) one obtains

$$\left(\frac{dC_{sc}}{dV}\right)_{V=V_m} = -\frac{\{q\epsilon_s(N_a + N_{TA})\}^{1/2} d\Psi_s/dV}{2\{\Psi_s - N_{TA}\Psi_{TA}/(N_A + N_{TA})\}^{3/2}_{V=V_m}}. \tag{6}$$

On substituting eqn. (2), (5) and (6) in (4), we finally obtain,

$$R_s = \frac{1}{2\,(\Psi_{sm} - N_{TA}\Psi_{TA}/(N_A + N_{TA}))\,(q/kT)^2 I_m - qI_m/kT}, \tag{7}$$

where Ψ_{sm} represents the surface potential at the capacitance peak and I_m is the corresponding current. It therefore follows that if the potential Ψ_{sm} and the current I_m are known then the series resistance can be estimated using eqn. (7). The values of Ψ_{sm} and I_m can be obtained from the I-V characteristics. However, certain procedure should be adopted in realising the values of Ψ_{sm}. It is necessary that the I-V characteristics should be linear over wide range of bias. In many cases, such linear dependencies have not been observed mainly due to parasitic effects associated with tunneling from interface states, recombinations and transport via shunt resistance. These effects primarily influence the I-V plots at low-bias. Therefore, to obtain the right value of Ψ_{sm}, the linear part of the I-V plot should be taken into consideration. By the method of extrapolation one can determine readily the saturation current density of the device. The value of $\phi^{1/2}\delta$ can be obtained from saturation current density knowing the barrier height from C-V characteristics [13]. With the known values of $\phi^{1/2}\delta$, one can readily obtain the value of Ψ_{sm} using equation (3). In order to verify the validity of the above technique, the theoretical I-V and C-V characteristics of a given device is generated for a particular value of R_s. These characteristics are then used to re-calculate the values of R_s with the help of equation (7).

To compare the present method with the previous one [6], we re-evaluate the value of series resistance considering the effect of deep level impurities and obtain

$$R_s = \frac{A}{I}\left[\frac{kT}{4qC_2} - \frac{M}{2C_2} + \frac{kT}{4qC_2}\sqrt{\left(9 - \frac{4M}{kT/q} + \frac{4M^2}{(kT/q)^2}\right)}\right], \tag{8}$$

where

$$M = \phi_b - C_2 V - V_p - N_{TA}\Psi_{TA}/(N_A + N_{TA}), \qquad C_2 = \frac{\epsilon_i}{\epsilon_i + q^2\delta D_{it}}$$

and

$$\phi_b = C_2(E_g/q + \chi - \phi_m) + (1 - C_2)\phi_o + qC_2\delta N_f/\epsilon_i.$$

The parameter ϕ_o represents the neutral level and N_f is the density of fixed charges.

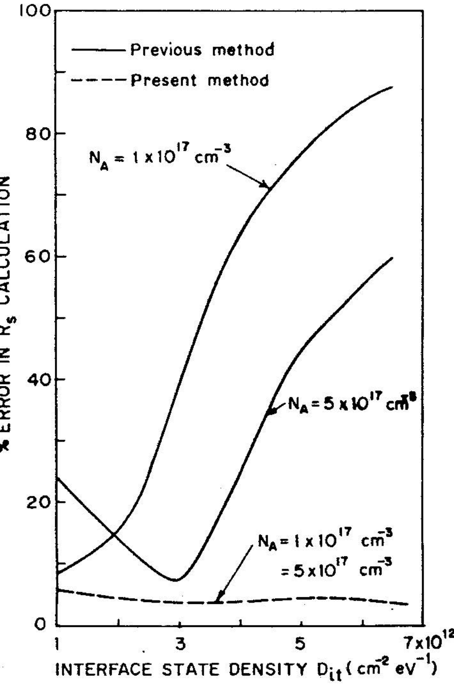

Fig. 1. Percentage error in R_s calculation for different doping concentrations as a function of interface state density using present and previous method. Dashed live curve represents the present technique and solid line curves are for the previous method modified for deep level impurities. Parameters used: $\phi_m = 4.4$ eV, $E_g = 1.12$ eV, $\chi = 4.05$ eV, $\delta = 10$ Å, $N_f = 1 \times 10^{11}$ cm^{-2} and $N_{TA} = 1 \times 10^{15}$ cm^{-3}.

3. Discussion

To examine the validity and the usefulness of the two techniques, the percentage error in the R_s calculation has been estimated for the two methods. Fig. 1 is an illustration on how the series resistance calculation is influenced by the density of interface states and doping concentration. The results obtained using our previous method show that the percentage error in the determination of R_s increases sharply as the interface state density increases. Also, it is noted that the percentage error is influenced by the doping concentration. However, the present method is free from such limitations. It is seen from the figure that, for the present method, the error is negligible compared to that of the previous one [6] and is almost constant over a wide range of interface state density. Moreover, the error is almost independent of the change of doping concentration. It may be mentioned that the technique discussed in Ref. 6 is valid for the low values of interfacial layer thickness and doping concentration so that the surface potential can be approximated as $\Psi_s = \phi_b - C_2V - V_n$.

The accuracy of the proposed method may be compared with other conventional techniques [1,4] which estimate the series resistance of metal-semiconductor devices. Norde's method [1] of evaluating R_s suffers from a major limitation that the minimum

Interfacial layer thickness δ in Å	Interface state density D_{it} in cm^{-2} eV^{-1}	Tunneling attenuation factor	R_s (exact) in ohms	R_s (calculated) in ohms		
				Norde [1]	Werner [4]	Present method
10	10^{12}	2	10	6.53	10	10.37
	10^{13}			3.05	9.3	10.29
20	10^{12}	7	10	5.16	8.8	9.89
	10^{13}			2.17	12.15	9.73

Table 1. Comparative study of the accuracies of different techniques for series resistance calculations. Parameters used in calculation: $\phi_m = 4.2$ eV, $\chi = 4.05$ eV, $N_A = 5 \times 10^{17}$ cm^{-3}.

of the Norde plot is much difficult to identify in certain cases. Particularly, the interfacial layer and interface states have not been included in the Norde's evaluation scheme. A relatively powerful method has been proposed by Werner [4] which requires measurements of dc conductance G and current of the device. From a plot of G/I vs G, one can obtain the value of series resistance. However, the method ignores the voltage drop across the interfacial layer. As discussed above, such a consideration leads to a simplified expression for Ψ_s which is linear in V and the technique gives reasonable values of R_s only for low doping concentration, interface state density and ultrathin oxide. The values of R_s extracted using the present scheme have been compared with those obtained using the methods of Norde [1] and Werner [4] in table 1. It is seen that, the latter two techniques are sensitive to interface state density and the oxide layer thickness, while the present scheme yields values which are close to the actual value of the series resistance.

The accuracy of the present method primarily depends on the correct estimation of the surface potential Ψ_{sm}, at which the capacitance attains a maximum. Its determination require a proper analysis of the I-V characteristics. It is required that the ln I vs. V characteristics should be linear over wide range of voltage and the value of tunneling exponent be known (in the case of MIS-tunnel diode). However, these requirements are not very important for MS-contacts or contacts with ultrathin insulating layer. In such cases, the tunneling attenuation factor is nearly unity and the determination of series resistance is relatively simpler.

In conclusion, the previous method of the determination of R_s from the capacitance-voltage characteristics has been found to be inefficient for high values of interfac e state density and doping concentration for inherent constraints imposed due to linearisation of the surface potential with bias voltage and exclusion of deep levels. The proposed method is free from the above limitations and capable of determining resistances with less than 10% error.

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