A Vertical Kelvin Test Structure for Measuring the True Specific Contact Resistivity

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Abstract—**A vertical Kelvin test structure, which can be used to measure the true specific contact resistivity of a metallization system, is proposed and studied. For this test structure, the driving current flows "vertically," thus the sheet resistance and current crowding effects are eliminated and measurement on the true specific contact resistivity becomes possible. Experimental works show that this test structure gives a more linear relation between resistance and contact area than the conventional six-terminal test structure.**

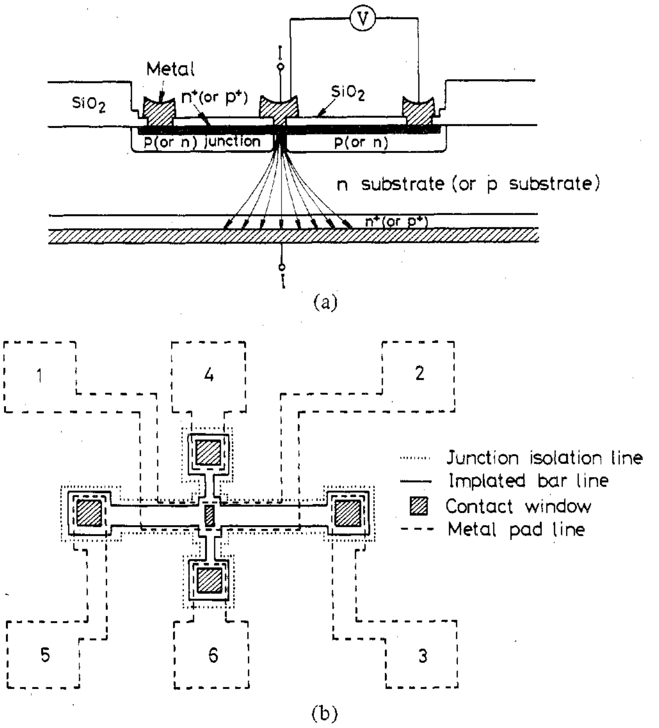
I. INTRODUCTION

SPECIFIC contact resistivity ρ_c is one of the most important parameters on studying interfacial properties of metallization systems. Many test structures [1]–[4] have been proposed to measure its value. However, due to some inherent parasitic factors such as the sheet resistance of the diffused layer and the lateral current crowdings (both horizontal and vertical), the "true" value of ρ_c is very difficult, if not impossible, to be measured [5]–[7]. The main reason for this difficulty comes from the fact that, for all these proposed test structures, the current flows "horizontally" in a diffused bar while the "vertical" interfacial contact resistance is to be determined.

In this letter, a "vertical" Kelvin test structure to measure the "true" specific contact resistivity is presented. For this test structure, the driving current flows "vertically" from the metal contact pad toward the contacted substrate. This eliminates the current crowding effects which are inherent in the horizontal type of test structures, and makes the determination of the "true" specific contact resistivity possible. This test structure can be incorporated with the six-terminal test structure [4] to compare the measured results.

II. TEST STRUCTURE

The cross section of the test structure is shown in Fig. 1(a) along with its top view in Fig. 1(b). The driving current I is forced from pad 1 toward the substrate and the voltage V is sensed between pads 2 and 3 along the implanted bar. The vertical current flow is restricted by an isolation p-n junction. For this structure, it can be seen that the current flows vertically and only through the contact window, hence the current distribution in the contact region is uniform provided that the contact region is metallurgically uniform. The contact resistance R_c is thus directly measured with the value of V/I and the specific contact resistivity is $A_c \cdot (V/I)$, where A_c is the contact area through which the current passes. No lateral current crowding effect, which is mentioned in [6] and [7], is expected. Also, the sheet resistance effect on determining the value of ρ_c becomes minimum for this test structure since it is not involved at all in determining ρ_c.



(a)

(b)

Fig. 1. (a) The cross-sectional view of the proposed vertical Kelvin test structure for measuring the true specific contact resistivity. (b) The top view of the structure. In the figure, the horizontal structure for the six-terminal measurement is also incorporated.

In Fig. 1, the six-terminal structure [4] is also incorporated and this has two merits. First, the voltage V can also be sensed between pad pairs 2-4, 2-5, and 2-6. The obtained values can be averaged with that of the pad pair 2-3 to reduce the error introduced by the misalignment between the isolation junction window and the contact window. Second, six-terminal measurement can be performed and the result can be compared with that obtained from the vertical structure.

III. EXPERIMENTS AND RESULTS

Test structures of Fig. 1 have been fabricated to compare the results obtained by the vertical structure measurement and

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the six-terminal measurement, respectively. Different contact systems of either Al(1-percent Si)/Si or Al(1-percent Si)/TiSi$_2$/Si were formed on n-type substrates of the resistivity of 3 ~ 5 Ω·cm. Contact regions of various dimensions (5 × 5 μm, 5 × 10 μm, 10 × 10 μm, 10 × 15 μm, 10 × 20 μm, 15 × 15 μm, 15 × 20 μm, 20 × 20 μm) were used. The alignment tolerance of the contact was 10 μm. The n$^+$ implanted bars and the p isolation junctions were formed by ion implantation and the junctions were kept as shallow as possible. The depths of n$^+$ junctions were 0.33–0.5 μm for 2 × 10^{15}/cm^2 to 6 × 10^{15}/cm^2 ion doses of As$^+$ and the junction depths of p isolations were 0.7 μm for 2 × 10^{13}/cm^2 ion dose of BF$_2^+$. The backsides of wafer were n$^+$ diffused and Al metallized. For each wafer, at least 200 test patterns were measured.

For all the test structures fabricated, the I–V characteristics were linear at the current levels of −5 to 0.5 mA. Contact resistances, measured in the linear region, of various contact areas are shown in Figs. 2 and 3 for Al(1-percent Si)/Si and Al(1-percent Si)/TiSi$_2$/Si contact systems, respectively, where R_{cv} were measured from the vertical structure and R_{cs} were measured from the six-terminal method. In these two figures, for two sets of measured points, two straight lines obtained by the least-square fitting are drawn. In Fig. 2, the slope of the R_{cv} straight line is −1.04, while that of the R_{cs} straight line is −0.88. In Fig. 3, the slope of the R_{cv} straight line is −0.85 and that of the R_{cs} straight line is −0.76. For both figures, the former are closer to the ideal value of −1. In these figures, it is also seen that R_{cv} values are always smaller than R_{cs} values and the differences become larger for larger contact areas. This is expected since the lateral current crowding and the sheet resistance effects (R_s = 22.67 Ω/□ and 46.5 Ω/□ for the case of Figs. 2 and 3, respectively) become serious in determining R_{cs} for the larger contact window if the alignment tolerance of the contacts is kept constant. This phenomenon had also been predicted by [6].

The apparent specific contact resistivities of contact systems were also measured with the vertical structure (ρ_{cv}) and the six-terminal method (ρ_{cs}) for a constant contact area. Fig. 4 is a plot of ρ_{cv} versus ρ_{cs} with the contact area of 20 × 20 μm. The various contact resistivities were obtained by implanting various doses of As$^+$ onto the contact window. It can be seen that ρ_{cs}/ρ_{cv} deviates more from 1 for smaller specific contact resistivities. Since it has been predicted that ρ_{cs} deviates more from the true value of ρ_c as ρ_c becomes smaller [7], this indicates that ρ_{cv} does give the closer value to the true specific contact resistivity.

IV. DISCUSSIONS AND CONCLUSIONS

In Fig. 3, the R$_{cv}$ line does not exhibit the ideal square law, i.e., the slope of −1. It is believed to be mainly caused by the nonuniformity of TiSi$_2$ formation at the contact interface. (The microscopy observation on the contact areas after stripping the contact metal confirmed this.) Besides the interface nonuniformity, for this test structure, the errors mainly come from the misalignment of the first mask to form the isolation junction and the third mask to open the contact window, and the lateral diffusion of the isolation junction. These two effects will make the current flow not strictly vertical at the periphery

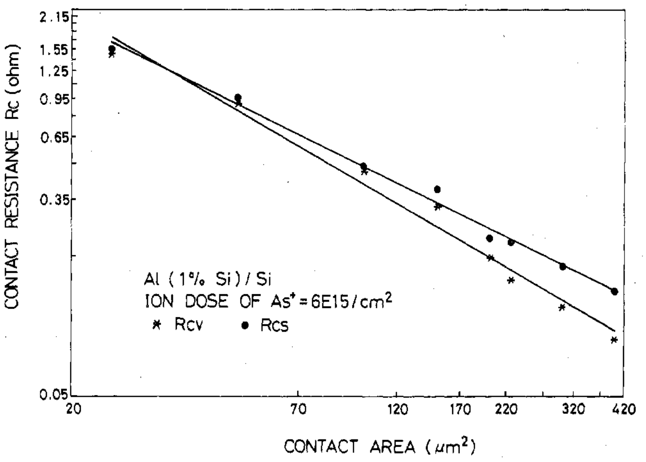

Fig. 2. The contact resistances of Al(1-percent Si)/Si are plotted versus the contact area, where R_{cv} were measured from the vertical structure and R_{cs} were measured from the six-terminal structure. The straight lines are obtained by the least-square-fitting method for two sets of measured values, respectively.

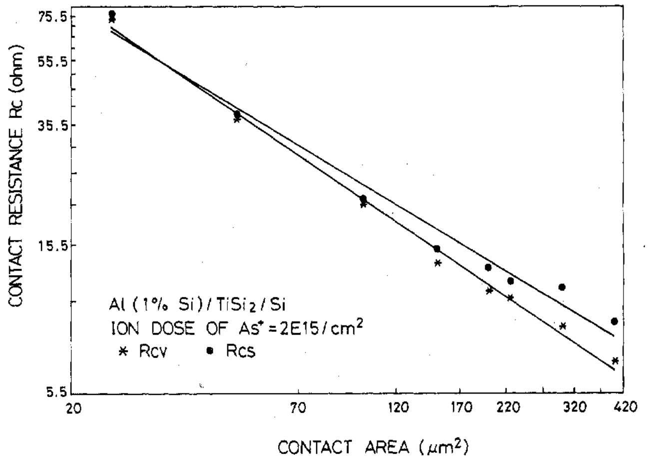

Fig. 3. The contact resistances of Al(1-percent Si)/TiSi$_2$/Si are plotted versus the contact area, where R_{cv} were measured from the vertical structure and R_{cs} were measured from the six-terminal structure. The straight lines are obtained by the least-square-fitting method for two sets of measured values, respectively.

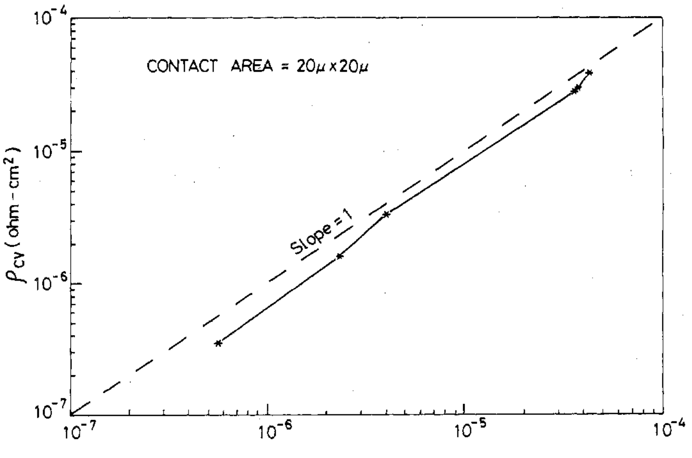

Fig. 4. The apparent specific contact resistivities of contact systems measured from the vertical structure ρ_{cv} are plotted with those measured from the six-terminal structure ρ_{cs}. The various contact resistances were formed by implanting various doses of As$^+$ onto contact regions.

of the contact region. However, the former error can be reduced by averaging the four R_{cv} values obtained by sensing on pad pairs of 2-3, 2-4, 2-5, and 2-6, respectively, and the latter error can be minimized by taking into account the lateral diffusion during the mask design. From the experimental results in Section III, the vertical test structure did give a more linear relation between contact resistance and contact area than the six-terminal test structure. Hence, it can be concluded that the vertical Kelvin test structure offers a potential method to measure the true contact resistance of contact systems.

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