Specific Contact Resistance Measurements of Metal-Semiconductor Junctions

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Abstract—Our research comprises the manufacturing of test structures to characterize the metal-semiconductor junctions with a number of techniques and materials. An extensive subsequent physical and electrical testing of the junctions is carried out. We present our first results on specific metal-to-silicide contact resistance characterization using the Cross-Bridge Kelvin Resistor (CBKR) and Transmission Line Model (TLM), and NiSi as the silicide**.**

Keywords—**Specific contact resistance, TLM, Kelvin structure, MOSFET, silicide**

I. INTRODUCTION

Future improvements of IC technology demand the introduction of many new materials i.e. for metal-semiconductor junctions in particular and studying both the technology and properties of such junctions in a broad sense. Metal-semiconductor junctions are essential to any electronic system containing semiconductors. These junctions have always been a topic of research [1-3].

The performance of MOS circuits depends strongly on transistor drive current. The drive current of the transistor is determined by the total device resistance, which consists of the channel resistance and the parasitic resistances associated with diffusions and contacts. As device dimensions shrink in each new technology generation, contact resistance scales as a power of the reciprocal dimensions [4]. It is expected that the contact resistance between silicide and source/drain region will dominate the total series resistance. This has serious consequences for current drive and device speed.

The silicide must provide low contact resistance to the doped silicon regions. The reduction of this contact resistance, and the corresponding contact resistivity is a big issue in order to not compromise the device performance. Thus the ability to accurately measure the contact resistance is essential to contact development. For this purpose, a set of test structures was fabricated, including standard Kelvin probe structures to measure metal-to-silicide contact resistivity and TLM structures with segments of varying length.

II. DESCRIPTION OF THE MEASUREMENT TECHNIQUES

A. *Transmission Line Model*

The theoretical expression of the contact resistance contribution to the series source and drain resistance is expressed as [5]:

$$\left(R_c\right)_{Transistor} = R_{cs} + R_{cd} = \frac{2\sqrt{\rho_c R_s}}{W * \tanh\left(L/L_c\right)}, \qquad \textbf{(1)}$$

where ρ_c is the specific contact resistance from the silicide to diffusion. The diffusion layer under silicide is described by R_s, which is the sheet resistance under the silicide, W is the transistor width and L is the length of the silicide contact. L_c is the transfer length defined as $L_c = (\rho_c / R_s)^{1/2}$.

The current tends to stay in the silicide as long as possible before moving into the silicon over a distance corresponding to the transfer length L_c. Two limiting cases for the contact resistance could be expressed. For $L >> L_c$, the equation (1) is reduced to:

$$R_{cs} + R_{cd} = \frac{2\sqrt{\rho_c R_s}}{W} = R_o \tag{2}$$

The limit expressed by (2) corresponds to the ideal case when the contact contribution of the source and drain to the series resistance is independent of the silicided contact length (L).

For $L << L_c$, (1) is reduced to:

$$R_{cs} + R_{cd} = \frac{2\rho_c}{LW} \tag{3}$$

The limit (3) denotes the case when the contact resistance depends on the contact area. The extraction of the contact resistance contribution to the series source and drain resistance cannot be done using transistor measurements; appropriate test structures necessary for contact resistance evaluation. The transmission line structure is a useful and simple method to accurately describe the behavior of the silicide contact resistance.

Silicide to silicon contact resistance is investigated using a set of dedicated test structures with silicided segments of varying lengths based on the Scott model of the Transmission Line Model (TLM) [6]. The TLM structure consists of alternating silicide and unsilicided segments formed by using salicide-blocking mask (Figure 1).

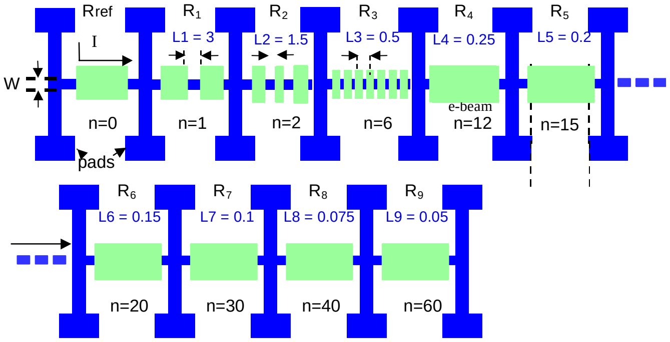

Figure 1. **TLM layout structure example**.

The measurements technique involves forcing the current through the reference structure not interrupted by silicide segments in series with the structures interrupted by 1, 2 or n silicided segments and measuring the voltage drop across each structure. As the structures have been designed to have equal silicide and not silicided segments lengths, the difference between the reference resistance and the others resistances is attributed to the contact resistance contribution. Thus, the contact resistance of each structure measured experimentally is expressed as:

$$(R_c)_{meas} * W = \left(\frac{R_i - R_{ref}}{n}\right) * W \ , \tag{4}$$

where R_i is the resistance of the structure interrupted by n silicided segments, R_{ref} is the resistance of the reference structure and W is the structure width. The theoretical expression of the silicide to silicon contact resistance for the test structure as stated by Scott is given as:

$$(R_c)_{meas} = \frac{\sqrt{\rho_c R_s}\tanh(L/2Lc)}{W}, \tag{5}$$

where $\rho_c = L_c R_0 W/2$ is the specific contact resistivity, R_s is the sheet resistance under the silicide, W is the structure width and L is the length of the silicided segment. L_c is the transfer length. Once more, two limiting cases for the contact resistance can be expressed, for $L >> L_c$ equation (5) reduces to:

$$(R_c)_{meas} = \frac{\sqrt{\rho_c R_s}}{W} = Ro\,. \tag{6}$$

The limit expressed by (6) corresponds to low contact resistance thus all the current flows through the silicide contact. The value of $R_o W$ obtained with the transmission line structure using the long silicided segments is equal to limit (2) achieved with a transistor with long silicided contact. For $L << L_c$ equation (5) reduces to:

$$(R_c)_{meas} = \frac{L}{W} Rs\ . \tag{7}$$

The limit of (7) shows the case when only a fraction of the current will flow in the silicided segment of TLM. In the transistor all the current has to enter the silicide, resulting in lower drive current when $L << L_c$. By plotting $(R_c)_{meas} W$ as a function of silicided length L, the contact resistance saturates for $L >> L_c$ to the maximum value $R_o W$.

The TLM contact resistance given by the equation (5) can be expressed as:

$$\frac{R_0 + (R_c)_{meas}}{R_0 - (Rc)_{meas}} = \exp\left(\frac{L}{L_c}\right). \tag{8}$$

Plotting the expression (8) as function of L allows to extract the transfer length L_c. Using extracted L_c and R_o values, the resistance of the test structure $(R_c)_{meas}$ can be calculated and, therefore, the specific contact resistance ρ_c.

B. Cross-Bridge Kelvin Resistor structures

The four-terminal Cross-Bridge Kelvin Resistor is commonly used to obtain ρ_c, a specific contact resistivity value (Figure 2). By forcing current I, and measuring Kelvin potential $V = V_2 - V_1$, contact resistance R_c can be found from $R_c = (V_2 - V_1)/I$ [7].

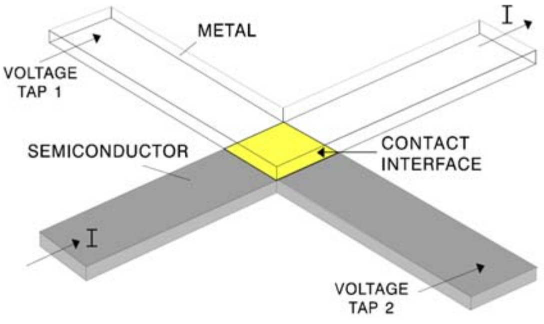

Figure 2. **Kelvin-CBKR structure example**.

The specific contact resistivity can be calculated directly as a product of contact area A and R_c, $\rho_c = R_c A$.

III. EXPERIMENTS AND RESULTS

For the contact resistance study (100) p-type Si wafers were used as starting material on which active areas were defined by Shallow Trench Isolation. Two dopant implantations were carried out: 1) low-dose well implantation B (180 keV) and 2) Highly Doped Drain (HDD) As implantation (20 keV). For the TLM, a silicide-blocking layer (SiO_2/Si_3N_4) was deposited and patterned using I-line lithography. The segments lengths, ranging from 0.5 to 3 µm and from 3.5 to 42 µm, have a width of either 2 µm or 8 µm. The smaller segments (0.25 µm to 60 nm) were printed with e-beam lithography. Each of the four structures has n silicided segments, where n equals 1, 2, 6, 12, 15, 20, 30, 50 and 60 (Figure 1). Finally, a 10-nm thick Ni layer was deposited and silicide was formed by two-step annealing (300 ^{o}C for 43 sec + 470 ^{o}C for 43 sec). The unreacted metal was selectively removed by wet etching.

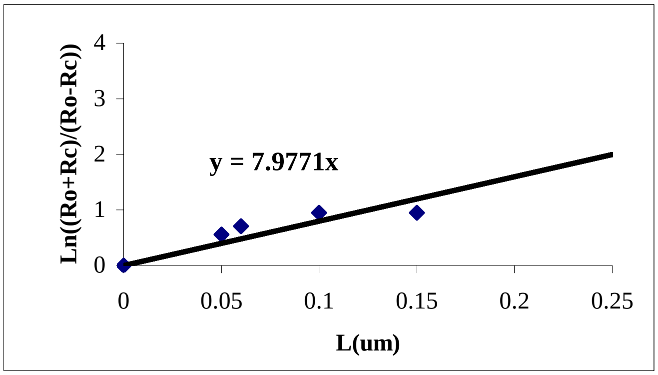

Figure 3. **ln(R_o+R_c)-ln(R_o-R_c) as function of silicided segment length. The slope equals to 1/L_c reveals *Lc* extraction**

The transfer length (L_c) value was extracted using expression (8) and found to be 125 nm (Figure 3).

Using extracted L_c and R_o values, the specific contact resistance for NiSi is calculated to be 1.42 x 10^{-8} Ω.cm^2. It can be seen in Figure 4 that the experimental data fit with the model for R_c (5) when the values extracted for L_c, ρ_c and R_o are implemented.

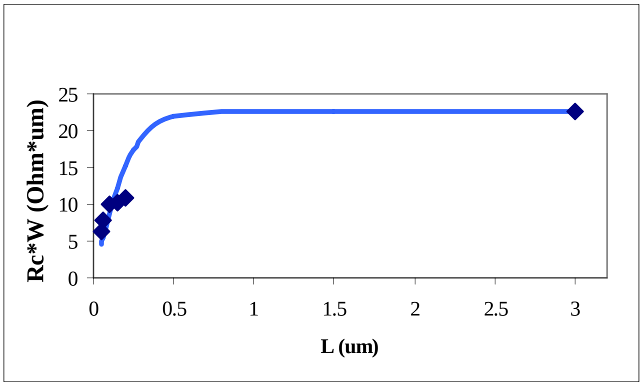

Figure 4. **A comparison of the curve fit values with the measured values**

Backend processing was applied in order to allow measuring KCBR structures with the metal contact area of 0.15*0.15 µm^2 and the silicided area of 0.8*0.8 µm^2.

Specific contact resistance was found to be 2.78 x 10^{-9} Ω.cm^2 for the metal to silicide contact and 2.92 x 10^{-7} Ω.cm^2 for the silicide to diffusion (As-doped silicon) contact. The I-V curves for both cases are shown in Figures 5 and 6.

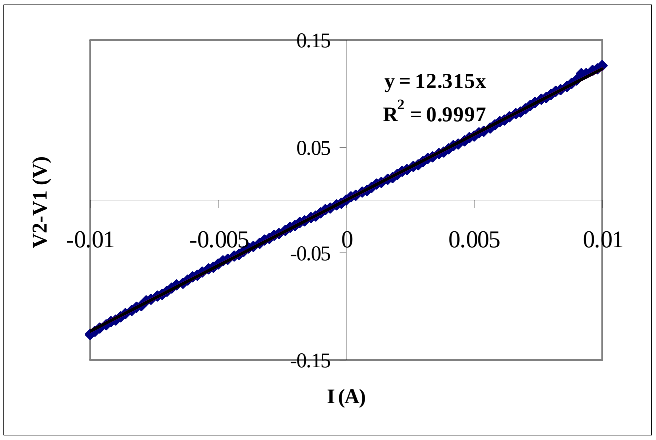

Figure 5. **Kelvin measurements I-V curve for metal to silicide (0.15*0.15 μm^2).**

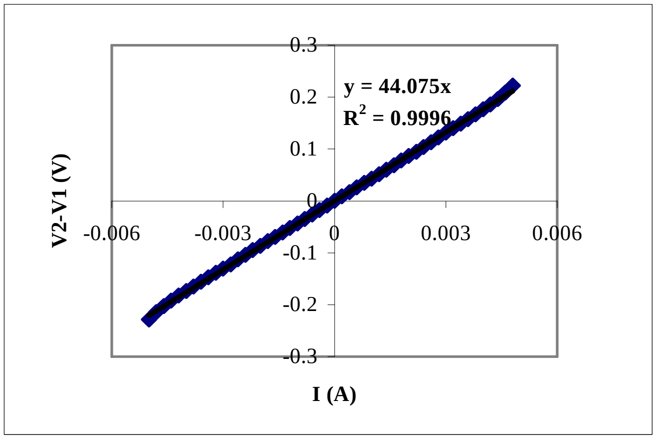

Figure 6. **Kelvin measurements I-V curve for silicide to As-doped silicon (0.8*0.8 μm^2).**

IV. DISCUSSION AND CONCLUSION

The contact resistance between silicide and highly As doped silicon regions was studied by making use of dedicated Transmission Line Method and Cross-Bridge Kelvin Resistor structures, both made on the same wafer. Specific contact resistivity for the metal to Ni silicide contact was found to be 1.42×10^{-8} Ω.cm^2 and 2.92×10^{-7} Ω.cm^2 for TLM and CBKR structures, respectively. The significant difference in results measured by two different methods may be explained by several reasons. Firstly, the Kelvin model does not account for the current flowing in the overlap region between the contact edge and the diffusion sidewall [8]. If the diffusion area is wider than the contact window, part of the current flows from the diffusion tap up into the contact window from the diffusion area. This effect can be even more pronounced in the case of low specific contact resistance values. Secondly, in case of TLM, the nominal sizes were used for the specific contact resistance extraction. However, this might not reflect the actual dimensions. Future research will focus on the understanding of the difference between the results obtained by both methods and ultimately the determination of the specifics of metal-semiconductor junctions.

ACKNOWLEDGEMENTS

This project is financially supported by Philips Research Leuven.

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