I-V and C-V methods to extract Al/polysilicon Schottky diode parameters

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Abstract: Series resistance, ideality factors, saturation currents and doping concentrations have been determined using I-V and C-V techniques. However, the usual equations cannot fit some diodes, may be because they are too approximated or because other mechanisms are present. In this work we use two methods based on C-V and I-V measurements to extract Schottky diode parameters. These methods are very easy to use and give results with more precision even when characteristics behavior is far from ideal. The influence of the material (polysilicon) has also been investigated.

Keywords: I-V curves; C-V curves; Schottky diodes; polysilicon.

1 Introduction

Microelectronics has been an engine for growth for the past five decades in nearly all technological fields. From a materials standpoint, it is largely based on single crystalline silicon. Furthermore, polysilicon has drawn considerable interest in some years ago due to its wide use in the fabrication of low cost terrestrial solar cells. The properties of polysilicon differ in important ways from those of single-crystal silicon due to the presence of grain boundaries [1,2]. These grain boundaries generally contain a high density of impurities and trapping centers which have significant effects on device performance [3].

In the other hand, the non uniformity of the grain size in polysilicon films lead to non uniform current flow and restricts details modeling of conduction in polysilicon [4]. Then, experimental characterizations are needed to understand and model polysilicon films.

All semiconductor devices and materials are characterized through the use of test structures. Metal-semiconductor contacts are the subject of considerable interest, and the capacitance-voltage (C-V) and current-voltage (I-V) as electrical characterization techniques are most commonly used to extract junction parameters. For the C-V method it is important that $C^2$ versus $V$ plots be linear and independent of frequency. For the I-V ones $\ln(I)$ versus $V$ must have the same behavior. Indeed, deviations from linearity are commonly observed in polysilicon structures.

In the present work, we use and develop two iterative methods to find junction parameters based on C-V and I-V measurements.

2 Conventional I-V and C-V methods

2.1 I-V method

The thermionic current-voltage relationship of a Schottky barrier diode, neglecting series and shunt resistance, is given by:

$$I = I_s \left[ \exp(\alpha V) - 1 \right]$$

where $I_s$ is the saturation current, $\alpha = q/nKT$ with $n$ the ideality factor and $KT/q = 25.10^{-3}$ V at $T=300K$.

When series resistances are considered the equation (1) becomes [4]:

$$I = I_s \left[ \exp(\alpha(V-R_s I)) - 1 \right]$$

The ideality factor $n$ incorporates all unknown effects making the device non linear when greater to unity.

Data plotted as $\ln(I)$ versus $V$ are linear when $V>>KT/q$.

In the conventional I-V method, the saturation current $I_s$ is determined by an extrapolation of the $\ln(I)$ versus $V$ curve to $V = 0$. The current axis intercept for the straight-line portion of this semilog plot at $V = 0$ is given by $I_s$. 

$$I = I_s \left[ \exp(\alpha(V-R_s I)) - 1 \right]$$
The deviation of the Log(I)-V curve from linearity for high voltages is \( \Delta V = IR_s \), allowing \( R_s \) to be determined according to \( R_s = \Delta V/I \). When \( R_s \) and \( I_s \) are determined, we can easily obtain \( n \) value.

### 2.2 C-V method

The capacitance-voltage (C-V) technique relies on the fact that the width of a reverse-biased space charge region of a semiconductor junction device depends on the applied voltage. The capacitance per unit area of a Schottky diode is given by:

\[
\frac{C}{A} = \left( \frac{Nq \varepsilon}{2(V_b-V)^{1/2}} \right)
\]

Where \( V_b \) is the barrier height, \( V \) the applied bias voltage, \( N \) the donor or acceptor density, \( \varepsilon \) the dielectric constant of semiconductor, \( q \) the magnitude of the electronic charge and \( A \) the contact area [5].

If one then plots the experimentally obtained values of \( 1/C^2 \) versus bias voltage, \( N \) and \( V_b \) may be determined from the slope and the intercept on the abscissa, respectively.

In principle, I-V and C-V methods are quite simple; in practice, a number of complications may arise which make techniques more difficult to use. Some of these complications lead, in general, in a non-linear behavior of Log (I)-V and \( (1/C^2) \)-V plots and it becomes very hazardous to determine diode parameters with accuracy.

### 3 Iterative methods

#### 3.1 Evaluating Current-Voltage (I-V) characteristics

Here, it will be shown how to determine diode parameters such as saturation current, ideality factor and series resistance from I-V characteristics of Schottky diodes or p-n junctions.

In this part, calculations are based on a method developed by A. Kaminski et al. [6, 7]. By writing the relation in Eq. (2) in its logarithmic form, it was demonstrated that

\[
Y = \alpha (-R_s + X) \quad \text{for} \quad I >> I_s
\]

with

\[
Y = \frac{\ln(I/I_0)}{I - I_0}, \quad X = \frac{V - V_0}{I - I_0}, \quad \alpha = \frac{q}{nKT} \quad \text{and} \quad \beta = \frac{2V_b}{A^2 Nq \varepsilon}
\]

\( (V_0, I_0) \) is a point of the I-V curve.

To get a better accuracy it consider a set of \( I - V \) data giving rise to a set of X-Y values, with \( i \) varying from 1 to \( N \). We calculate \( X \) and \( Y \) values for \( I_0 = I_0 \) and \( I = I_{0+1} \) up to \( I = I_N \). This gives \( (n-1) \) pairs of X-Y data. We start again with \( I_0 = I_{0+1} \) and \( I = I_{0+2} \) up to \( I_N \) and get (n-2) additional X-Y data, and so on, up to \( I_0 = I_{N+1} \).

Finally, we obtain \( n(n-1)/2 \) pairs of X-Y data that means more values for the linear regression. The linear regression of Eq. (2) gives \( \alpha \) and \( R_s \). At last, knowing \( R_s \), the reverse saturation current is obtained by plotting \( \ln I \) versus \( (V-IR_s) \).

#### 3.2 Evaluating Capacitance-Voltage (I-V) characteristics

Here we develop a new method based on the same principle of I-V method described above. This method concerns directly the usual measured C-V data. We start from

\[
\frac{1}{C^2} = \alpha V + \beta
\]

with \( \alpha = -\frac{2}{A^2 Nq \varepsilon} \) and \( \beta = \frac{2V_b}{A^2 Nq \varepsilon} \)

For a data pair defined by \((V_0, C_0)\) we have

\[
\frac{1}{C^2_0} = \alpha V_0 + \beta
\]

By subtracting Eqs. (5) and (6) we obtain

\[
\frac{1}{C^2} - \frac{1}{C^2_0} = \alpha (V - V_0)
\]

Taking \( Z = \frac{1}{C^2} - \frac{1}{C^2_0} \) and \( X = V - V_0 \) we have a straight line

\[
Z = \alpha X
\]

We consider a set of \( C_i - V_i \) data giving rise to a set of \( Z - X \) values, with \( i \) varying from 1 to \( N \), and we continue in the same way as I-V iterative method.

We determine the doping concentration \( N \) from the linear regression of Eq. (8) giving \( \alpha \). When this one is determined we can obtain \( \beta \) by fitting the relation in Eq. (5) by a linear function defined by the value of the slope \( \alpha \).

The advantage of this method is that when \( 1/C^2 \)-V curve present several linear parts with different slopes, it can inform about the range of \( V \) which give accurate values of the barrier height \( V_b \).
4 Results

Test structures are Schottky diodes Al/polysilicon with an area of 1mm$^2$. Polysilicon wafers are P type elaborated by PHOTOWATT and doped Bore at $10^{17}$cm$^{-3}$.

We were interested in polysilicon because it presents, generally, a non linear behavior of its characteristics which let the evaluation of diode parameters very difficult.

4.1 C-V results

Experimental C-V characteristics at 1 MHz show that the capacitance varies proportionally with $V^{1/3}$ as given in Fig.1. This behavior is also observed on polysilicon junctions by several authors [8].

![Fig.1. Characteristics 1/C$^3$ as a function of the reverse bias voltage.](image1)

From the slope, we find $N = 7.18 \times 10^{16}$ cm$^{-3}$.

A value of $7.5 \times 10^{16}$ cm$^{-3}$ is obtained from Z-X linear regression as given in Fig. 2. One can see that the second value give more precision in the determination of $N$ because it approaches the doping value $10^{17}$ cm$^{-3}$.

![Fig. 2. Z-X characteristics.](image2)

4.2 I-V results

In order to calculate saturation current $I_s$, ideality factor $n$ and series resistance $R_s$ we use the method presented above. An example of experimental I-V characteristic is given in Fig. 3 and one can see that ln(I)-V curve is not linear.

Then the conventional method becomes very difficult to use.

![Fig. 3. Log (I) versus V plot for Al/polysilicon Schottky diode.](image3)

So we use Y-X plot to determine diode parameters. Linear regression in Fig. 4 gives an ideality factor $n = 4.9$ and a series resistance $R_s = 530.54 \Omega$.

![Fig. 4. Y-X characteristic.](image4)

By plotting ln (I) versus (V-R$I$) curve, as shown in Fig. 5, we find saturation current $I_s$ equal to 5.84 mA.

The device presents high value of ideality factor. This can be explained by the presence of grain boundaries and therefore of traps. That give rise to different conduction processes like trap assisted tunneling and recombination [4,6] which affect the current.
Values of saturation current $I_s$ and series resistance $R_s$ are physically acceptable [9].

5 Conclusion

This study was originated by the intention of determining Schottky diode parameters when $1/C^2$-V and $\ln(I)$-V curves present a non linear behavior. That is the case of Al/polysilicon structures. Capacitance was found to be proportionnel to $V^{1/3}$ as for gradual doping profile. L(I)-V curves are nonlinear but X-Y ones are, allowing us to determine ideality factor, series resistance and saturation current.

We know that any damage at the interface affects the I-V behavior because defects may act as recombination centers or as intermediate states for trap-assisted tunnel currents. Either one of these mechanisms raises ideality factor which we find equal to 4.9.

References:


