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THE INFLUENCE OF INTERSTITIAL Ga AND INTERFACIAL Au_2P_3 ON THE ELECTRICAL AND METALLURGICAL BEHAVIOR OF Au-CONTACTED III-V SEMICONDUCTORS

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ABSTRACT

The introduction of a very small amount of Ga into Au contact metallization on InP is shown to have a significant effect on both the metallurgical and electrical behavior of that contact system. Ga atoms in the interstices of the Au lattice are shown to be effective in preventing the solid state reactions that normally take place between Au and InP during contact sintering. In addition to suppressing the metallurgical interaction, the presence of small amounts of Ga is shown to cause an order of magnitude reduction in the specific contact resistivity. Evidence is presented that the reactions of GaP and GaAs with Au contacts are also drastically affected by the presence of Ga. The sintering behavior of the Au-GaP and the Au-GaAs systems (as contrasted with that of the Au-InP system) is explained as due to the presence of interstitial Ga in the contact metallization. Finally the large, two-to-three order of magnitude drop in the contact resistance that occurs in the Au-InP system upon sintering at 400 C is shown to be a result of the formation of an Au_2P_3 layer at the metal-semiconductor interface. Contact resistivities in the 10^{-6} ohm cm^2 range are obtained for as-deposited Au on InP when a thin (20 A) layer of Au_2P_3 is introduced between the InP and the Au contacts.

INTRODUCTION

Gold and gold-based metallizations are commonly used to make electrical contact to the III-V semiconductors. An in-depth study of the reaction of Au with InP at this laboratory has led to a detailed understanding of the mechanisms involved in that interaction.[1-3] The insights gained in the study of the Au-InP system have made it possible to improve our understanding of the metal-semiconductor reactions that take place in other Au/III-V systems that are difficult to analyze because they do not exhibit the dramatic color changes that accompany the phase transitions in the Au-InP system. In particular we have found that the differences between the reaction of gold with InP and its reaction with Ga-based III-V semiconductors can be attributed to the effect of small amounts of gallium in the Au lattice. In the first part of this paper we detail the similarities and differences between the metallurgical interactions that take place in the Au-InP system and those that take place in the Au-GaAs and the Au-GaP systems. We then present evidence that suggests that the differences are a result of the presence of Ga in the contact metallization.

In the second part of the paper we confine our attention to the Au-InP system and to a consideration of the electrical aspects of that system. We start by showing that the introduction of small amounts of Ga into as-fabricated Au contacts at low (110 C) temperatures causes an order-of-magnitude reduction in the specific contact resistivity.

We next consider the two-to-three order of magnitude drop in the contact resistance that is observed when the Au-InP system is

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heated to the 380-to-400 C range. We give evidence that this resistance drop, which is accompanied by the dissolution of large amounts of InP into the metallization (and which ensures the destruction of all but the very deepest junction devices), is the result of the formation of an Au_2P_3 layer at the metal-InP interface. Finally we show that contact resistivities in the 10^{-6} ohm cm^2 range can be obtained with <u>as-deposited</u> Au contacts if a thin (20 A) layer of Au_2P_3 is introduced between the InP and the Au contacts.

EXPERIMENTAL

Polished, (100) oriented, p-type InP, Zn doped to 3×10^{16} cm^{-3} was used in the metallurgical investigations. In the electrical investigations we used epitaxially deposited n/p diodes (2000 A junction depth) for the transmission line method (TLM) resistance measurements[4]. The substrate doping was 8×10^{16} cm^{-3} (Zn), and the epi-layer doping was 1.7×10^{18} cm^{-3} (Si). For resistance measurements using the Cox and Strack (C&S) technique[5] we used bulk n-type InP, (100) oriented, S doped to 5×10^{18} cm^{-3}.

Contact deposition was by electron beam evaporation during which the substrates were not actively cooled. A metal thickness of 2000 A was used for the Au-only contacts. Gallium was introduced into the metallization by sandwiching either a 200 A or a 20 A Ga layer between two 900 A Au layers. The former, upon thorough mixing, would result in a 9 a% Ga/Au mixture, and the latter in a 1 a% mixture. We found that it was necessary to homogenize the Ga content via low temperature heat treatment prior to sintering at

elevated temperatures, i.e., at temperatures of 420 C and above. A 30 minute heat treatment at about 320 C was used for this purpose. We found that without this homogenization step the effect of Ga addition was significantly reduced.

Compositional analysis was performed via x-ray photoelectron spectroscopy (XPS). The XPS system was specifically calibrated for use with both the Au-In and the Au-Ga binary systems.

Sintering was performed in a rapid thermal annealing (RTA) apparatus. The ambient during sintering was forming gas.

The diodes used for the TLM measurements had Au-Zn ohmic back contacts. This permitted us to monitor the degree of emitter dissolution/perforation during sintering by observing the quality of the diode I-V characteristic. As a measure of the I-V quality we arbitrarily defined a diode conduction voltage V_1 as the voltage at which the forward current through the TLM patterned diode (area 5.6 X 10^{-3} cm^2) is 1 mA.

METALLURGICAL EFFECTS

The Au/III-V Interaction: Similarities. In the early stages of the contact sintering process there is a close correspondence between the reactions of the three technically important III-V semiconductors, InP, GaP, and GaAs, with Au contact metallization. The reactions all begin with the entry of both semiconductor components into the contact metallization.[1-3,6-8] In each case the group III atoms take positions on the Au lattice so as to form, ultimately, a saturated solid solution (alpha phase) with the host metallization. The group V atoms, on the other hand, either take

non-lattice sites in the metallization or exit the system without chemically reacting.[1-3,6-8]

In all three cases the entry of the group III atoms takes place via a dissociative diffusion mechanism[1-3,6], the distinguishing characteristics of which are an extremely rapid low temperature diffusion rate and a peak in the group III element concentration profile at the free surface of the metallization.[9-11]

Another common characteristic is the fact that the diffusion process, at least in the Au-InP and the Au-GaAs systems, is highly unilateral. Although we have not investigated the Au-GaP system, SiO_2 capping experiments done on the Au-InP and the Au-GaAs systems indicate that, while there is substantial diffusion of the semiconductor components into the metallization, there is little or no diffusion of metal atoms into the semiconductor.[1,6]

The Au/III-V Interaction: Differences. InP, GaP and GaAs react quite similarly with Au as the sintering process proceeds through what we will refer to as stage I (the formation of the alpha phase). Heat treatment beyond this point, however, reveals several substantial differences between the InP-Au system and the Au-GaP and Au-GaAs systems. What is found is that 1) the metallization in the InP-Au system, upon further sintering, proceeds through at least two more phase transitions, while in the GaP-Au and GaAs-Au systems no reaction is observed beyond stage I, and 2) during stage II in the Au-InP system the group V element reacts with the contacting metal to form Au_2P_3 at the metal-semiconductor interface, whereas no reaction products involving the group V element are found in either the Au-GaP system or the Au-GaAs system.

The investigations of both Pecz et al.[8] and Piotrowska et al.[7], for example, indicate that unless melting occurs[12] the only phase formed in the Au-GaP system after extended sintering is the alpha phase. Both investigators reported finding no group V related compounds.

Similar results have been found for the GaAs-Au system. However, since the GaAs-Au system has been investigated much more thoroughly than the GaP-Au system, there is much more data available, with some results in conflict with others.

If one considers only cases where Au deposition is performed at ambient temperature, where melting has not occurred, and where the sintering temperature does not exceed about 450 C, then the preponderance of evidence indicates that the reaction of Au with GaAs stops when enough Au has entered the metallization to form the alpha phase.[13-16] There are no reports of the formation of any arsenic related compounds.

There are, however, a few reports of the appearance of other phases. Two laboratories have reported observing crystallites of the beta phase dispersed in the alpha phase matrix[17,18], and small particles of Au_2Ga (but no beta phase) have been reported by another[19]. Of the two groups reporting beta phase formation, one indicates that the it is seen in only some of the sintered samples, prompting the authors to attribute its presence to uncontrolled experimental conditions such as GaAs surface preparation[18]. No other observations of Au_2Ga are reported. Thus, while there are several reports of the appearance of additional phases, the evidence supporting the alpha phase as terminal in the Au-GaAs system far outweighs the evidence to the contrary. We therefore feel that it is reasonable to conclude that in this system as in the Au-GaP

system, the metal-semiconductor reaction is complete (subject to the restrictions stated above) once the alpha phase has formed.

In contrast with these two Ga-based systems, recent work has shown that, during sintering, the InP-Au system progresses through at least three phase changes.[2,3] During these three stages, all of which are solid state in nature, both In and P leave the semiconductor and enter the metallization. The first stage is essentially the same as that occurring in the GaP-Au and GaAs-Au systems, as discussed previously. In this stage, which continues until the In content in the Au lattice reaches the solid solubility limit, In atoms enter the metallization interstitially and diffuse until encountering vacant sites in the Au lattice, at which point they take substitutional positions on the Au lattice by annihilating the vacancies (dissociative diffusion).[2]

In the second stage the saturated Au(In) solid solution is converted to Au_3In. During this stage In atoms again enter the metallization interstitially, but in this case they diffuse to the Au(In)/Au_3In interface where they displace substitutional Au atoms into interstitial positions (kickout mechanism).[2] The interstitial Au atoms thus formed then diffuse to and react with newly released P atoms to form Au_2P_3 at the metal-semiconductor interface. The rate of entry of In into the metallization is the rate limiting step in this second stage.[2]

The third stage, in which the pink colored Au_3In is converted to the silver colored Au_9In_4, also takes place via a kickout mechanism.[3] In this case, however, the rate limiting step has been shown to be the kickout or exchange step itself.

The Effect of Ga in the Au Lattice. The question that arises at this point is why these three systems, which behave so similarly

in the early stages of contact sintering, are so different in the later stages. Why, specifically, does the Au-InP reaction progress through three consecutive stages during the contact sintering process, while both the Au-GaP and the Au-GaAs reactions stop at the completion of stage I?

An insight into this difference in behavior is provided by the phosphorus release studies of Mojzes et al.[20], where it was shown that the addition of Ga to Au contacts on InP is effective in preventing the release of P during subsequent heat treatment. The presence of Ga in the Au lattice, therefore, apparently inhibits the Au-InP interaction. Since it occurred to us that this effect may explain the differences between the Au-InP system and the Au-GaP and Au-GaAs systems we set about to determine the mechanisms involved.

We started by introducing various amounts of Ga into Au contacts on InP and studying the effect it had on the metal-semiconductor reaction. Figure 1 shows the effect of annealing a 2000 A thick Au layer on a polished, (100) oriented InP substrate at 355 C. It can be seen that in 40 minutes the Au has been converted almost completely into the pink colored Au_3In, i.e., stage II is essentially complete. It can also be seen that the addition of as little as 1 a% Ga to the contact metallization significantly retards the stage II reaction, and the introduction of 9 a% Ga effectively stops it.

Figure 2 compares the XPS concentration profile of the Au-contacted sample in figure 1 with that of the Au-1 a% Ga contacted sample after both had been sintered at 355 C for 40 minutes (phosphorus profile deleted for clarity). It should be noted that, in addition to reducing the net amount of In that entered the metallization, the Ga addition eliminated the peak in

the In concentration at the free surface of the metal that is
inevitably observed in Au-InP couples, even those that have not been
sintered at elevated temperatures[9-11]. A Ga peak replaces the In
peak at the metal surface.

Figure 3 shows the effect of Ga addition on the stage III
Au_3In-to-Au_9In_4 transition. As can be seen, the reaction is
substantially retarded by the introduction of as little as 1 a% Ga.
With the addition of 9 a% Ga there was no sign of the silver colored
Au_9In_4 even after an hour at 435 C. The 1 a% Ga sample, however,
did turn silver colored after 60 minutes at that temperature.

Finally we found that the effectiveness of the Ga addition
decreases with time at room temperature. The reaction retarding
ability of a 1 a% Ga addition, for example, completely disappears
after aging for 4 months at ambient temperature.

The Function of Ga. As mentioned above, the introduction of
Ga eliminates the In concentration peak usually observed at the free
surface of the metallization in Au-InP couples (figure 2). Since
this peak is a characteristic of dissociative diffusion, its absence
indicates that Ga is somehow preventing In from diffusing
dissociatively, i.e. interstitially, in the Au lattice. On the
other hand, since we do observe a peak in the Ga concentration at
the metal surface, it is apparent that Ga is itself being
transported dissociatively in that lattice.[21] These facts
strongly suggest that Ga preferentially enters the Au interstices
and effectively "saturates" them to the point of preventing In (and
as we shall see, very probably Au) from entering the interstitial
pool.

Such an hypothesis is indeed consistent with the observed
facts. To begin with, all three stages in the Au-InP reaction

involve the formation and diffusion of the In interstitial (In_i).
The prevention of In_i formation by a "saturated" Ga interstitial
solid solution would suppress, as observed, all three stages of the
Au-InP interaction.

This hypothesis also explains the changes observed in the
effectiveness of the Ga additions that occur as a result of room
temperature aging. When the total concentration of Ga in the Au
lattice is below the solid solubility limit, interstitial Ga (Ga_i)
is a metastable species. The Ga_i pool should, with time, become
entirely converted to substitutional Ga through vacancy
annihilation. The Ga_i concentration should thus decrease with time,
and, according to our hypothesis, so should its ability to suppress
the Au-InP interaction. The room temperature aging experiments show
that this is indeed what happens.

The effect of a decreasing Ga_i concentration is also seen at
elevated temperatures. In figure 1, for example, we see that after
about 40 minutes at 355 C the conversion rate in the 1 a% Ga sample
proceeds at the same rate as the gallium-free sample. Once a
sufficient amount of Ga_i has been converted to substitutional Ga the
reaction is no longer suppressed, and it proceeds as if the Ga were
not present.

To summarize, an explanation is suggested for the reaction
suppressing behavior of Ga additions to Au contact metallization
which appears to be consistent with the observed facts. We suggest
that a portion of the added Ga atoms preferentially enter and
"saturate" the interstitial regions of the Au lattice, thereby
precluding the entry therein of interstitial In (and possibly other
species). Since In_i formation and migration are necessary for all
three stages in the Au-InP interaction to take place, all aspects of

the reaction of Au with InP are suppressed if sufficient Ga_i is present.

The Effect of Ga in the Au-GaP and Au-GaAs Systems. As we have seen, both GaP and GaAs differ from InP in their reaction with Au in that the Ga-based systems do not react beyond stage I (alpha phase formation), whereas the In-based system proceeds on through at least two more phase transitions. We can explain this behavior very easily if we assume that the "saturation" of the interstices of the Au lattice by Ga interstitials precludes the formation of Au as well as In interstitials. Thus in the Au-GaP and the Au-GaAs systems where the metallization would be expected to contain significant amounts of interstitial Ga, interstitial Au atom formation would not be possible. If the presence of Ga prevents the formation of interstitial Au, then stages II and III in the Au-GaP and the Au-GaAs systems (assumed to be analogous to stages II and III in the Au-InP system) would not take place because the kickout mechanism, which results in the formation of interstitial Au, would not be able to function.

While stages II and III in the Ga-based systems would be suppressed, according to our hypothesis, by the presence of Ga in the Au metallization, stage I would proceed uninhibited (as observed) since the only species involved in that stage is the Ga interstitial.

ELECTRICAL EFFECTS

The Effect of Ga Additions. We have seen that the addition of small amounts of Ga to Au contact metallization has a significant

effect on the metallurgical characteristics of the contacts. We have found that the electrical characteristics of the Au-InP system are also affected by the introduction of Ga. Figure 4, for example, shows the variation in specific contact resistivity (TLM measurements) during isochronal annealing for an InP epi diode with Au-only contacts. The contact resistance is not significantly affected until temperatures in the vicinity of 380 C are reached, after which it is seen to drop precipitously. According to figure 5, however, the improvement in contact resistance is accompanied by a severe degeneration of the diode I-V characteristic. Emitter perforation caused by the dissolution of InP into the metallization has resulted in direct contact between the metallization and the base of the diode. The resulting diode conduction voltage V_1 is thus reduced by a factor of two, to a level characteristic of a Schottky barrier.

Also shown in figure 4 is the behavior of an identical diode contacted with a Au-9 a% Ga mixture. As can be seen, the as-fabricated contact resistance is an order of magnitude lower than for the sample with Au-only contacts. The divergence in the contact resistances can be seen to approach two orders of magnitude as the temperature is raised to the 250-to-300 C range. Although raising the temperature beyond the 300 C range causes the resistance to rise, the presence of the Ga does prevent the diode-destroying dissolution of InP into the contact metallization. This is attested to by the relative invariance of V_1 with temperature (figure 5).

Because the metallurgical characteristics of the Au-InP system were shown to be affected by the addition of very small amounts (1 a%) of Ga, we sought to determine if this were so for the electrical characteristics as well. Figure 6 illustrates the effect of adding

only 1 a% Ga to the contact metallization. As shown, the as-fabricated resistance is again found to be an order of magnitude lower than for Ga-free contacts. The smaller amount of Ga, however, does not appear to be sufficient to prevent diode degradation at the higher temperatures, as both the contact resistance and V_1 are seen to fall off.

It is clear that contact resistances are considerably lower when the Au contacts contain Ga. It is not clear, however, whether the Ga additions actually reduce the contact resistance, or whether they merely prevent resistance increases that occur in Au-only contacted devices during device fabrication (i.e., during low temperature fabrication steps such as e-beam evaporation or photoresist baking).

To answer this question we 1) fabricated a number of samples with Au-only contacts, 2) measured their as-fabricated contact resistivities 3) deposited Ga on the Au contacts, and 4) subjected the samples to low temperature heat treatment while monitoring the contact resistivity This procedure required remasking the samples (via photolithography) after the Au-only contact resistivities were measured, and then depositing, in sequence, 200 A Au, 200 A Ga, and then 200 A Au over the original metallization. The contact resistivities were then measured as the samples were annealed at low temperatures.

The results are shown in figure 7. As can be seen, the resistance of the sample heated to 110 C to simulate the photoresist baking step dropped about an order of magnitude as a result of the low temperature heat treatment. These results indicate that the Ga does something to actively reduce the resistance (rather than passively preventing an inherent degradation of the Au contacts).

It is not clear exactly how the Ga additions reduce the contact resistance, although the rapid transport of the newly deposited Ga through several thousand Angstroms of Au at these low temperatures confirms its interstitial nature. We know from the previous discussion that interstitial Ga suppresses the entry of In from the InP into the metallization. We also know that without the Ga, In dissolves into and is quickly transported away from the metal-semiconductor interface.[2,3] Phosphorus, on the other hand, which is released with the In, is thought to accumulate at or near the interface at low temperatures (stage I) and only slowly to diffuse out of the system.[2,3] This results in a phosphorus rich interface. The Ga additions, by slowing down the rate of entry of In (and P) into the metallization, should reduce the amount of accumulated P at the interface by giving it time to disipate. The literature contains a number of references correlating contact resistance reductions with the achievement of a phosphorus-poor Au-InP interface.[22-24] Perhaps the same mechanism is operational here.

The 400 C Contact Resistivity Drop. The most striking feature of figure 4 is the large drop in contact resistivity that takes place when the Au-InP couple is sintered for a few minutes in the vicinity of 400 C. In figure 8 we show the electrical and metallurgical behavior of such a sample during an isothermal heat treatment at 353 C. As can be seen, the resistivity drop begins when the pink compound Au_3In starts to appear, and is complete when the metallization is 100 % pink colored. It is quite obvious, therefore, that the drop in contact resistance is a result of the stage II $Au(In)$-to-Au_3In phase transition.

Stage II in the Au-InP system is accompanied by a number of physical changes, any or all of which may be responsible for the observed electrical effects.[1]   The three most obvious changes are 1) the geometrical changes (pitting) in the InP surface, 2) the appearance of the alloy Au_3In, and 3) the formation of the compound Au_2P_3 at the metal-semiconductor interface.   To determine which, if any, of these are responsible for the resistance drop, we performed the following experiment (summarized in figure 9) where we selectively removed/replaced the various stage II products.   To do this we had to be able to accurately remask and redeposit on our contact resistivity measurement patterns.   We found that the alignment accuracy required for pattern replacement in the case of the TLM pattern where current flow is lateral to the pattern was beyond our capability.   We therefore switched to a Cox and Strack (C&S) pattern for these experiments where the current flow is normal to the pattern and lateral alignment is not as critical.   It should be noted that the doping level in the material used in these C&S measurements is somewhat higher than that in the material used for the TLM measurements.   Thus the overall resistivity levels in the C&S samples are lower than those in the TLM samples.[25]

The procedure consisted of preparing a number of C&S patterns on bulk n-type InP and heat treating them for 3 minutes at 390 C to induce the stage II phase transition.   As shown in figure 9 a two order of magnitude drop in contact resistivity accompanied the stage II transition.

We then removed all reaction products (Au_3In and Au_2P_3) from some of the samples and only the Au_3In alloy from others.[1]   We found, to our surprise, that we were able to make contact resistivity measurements on the latter samples where only the Au_2P_3

layer remained. The results are shown in the figure where it can be seen that the resistivities of these samples remained essentially the same as those of the fully metallized samples. Upon remasking and then redepositing a 2000 A Au layer over the original patterns we found that the samples where we had removed both the Au_2P_3 and the Au_3In exhibited high resistance, whereas in the samples where the Au_2P_3 layer was left intact the contact resistivity remained low.

From the above results we can conclude that the resistance drop is due neither to the changes in the InP surface geometry nor to the presence of the Au_3In alloy. The large contact resistance drop that accompanies the stage II transition is due to the formation of the compound Au_2P_3 at the metal-InP interface.

The Effect of Thin Au_2P_3 Interfacial Layers. The stage II transition that results in the formation of interfacial Au_2P_3 is unfortunately accompanied by the dissolution of substantial amounts of InP into the contact metallization.[1] In an attempt to achieve the low contact resistance attendant to Au_2P_3 formation while avoiding the destructive effects of InP dissolution, we investigated the effectiveness of very thin Au_2P_3 interlayers. To this end we prepared a number of TLM patterned samples with very thin (30 - 100 A) Au layers. The samples were then heated to 400 C for several minutes to induce the stage II transition in the thin metallization. The TLM patterns were then carefully remasked and the metallization built up by evaporating 2000 A Au on top of the existing pattern. A summary of the resulting contact resistivities is given in figure 10 where they are compared to a sample with no thin interlayer that had been sintered at 400 C. Also in the figure are the values of V_1 for the various contact systems.

While sintering lowered the resistivity of the samples without the presintered interlayer by several orders of magnitude (from the 10^{-4} ohm cm^2 range to the 10^{-6} ohm cm^2 range), it also reduced the value of V_1 to the Schottky barrier level. The samples with the thin interlayers, on the other hand, exhibit the same low contact resistivity values but their conduction voltages are not degraded. Partial lowering of V_1 can be seen for the samples with 100 A interlayers where there apparently was enough Au in the initial thin layer to allow some perforation of the 2000 A thick emitter during the heat treatment to induce the stage II transition. It is possible that interlayers even thinner than those used here may be effective in lowering the contact resistance, but Au layers thinner than 30 A make mask realignment extremely difficult. Even for a Au thickness of 30 A, however, the thickness of the resulting Au_2P_3 layer is less than 20 A (assuming uniform phosphide thickness and a reaction that proceeds as: 3 InP + 11 Au -> 3 Au_3In + 1 Au_2P_3).

It is possible, therefore, to achieve specific contact resistivities in the 10^{-6} ohm cm^2 range with Au contact metallization without sacrificing emitter integrity if a thin Au_2P_3 interlayer is introduced at the Au-InP interface.

SUMMARY

The major conclusions that can be drawn from the preceding analysis can be summarized as follows:

1. The differences between the reaction of Au with InP and its reaction with GaP and GaAs are the result of the presence of small amounts of Ga in the contact metallization.

2. When Ga is introduced into Au contact metallization it preferentially enters and saturates the interstices of the Au lattice, thereby precluding entry therein of other species, specifically In and Au.

3. Because In interstitial formation and migration are involved in all three stages of the Au-InP interaction, all aspects of the reaction of Au with InP are suppressed if sufficient Ga_i is present.

4. By preventing interstitial Au formation the presence of Ga_i inhibits all phase transitions beyond formation of the alpha phase in the Au-GaAs and Au-GaP systems.

5. The addition of small amounts (1 a%) of Ga to Au contact metallization on InP is effective in reducing the specific contact resistance by an order of magnitude.

6. The large, two-to-three order of magnitude drop in the contact resistance that occurs in the Au-InP system upon sintering at 400 C is a result of the formation of an Au_2P_3 layer at the metal-semiconductor interface.

7. Contact resistivities in the 10^{-6} ohm cm^2 range can be obtained for <u>as-deposited</u> Au on InP if a thin (20 A) layer of Au_2P_3 is introduced between the InP and the Au contacts.

ACKNOWLEDGEMENT

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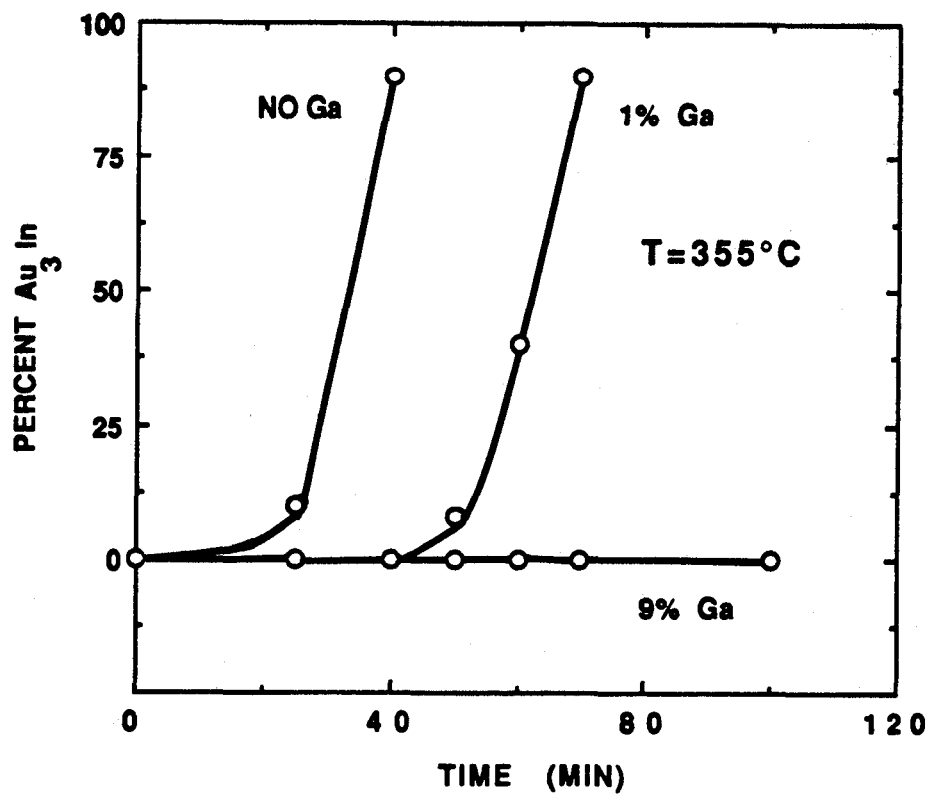
FIGURE CAPTIONS

Figure 1. Percent Au(In)-to-Au$_3$In conversion as a function of time at 355 C. Solid curves are arbitrary fit through data.
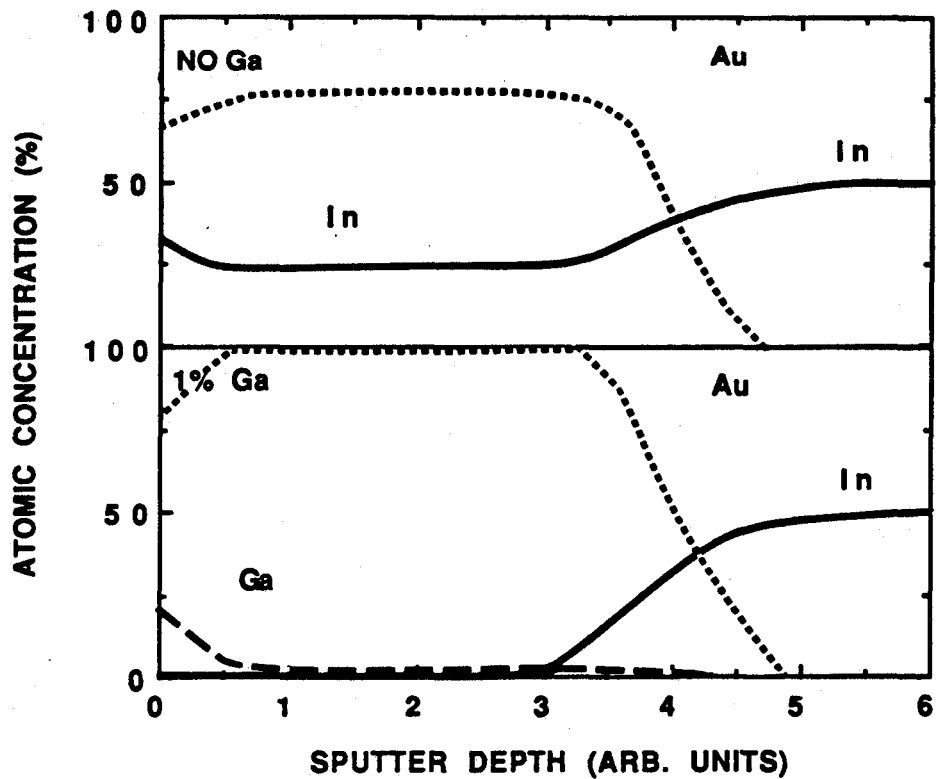
Figure 2. XPS concentration depth profiles for Au-only (upper) and Au-1 a% Ga (lower) contacts after 40 minutes at 355 C.
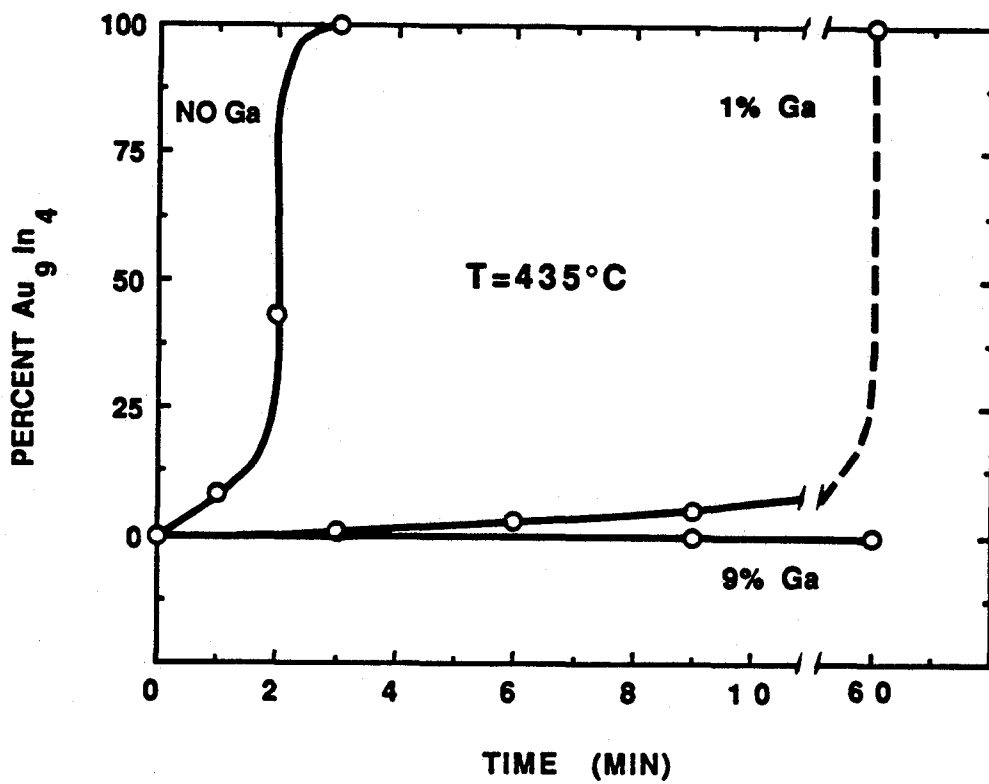
Figure 3. Percent Au$_3$In-to-Au$_9$In$_4$ conversion as a function of time at 435 C. Solid curves are arbitrary fit through data.
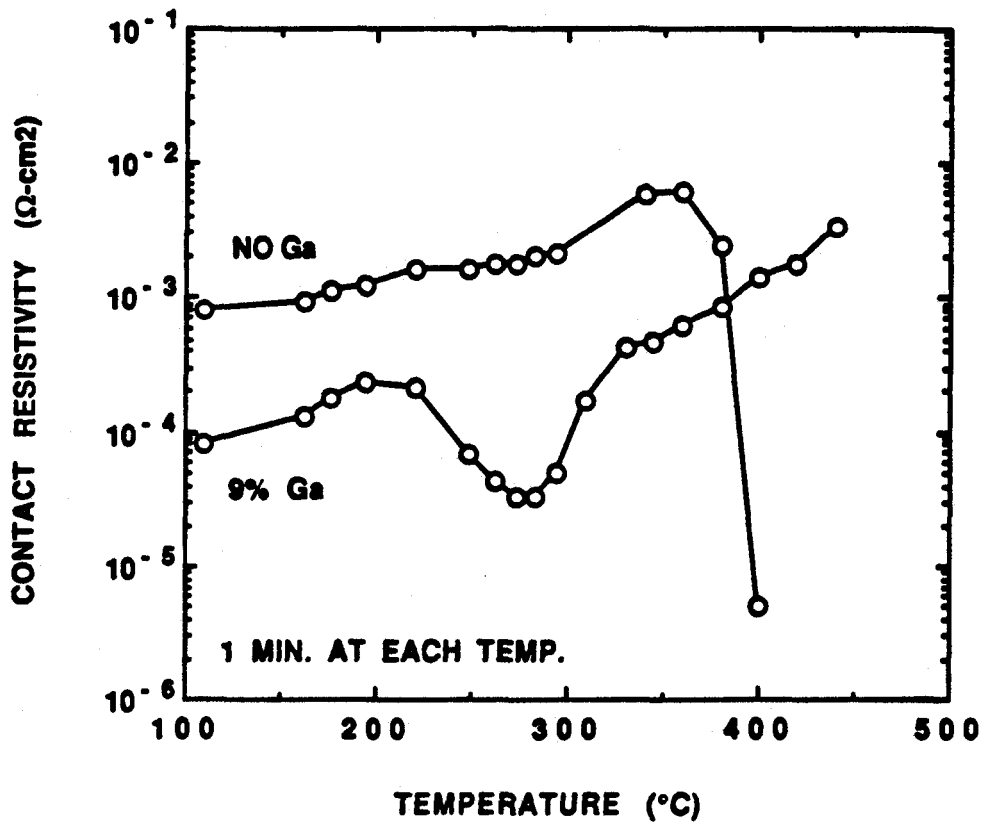
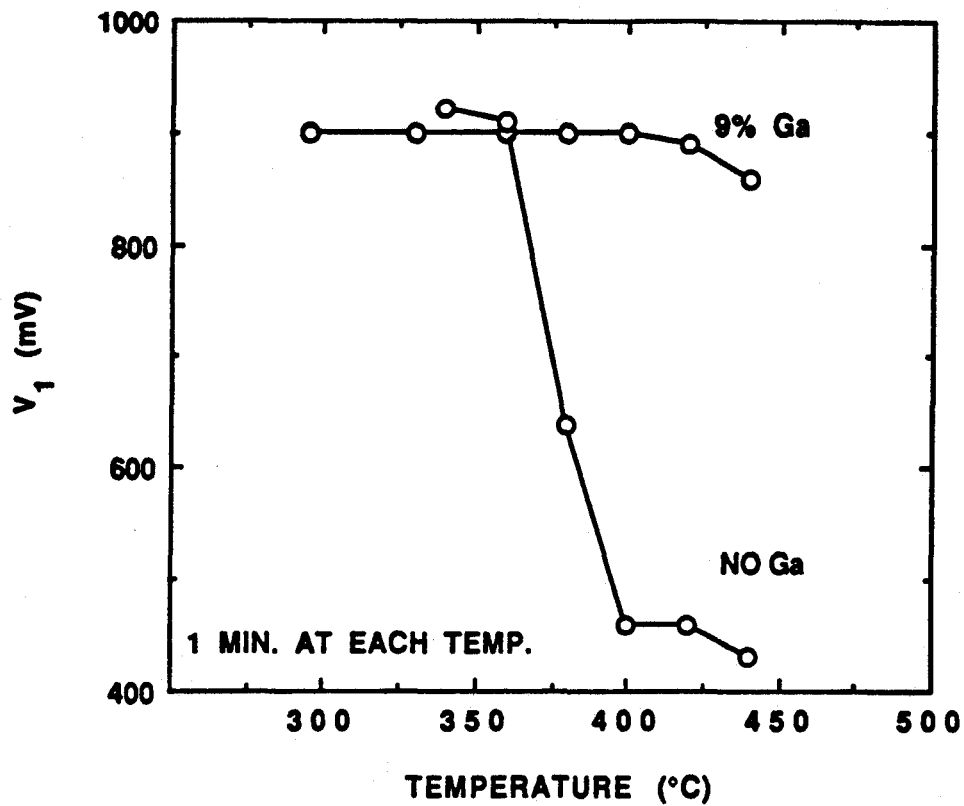Figure 4. The effect of sintering on specific contact resistivity. One minute at each temperature.

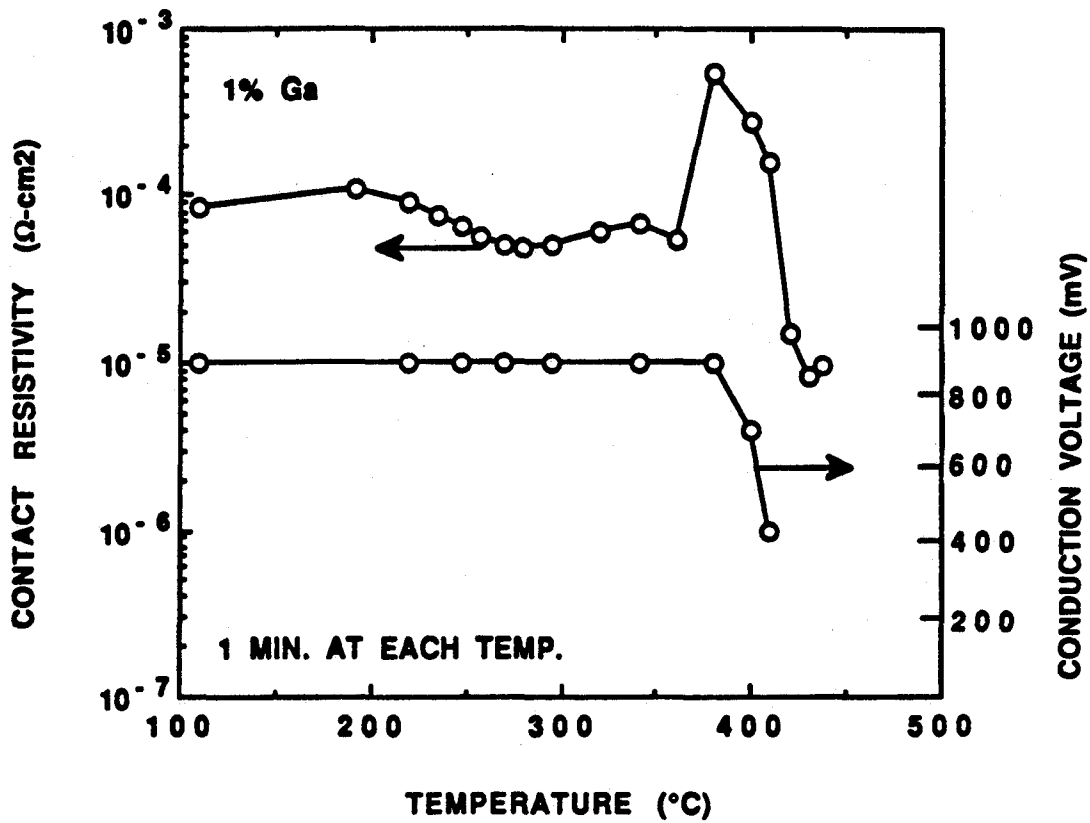Figure 5. The effect of sintering on the diode conduction voltage V_1. One minute at each temperature.

Figure 6. The effect of sintering on contact resistivity and conduction voltage for Au-1 a% Ga contacts.

Figure 7. The variation of contact resistivity with time after introduction of Ga. Arbitrary fit to data.

Figure 8. Contact resistivity and percent Au(In)-to-Au$_3$In conversion for Au-only contacts as a function of time at 353 C.

Figure 9. The effect of contact removal and replacement on the specific contact resistivity.

Figure 10. The variation of contact resistivity and conduction voltage with thickness of sintered Au. Total Au thickness in all cases approximately 2000 A.

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Figure 4. The effect of sintering on specific contact resistivity.
One minute at each temperature.

1000

900 ── 9% Ga

V_1 (mV)

800

600

NO Ga

1 MIN. AT EACH TEMP.

400

300   350   400   450   500

TEMPERATURE (°C)

Figure 5. The effect of sintering on the diode conduction voltage
V_1. One minute at each temperature.

Figure 6. The effect of sintering on contact resistivity and conduction voltage for Au-1 a% Ga contacts.

Figure 7. The variation of contact resistivity with time after
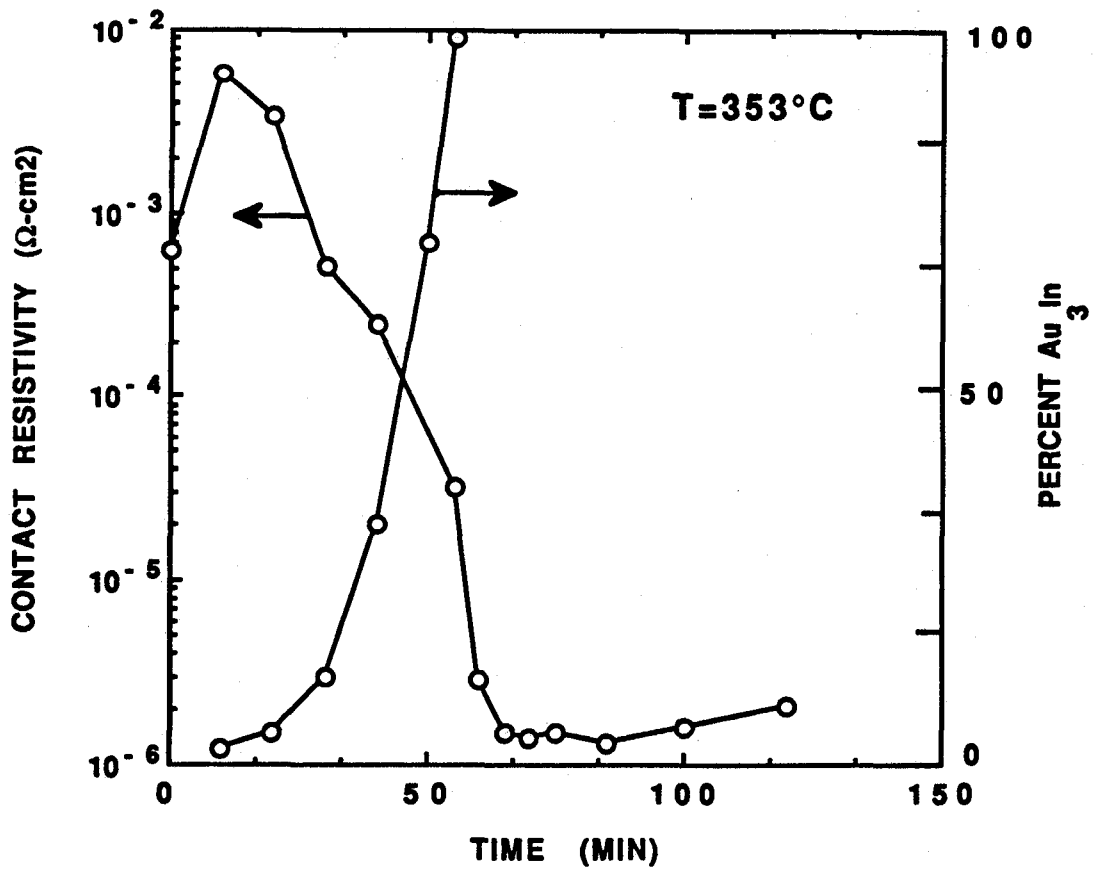introduction of Ga. Arbitrary fit to data.

Figure 8. Contact resistivity and percent Au(In)-to-Au$_3$In conversion for Au-only contacts as a function of time at 353 C.
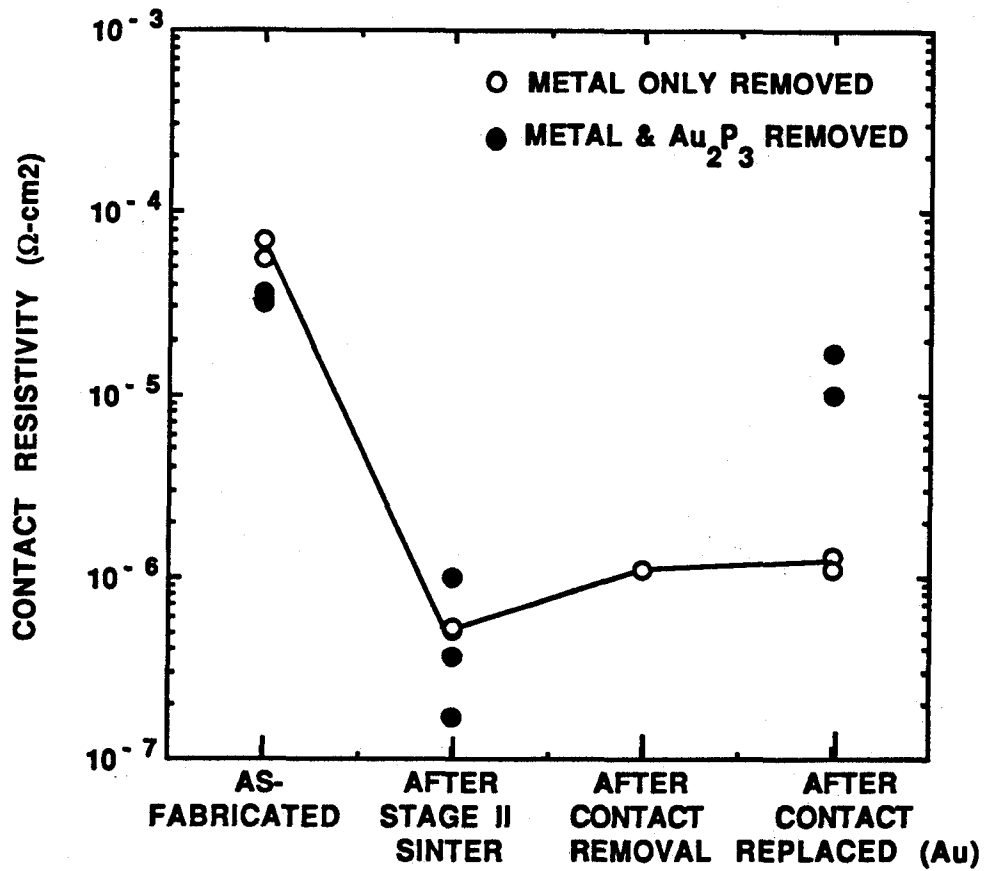
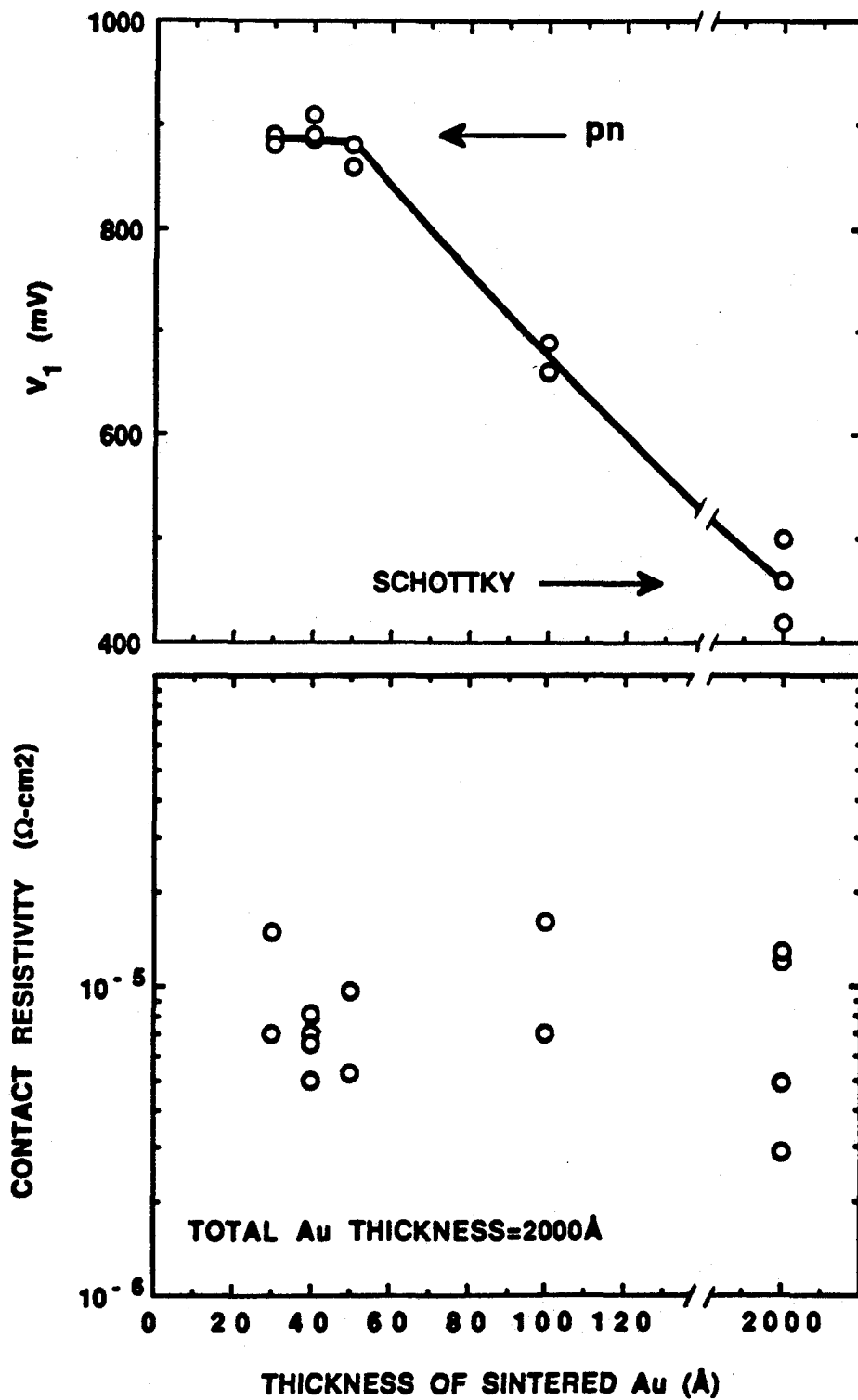Figure 9. The effect of contact removal and replacement on the specific contact resistivity.

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