Cross-Bridge Kelvin Resistor (CBKR) Structures for Silicide-Semiconductor Junctions Characterization

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***Abstract*—Analyzing the contact geometry factors for the conventional CBKR structures, it appeared that the contact geometries conventionally used for the metal-to-silicide contact resistance measurements were not always satisfactory to reveal the specific contact resistance values. To investigate these geometry-related issues, we therefore designed and realized new CBKR structures having a large variety of contact shapes, overlaps and diffusion area widths. The process flow was adjusted for self-aligned silicides as well as for planar silicide structures.**

***Index Terms*— Contact resistance, CBKR, CMOS, junction, Kelvin resistor, semiconductor, silicide**

I. Introduction

Silicides were introduced into the technology of electronic devices some thirty years ago; since then, they have been continuously used to form both ohmic and rectifying contacts to silicon. In conventional CMOS devices, a metal silicide is used to reduce the sheet and contact resistances whilst making contacts to gate, source and drain regions. As device dimensions shrink with each new technology generation, silicide-to-source/drain contact resistance becomes a significant part of the total series resistance. For this reason, there is an urgent need to accurately measure the silicide-to-silicon contact resistance as well as to understand the factors that can affect it [1, 2].

The characterization of silicide-semiconductor junctions requires the use of various test structures. Since the specific contact resistance is easily extracted from measured contact resistance, Cross-Bridge Kelvin Resistor (CBKR) structures are often used to characterize metal-semiconductor contact in VLSI and ULSI technology [3-6].

On the other hand, CBKR is very sensitive to the lateral crowding current around the contact when the contact window is smaller than the diffusion tap. This current accounts for the additional resistance that induces a voltage drop at the contact periphery. For high quality contacts with low specific contact resistances and for high sheet resistances (e.g., silicide-silicon contacts), this additional resistance becomes extremely important [7-8].

Our research is therefore concerned with the new geometry design, manufacturing and characterization of advanced CBKR structures, which are more adapted to accurate contact resistance measurements of silicide-to-silicon contacts.

II. Theoretical Considerations

A. One Dimensional CBKR Model

The four-terminal Cross-Bridge Kelvin Resistor is commonly used to obtain ρ_c, a specific contact resistance value (Fig. 1). By forcing current I, and measuring Kelvin potential (V_2-V_1) between the taps, contact resistance R_c can be found from $R_c = (V_2-V_1)/I$.

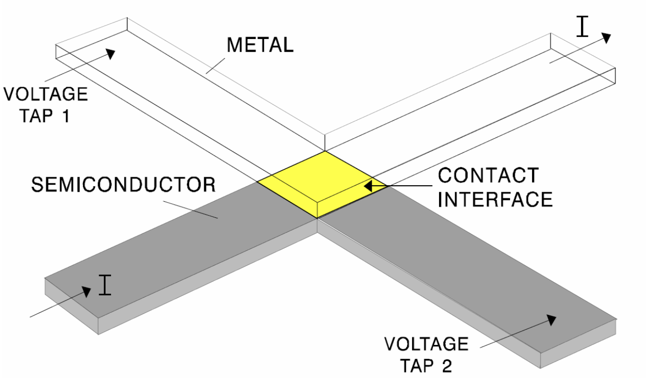

Fig. 1. Conventional CBKR structure example

In this 1D-Kelvin Model approach, the specific contact resistance can be calculated directly as a product of contact area A and R_c: $\rho_c = R_c A$.

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B. *Two Dimensional CBKR Model*

The 1D-Kelvin Model does not account for the current flowing in the overlap region between the contact edge and the diffusion sidewall and may be used only in the case of high specific contact resistances. It was also shown that this effect becomes crucial for the relatively high sheet resistance values of diffusion areas [6, 7, 8].

In that case the so-called 2D-Kelvin Model should be applied. The actually measured resistance (R_k) is then a sum of the resistance due to the voltage drop across the actual contact (R_c) and the resistance due to the current flow around the contact in the overlap region (R_{geom}), see equation (1). The specific contact resistance ρ_c can further be extracted from equation (2), where R_s is the diffusion sheet resistance; A is the actual contact size; W is the diffusion width. The schematic representation of the Kelvin contacts geometry with the 2-D approach can be found in Fig. 2.

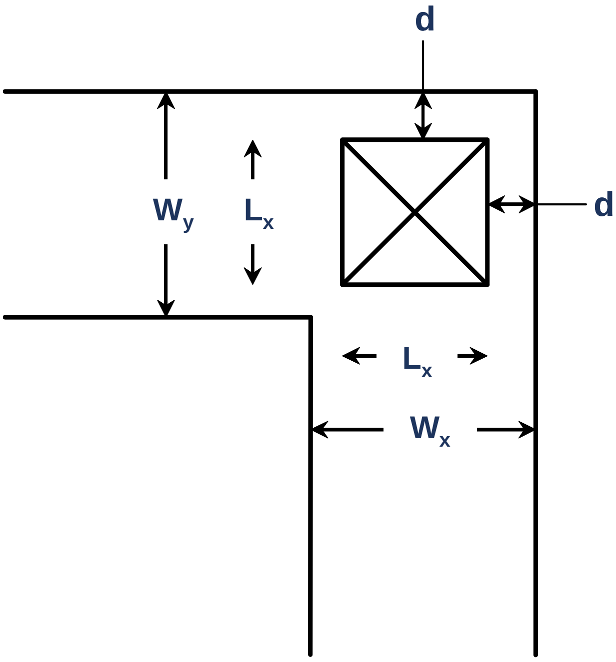


Fig. 2. Parameter definition in 2D-Kelvin Model approach.

$$R_k = R_c + R_{geom} \qquad (1)$$

$$R_k = \frac{\rho_c}{A} + \frac{4R_s d^2}{3W_x W_y}\left[1 + \frac{d}{2(W_x - d)}\right] \qquad (2)$$

III. EXISTING TEST STRUCTURES

The initial CBKR test structures were earlier fabricated at Philips Research Leuven, see ref [9]. The metal contact area was 0.15 × 0.15 µm and the silicided area was 0.8 × 0.8 µm. The specific contact resistance, applying the 1D-Kelvin approach, 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 NiSi-to-diffusion (i.e., As-doped silicon) contact.

Applying the 2-D approach in order to analyze the same data, one can show that the existing Kelvin geometry can not reveal the accurate specific contact resistance value for the silicide-to-diffusion contact. The important 2D-Model results are presented in Table I. An unrealistic correction factor over 100% should be applied.

TABLE I
2D-KELVIN MODEL PARAMETERS SUMMARY FOR EXISTING STRUCTURES

Sample	R_k Ω	R_{geom} Ω	ρ_c Ω CM^2	R_{geom} / R_K % [a]
NiSi to n-type	46	45	6.9·10^{-9}	97.7
NiSi to p-type	76	85	n/a	112.8

Other parameters (see Fig. 2): d = 2.6 µm, $W_x = W_y$ = 6 µm, $L_x = L_y$ = 0.8 µm

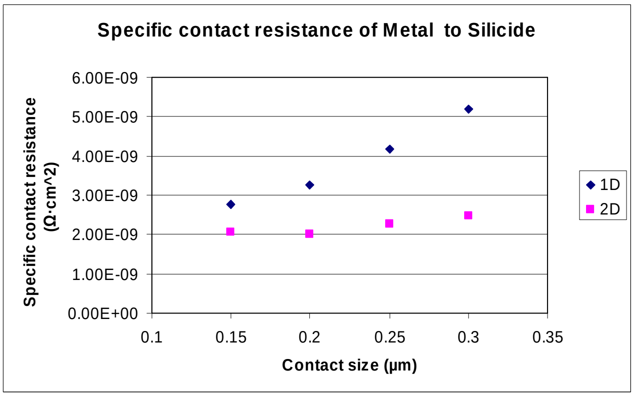


Fig. 3. Specific contact resistance dependence on contact size for Al to NiSi contacts.

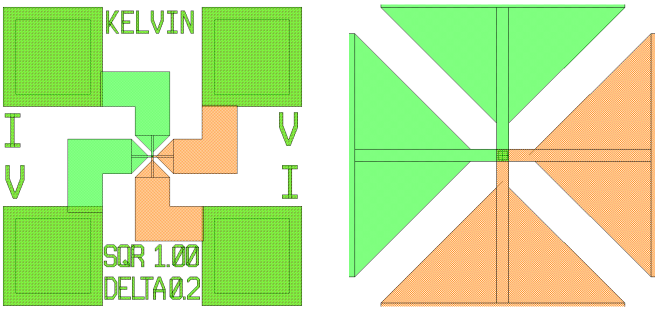
On the other hand, a correction factor of 30% should be used for the metal-to-silicide contacts. The results are shown in figure 3. The dependence of the specific contact resistance on the contact area clearly shows this effect. Previous measurements [9-10] show a significant difference between the results obtained by TLM and our CBKR measurements. This difference is most likely related to the existing contact geometry, which was not satisfactory to reveal the specific contact resistance value for the silicide-to-diffusion contacts in relation with the relatively high sheet resistance of the diffusion area. Therefore, we concluded that new Kelvin structures should be designed and realized.

IV. DESIGN OF NEW TEST STRUCTURES

A new design of Kelvin structures has been realized. The structures include a large variety of contact geometries (i.e., shapes, see Figs. 4, 5) and contact overlaps between diffusion and contact areas (see Table II). Our aim is to obtain the most suitable structures for accurate contact resistance measurements. The measurements are planned to be carried out for Ni-, Co-, Pt- and Ti-silicides including both built-in and planar structures.

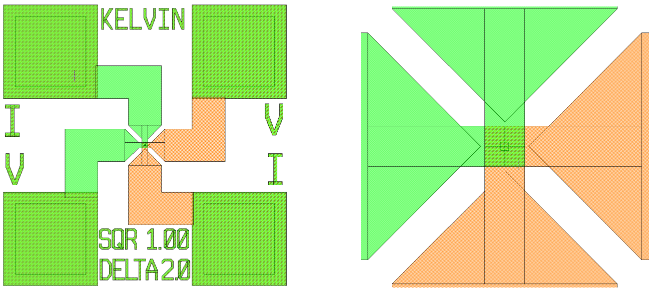
TABLE II
IMPORTANT CHARACTERISTICS OF NEW KELVIN STRUCTURES

Silicide	*d* µM	W_X µM	W_Y µM	L_X µm	L_y µm
NiSi	0.2 - 5	1-10	1-10	1-8	1-8
PtSi	0.2 – 5	1-10	1-10	1-8	1-8
$CoSi_2$	0.2 – 5	1-10	1-10	1-8	1-8
$TiSi_2$	0.2 - 5	1-10	1-10	1-8	1-8



A B

Fig. 4. Newly-designed CBKR structure covering a spectrum of geometries and overlaps. A shows the complete structure; B shows a blow up of the actual contact hole.



A B

Fig. 5. Newly-designed CBKR structure covering a spectrum of geometries and overlaps. A shows the complete structure; B shows a blow up of the actual contact hole.

V. REALIZATION OF NEW TEST STRUCTURES

For the contact resistance study, (100)-oriented p-type Si wafers were used. A thin scatter oxide layer was defined by dry oxidation. Two dopant implantations were carried out: 1) low-dose well implantation of P ($8\cdot10^{12}$ cm^{-2} dose at 420 keV) or B ($1\cdot10^{13}$ cm^{-2} dose at 180 keV); and 2) Highly Doped Drain (HDD) implantation of As ($3\cdot10^{15}$ cm^{-2} at 30keV) or B ($3\cdot10^{15}$ cm^{-2} at 5keV).

To define the contact, a silicide blocking layer (SiO_2/Si_3N_4) was deposited and patterned using I-line lithography. Further, various metal layers were deposited and their silicides were formed by means of one- or two-step annealing procedures. The non-reacted metal was selectively removed by wet etching. Back-end processing was applied to provide metal contacts to the CBKR structures. The deposition and structuring of TiW (barrier layer), and Al finalized the structures.

Electrical characterization of the newly-designed CBKR test structures is ongoing.

VI. CONCLUSION

For the existing CBKR test structures, the silicide-to-diffusion specific contact resistance was measured. A significant difference between the results earlier obtained by TLM and CBKR was observed. Analyzing the contact geometry factors for the Kelvin structures, it appeared that the 1D-Kelvin model did not account for the current flowing in the overlap region between the contact edge and the diffusion area. For that reason, the 2-D Kelvin approach was applied. However, the contact geometry, which was previously used for the metal-to-silicide contact resistance measurements, was not satisfactory to reveal the specific contact resistance value for the silicide-to-diffusion contacts due to the relatively high sheet resistance of the diffusion area.

To improve the accuracy of the measurements, new CBKR structures have been designed. The new design contains structures having a large variety of contact shapes, overlaps and diffusion area widths. The process flow is adjusted for self-aligned silicides as well as for planar silicide structures. Electrical characterization of the newly-designed CBKR test structures is ongoing.

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