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Prepared for the  
Fourth International Conference on Indium Phosphide  
and Related Materials  
sponsored by the Institute of Electrical and Electronics Engineers  
Newport, Rhode Island, April 21-24, 1992





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In the past, the achievement of good electrical contact to InP has inevitably been accompanied by mechanical degradation of the InP itself. Most contact systems require heat treatment after metal deposition that results in the dissolution of substantial amounts of InP into the metallization. Devices such as the solar cell, where shallow junctions are the rule, can be severely degraded if the damage to the semiconductor substrate is not precisely controlled.

While there are several remedial approaches to control the sinter-induced metallurgical interactions such as the use of rapid thermal annealing (RTA) techniques or the imposition of diffusion barriers between the InP and the current carrying metallization, their use adds complexity and an element of trial-and-error to the contacting process.

A better solution would be to eliminate the need to sinter the contacts and thus avoid the device-destroying metallurgical interactions that accompany high temperature processing. In this paper we describe two contact systems that provide low contact resistance to InP solar cells that do not require subjecting the current carrying metallization to a post deposition sintering process. We show that these two systems, one nickel-based and the other silver-based, provide contact resistivity ( $R_c$ ) values in the low  $10^{-6}$  ohm  $cm^2$  range, as fabricated, without the need for sintering.

Before discussing our results, however, let us consider the metal-semiconductor reactions that take place between InP and Ni and between InP and Ag.

## The InP-Ni Interaction

Figure 1 shows the variation of  $R_c$  (TLM measurements) for Ni contacts (2000 Å thick) on (100) n-InP (Si:  $1.7 \times 10^{18} cm^3$ ) during heat treatment at 400 C. Within a matter of minutes  $R_c$  is seen to drop several orders of magnitude to the mid  $10^{-7}$  ohm  $cm^2$  range. As the sintering proceeds, however,  $R_c$  eventually rises back up to the  $10^{-4}$  ohm  $cm^2$  range.

To determine the causes of the  $R_c$  variations we attempted to profile the sintered contacts using both AES and EDS. We performed these measurements on

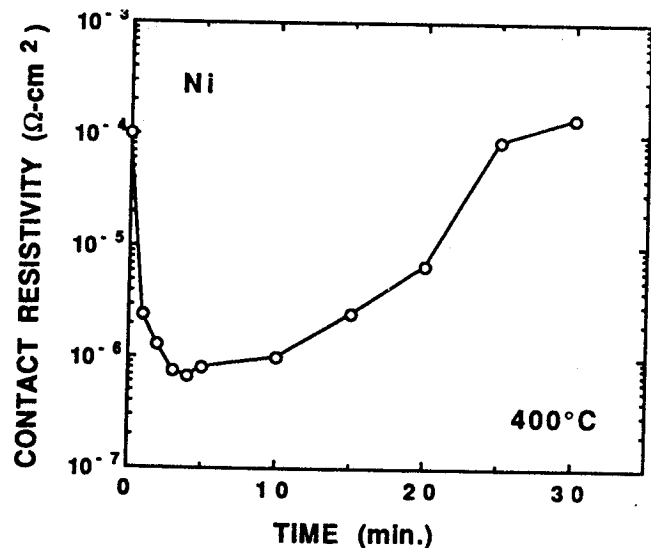


Fig. 1 The variation of  $R_c$  for Ni-contacted InP during sintering at 400°C.

samples that had been sintered for several minutes (low  $R_C$ ) and for extended periods (high  $R_C$ ). Prior to EDS examination we chemically etched the samples using  $HNO_3$ - and Thiourea-based etches so as to expose the subsurface structure.

Both the EDS and the AES analyses indicated that the contacts sintered for only a minute or so (low  $R_C$ ) consist of three distinct layers. The outermost layer consists almost entirely of In metal containing a small amount (15%) of P. Beneath the In layer in these low  $R_C$  samples we found two Ni-P layers. The analysis indicates that the layer which is in contact with InP is the compound  $Ni_3P$  with a phosphorus content of 25 at%. The analysis further indicates that the more remote layer consists of the 33 at% phosphorus compound  $Ni_2P$ . A schematic diagram of the suggested structure is given in figure 2a. The relative positions of the two phosphide layers is somewhat surprising in light of the fact that the phosphorus source is the InP. One would have expected the more P rich compound to form adjacent to the InP, and not vice-versa.

A similar analysis was performed on samples subjected to extended sintering (high  $R_C$ ). The only major difference between these

and the previous samples was that, in this case, only one phosphide layer is observed between the InP and the In-rich layer. The data indicates that this layer is composed of  $Ni_2P$ . The resulting structure is described schematically in figure 2b.

Since the presence of the  $Ni_3P$  interlayer is correlated with the achievement of low  $R_C$  values, we suggest that the formation of this layer in the early stages of the sintering process is the cause of the dramatic drop in  $R_C$ , and that its disappearance (via conversion to  $Ni_2P$ ) upon extended heating results in the observed rise in  $R_C$ . Similar  $R_C$ -lowering characteristics have been reported for  $Au_2P_3$  in the Au-InP system.<sup>(1)</sup>

#### The Ag-InP Interaction

In a manner similar to the Ni-InP system, the specific contact resistivity of Ag-contacted InP drops quickly upon sintering at 400 C. Figure 3 shows the variation of  $R_C$  with time at 400 C for 2000 Å thick Ag contacts on the same InP substrate material described previously.  $R_C$  values in the low  $10^{-6}$  ohm  $cm^2$  range are readily

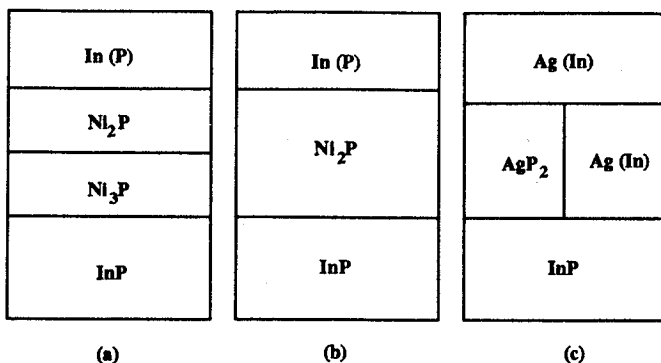


Fig. 2 Schematic description of sintered contacts. a) Ni-InP, 400°C, 4 min., b) Ni-InP, 400°C, 30 min., and c) Ag-InP, 400°C.

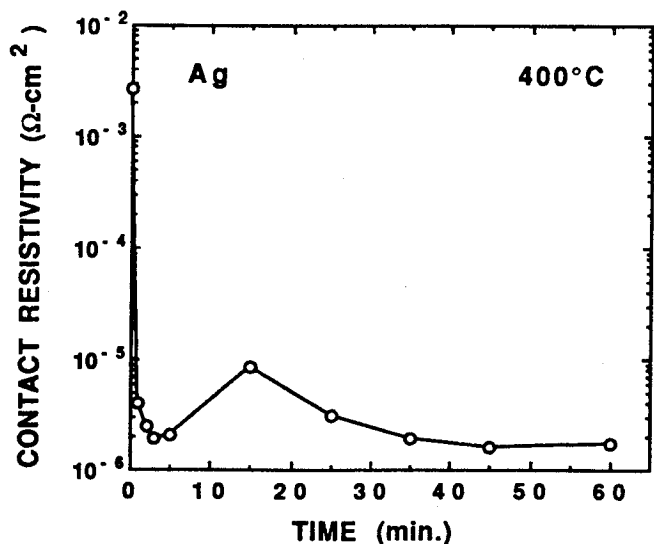


Fig. 3 The variation of  $R_C$  for Ag-contacted InP during sintering at 400°C.

achieved after a minute or so at 400 C. This system differs from the Ni-InP system, however, in that extended sintering does not cause a rise in  $R_C$ .

As we did in the previous case, we attempted to profile the reacted metallization by combining various chemical etches with EDS and XPS analyses. Employing KI- and Thiourea-based etches to reveal subsurface details, we have found that there are two major layers in the sintered metallization. Our analysis indicates that at the free surface of the contact metal there is a layer of Ag containing some In. Between this layer and the InP surface we have found a second layer consisting of regions of an Ag-P compound coplanar with regions of Ag(In). This structure (figure 2c) is present after sintering for 1 minute at 400 C and remains qualitatively unchanged during extended sintering at that temperature. The Ag-P compound which we have shown to be in intimate contact with the InP and to account for about 50 % of the metal-semiconductor contact area, has been observed by others and positively identified as  $AgP_2$ .<sup>(2)</sup>

The correlation between the drop in  $R_C$  and appearance of  $AgP_2$  at the metal-InP interface leads one to suspect that there is a cause-and-effect relationship between the two events. It is suggested, therefore, that in the Ag-InP system, as in the Au-InP and the Ni-InP systems, significant reductions in the specific contact resistivity can be achieved by introducing an appropriate metal-phosphide layer between the InP and the current carrying metallization.

#### Non Destructive Contacts

In the foregoing we have shown that low contact resistivities can be achieved with either Ni or Ag contacts. In both of these systems, however, a

sintering schedule sufficient to produce low  $R_C$  values (several minutes at 400 C) results in the dissolution of large amounts of InP into the contact metallization. The result is emitter perforation and a shunting of the electrical characteristics of the device. The diodes used in figures 1 and 3, for example, were seriously shunted after a minute at 400 C.

Since the reason for the sintering step is thought to be to generate certain metal phosphides at the metal-InP interface, it follows that one should be able to eliminate the need for sintering by introducing the appropriate phosphide layer by some other means. While it is no doubt possible to introduce a phosphide layer via vapor or chemical deposition, there is a simpler, albeit slightly more destructive, way to deposit the layer.

Since the electrical characteristics of the contact system are controlled by the nature of the interface between the InP and the metal phosphide, it seems reasonable to conclude that a very thin phosphide layer would suffice. Thus, if a very thin (Angstroms thick) metal layer were deposited on the InP and sintered, the required phosphide would form, but it would be accompanied by only a very small amount of emitter dissolution. The contacts could then be built up with a conductive metal. In this way gross damage to the semiconductor device could be avoided while still achieving the low  $R_C$  values attendant to interfacial phosphide formation. It should be noted that the use of a thin interfacial phosphide layer has proven successful in the Au-InP system.<sup>(3)</sup>

To test this idea in the present systems we fabricated a number of TLM patterns by first evaporating 40 Å of either Ag or Ni. The thin layers were sintered

at 400 C for two minutes to generate the respective phosphide layers. The samples were then carefully remasked and the patterns built up with a conducting metal (Au used here).

Figure 4 shows electron micrographs of the thin sintered layers prior to remasking and buildup. The Ag structure consists of unconnected islands that cover about one third of the surface area. Ni, on the other hand, forms an open dendritic lattice with about a 50 % surface coverage. The resulting as-fabricated  $R_C$  values (after Au buildup) are shown in figure 5 where they are compared with

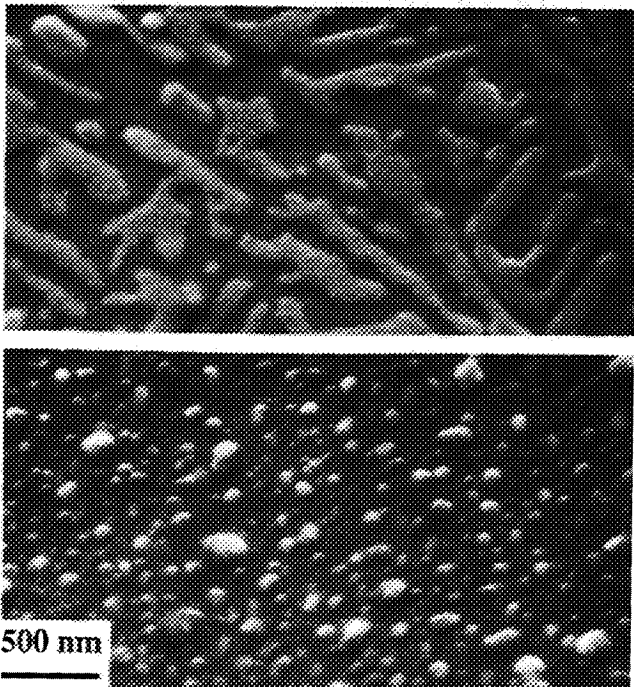


Fig. 4 Structure of thin metallization layers after sintering at 400°C for 2 min. Upper: Ni, Lower: Ag.

previous results employing a thin gold phosphide interlayer<sup>(3)</sup> and with  $R_C$  values typical of Au contacts prior to sintering. When the current-voltage characteristics of the diodes upon which these contacts were deposited (2000 A junction depth) were inspected, there was no sign of device shunting. The conduction voltages (see ref 1) for all of the Ni- and Ag-contacted samples in figure 5 were in the 900-to-950 mV range, indicating negligible diode degradation.

We can conclude, therefore, that it is indeed possible to achieve specific contact resistivities in the low  $10^{-6}$  ohm  $cm^2$  range without compromising emitter integrity through the introduction of any of a number of metal-phosphide interlayers including  $Ni_3P$ ,  $AgP_2$ , and  $Au_2P_3$ .

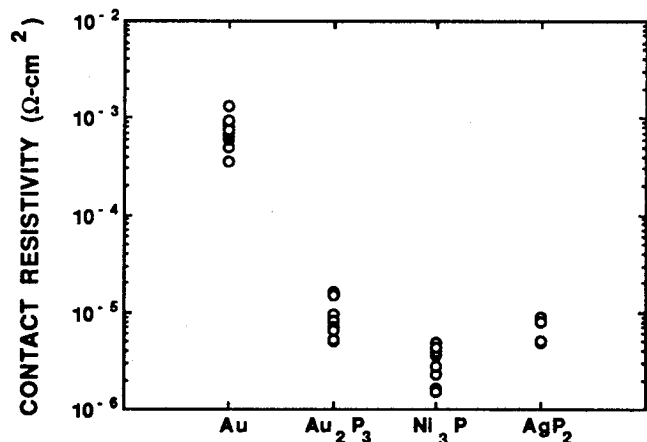


Fig. 5 As-fabricated contact resistivities for contacts with  $Au_2P_3$ ,  $Ni_3P$ , &  $AgP_2$  interlayers.

#### Acknowledgements

The authors wish to thank Frank S. Honey for providing the AES analysis and Douglas T. Jayne for providing the XPS analysis. Work performed by N.S.F. and A.L.K. was done under contracts NAS3-25266 and NAS3-30759, respectively, with the NASA Lewis Research Center.

### References

- 1) V.G.Weizer and N.S.Fatemi, "The Influence of Interstitial Ga and Interfacial  $Au_2P_3$  on the Electrical and Metallurgical Behavior of Au Contacted III-V Semiconductors", J. Appl. Phys. 69, 8253 (1991).
- 2) D.L.Kirk and J.S.K.Mills, "The Appearance of  $AgP_2$  Within the Interface of Silver Metal and (100) Indium Phosphide", Thin Solid Films 67, L29 (1980)
- 3) N.S.Fatemi and V.G.Weizer, "The Formation of Low Resistance Electrical Contacts to Shallow Junction InP Devices Without Compromising Emitter Integrity", J. Electron. Mat. 20, 875 (1991).

# REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

<b>1. AGENCY USE ONLY (Leave blank)</b>		<b>2. REPORT DATE</b> 1992	<b>3. REPORT TYPE AND DATES COVERED</b> Technical Memorandum	
<b>4. TITLE AND SUBTITLE</b> Sinterless Contacts to Shallow Junction InP Solar Cells			<b>5. FUNDING NUMBERS</b>  WU-506-41-11	
<b>6. AUTHOR(S)</b> V.G. Weizer, N.S. Fatemi, and A.L. Korenyi-Both				
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b>  National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135-3191			<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>  E-7036	
<b>9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)</b>  National Aeronautics and Space Administration Washington, D.C. 20546-0001			<b>10. SPONSORING/MONITORING AGENCY REPORT NUMBER</b>  NASA TM-105670	
<b>11. SUPPLEMENTARY NOTES</b> Prepared for the Fourth International Conference on Indium Phosphide and Related Materials sponsored by the Institute of Electrical and Electronics Engineers, Newport, Rhode Island, April 21-24, 1992. V.G. Weizer, NASA Lewis Research Center; N.S. Fatemi, Sverdrup Technology, Inc., Lewis Research Center Group, 2001 Aerospace Parkway, Brook Park, Ohio 44142 (work funded under NASA contract NAS3-25266); A.L. Korenyi-Both, Calspan Corporation, 7550 Lucerne Drive, Suite 401, Cleveland, Ohio 44130 (work funded by NASA contract NAS3-30759). Responsible person, V.G. Weizer, (216) 433-2230.				
<b>12a. DISTRIBUTION/AVAILABILITY STATEMENT</b>  Unclassified - Unlimited Subject Category 44			<b>12b. DISTRIBUTION CODE</b>	
<b>13. ABSTRACT (Maximum 200 words)</b>  In the past, the achievement of good electrical contact to InP has inevitably been accompanied by mechanical degradation of the InP itself. Most contact systems require heat treatment after metal deposition that results in the dissolution of substantial amounts of InP into the metallization. Devices such as the solar cell, where shallow junctions are the rule, can be severely degraded if the damage to the semiconductor substrate is not precisely controlled. In this paper we describe two contact systems that provide low contact resistance to InP solar cells that do not require subjecting the current carrying metallization to a post deposition sintering process. We show that these two systems, one nickel-based and the other silver-based, provide contact resistivity ( $R_c$ ) values in the low $10^{-6}$ ohm $cm^2$ range, <u>as fabricated</u> , without the need for sintering.				
<b>14. SUBJECT TERMS</b> Indium phosphide; Electrical contacts; Silver; Nickel			<b>15. NUMBER OF PAGES</b> 6	
			<b>16. PRICE CODE</b> A02	
<b>17. SECURITY CLASSIFICATION OF REPORT</b> Unclassified	<b>18. SECURITY CLASSIFICATION OF THIS PAGE</b> Unclassified	<b>19. SECURITY CLASSIFICATION OF ABSTRACT</b> Unclassified	<b>20. LIMITATION OF ABSTRACT</b>	