SAND95-2117C

CONF-960457--1

COVER SHEET
ICMCTF96 CONFERENCE

Paper Number: H6.05

Title of Paper: Adhesion Studies of GaAs-based Ohmic Contact and Bond Pad Metallization

RECEIVED
MAR 2 2 1996
OSTI

Name of Authors: P. K. Seigal, R. D. Briggs, D. J. Rieger, A. G. Baca, A. J. Howard

Full Name of Principal Author to Receive All Corresponcence:

Pamela K. Seigal

Full mailing Address of Principal Author:

MS 1082, Dept. 1333
Sandia National Laboratories
P. O. Box 5800
Albuquerque, NM 87185-1082

Telephone Number: (505) 844-0258

Telefax Number: (505) 844-8480 include "858/1234" on FAX cover sheet

e-mail address: seigalp@sandia.gov

Keywords for Paper: GaAs contact metallization, metal adhesion, gold alloy bond pads.

Adhesion Studies of GaAs-based Ohmic Contact and Bond Pad Metallization

P. K. Seigal, R. D. Briggs, D. J. Rieger, and A. G. Baca

Sandia National Laboratories, Microelectronics and Photonics Directorate

Albuquerque, NM 87185-1082 E-mail seigalp@sandia.gov

A. J. Howard

Intel Corporation

Rio Rancho, NM 87124

The adhesion strength and surface morphology of commonly used n- and p-type ohmic contacts and pad metallization schemes for GaAs were investigated. GeNiAu, GePdAu, BeAu, and TiPtAu, being studied as potential ohmic contacts for internal optoelectronic device applications had quantitative measurements made using wire bond pull testing to determine adhesion. Bond pad metals deposited as evaporated TiAu, TiPtAu and 2-5 micron thick electroplated Au deposited on both semi-insulating GaAs and on Si_3N_4/GaAs were evaluated independently from the ohmic contact metals. In all the samples, we observed a strong correlation between surface treatment, surface morphology, wire bondability, and bond strength. Very high bond strengths (pull test average values above 6.5 grams force with 25 micron diameter gold wire), were obtained for n-type, p-type, and bond pad metals. Average values of 8.0 gram force were achieved with a two-step GeAu/NiAu/TiPtAu metallization scheme, while the one-step deposition yielded poorer values. Adhesion was also monitored after aging at 250 °C in air for four different times up to 60 hours by means of wire bond pull testing, with little degradation occurring.

This work performed at Sandia National Laboratories was supported by the U. S. Department of Energy under contract DE-AC04-94AL85000.

Introduction

N-type GaAs optoelectronic devices commonly utilize a contact made with germanium-gold or germanium-nickel-gold alloys.[1,2] P-type material contact is generally made from beryllium-gold[3,4] or titanium-platinum-gold. While achieving low resistive contacts for good electrical performance at wafer level probing, these contact materials do not always provide the optimum metallization for packaging. Instead separate metallization schemes designed specifically for wire bonding or solder attach are incorporated. The bond pad may be located either coincident to the contact or away from the contact where it might be placed directly on semi-insulating GaAs or on top of a dielectric thin film layer. See figure 1 which illustrates a typical cross sectional view of contact metal and bond pad metal topology. While some of Sandia National Laboratories' research was focused on improving the electrical performance characteristics of the contacts, a parallel effort was undertaken to improve the bondability of the same metal alloys in order to demonstrate package level reliability of our device prototype. The influence of alloy composition, pre-deposition cleaning, and post evaporation treatment on the adhesion of ohmic metals and bond pad metals was examined in this investigation. The changes found to have the greatest impact on wire bonding are the areas reported in this study, with the electrical performance reported separately.[5]

Experiment

Sandia's baseline n-type ohmic contact process is one of GeAu/NiAu, using 26 nm of germanium; 54 nm of gold; 15 nm of nickel; and 200 nm of gold deposited by electron beam evaporation, followed by a rapid thermal anneal. The GeAu/NiAu metal composition was modified and a change from a one-step deposition to a two-step deposition for bond pad metallization was undertaken. The thickness of the final gold top layer was also increased. Five variations of GeNiAu contact metals were part of the study.

A common p-type contact used as a reference in this study was Beryllium2%-Gold alloy, with bond pad metal of Titanium-Platinum-Gold added. Four variations of BeAu p-type contact metals are included in the study.

Four sample of PdGeAu contact metal variations were also included along with a single TiPtAu sample. Fourteen total alloy depositions comprised the ohmic contact portion of the study. The composition and annealing cycle for each sample are listed in Table 1.

Separate bond pad metals, deposited on GaAs or on Si_3N_4 were also evaluated. The eight variations are summarized in Table 2. The bond pad metals did not receive an anneal. All the samples were processed by the Compound Semiconductor Research Laboratory (CSRL) at Sandia National Laboratories and submitted for wire bonding pull test analysis with only an identification number in order to insure impartial evaluation.

The substrates used for <u>contact metal</u> adhesion in this study were GaAs (100) wafers. Bulk substrates were used instead of epitaxially grown layers in order 1) to focus on the wire bond-to-metal pad material interface and 2) to use readily available materials rather that waiting for epitaxially grown samples. The patterning process consisted of liftoff photolithography, O_2 Descum, 20:1 clean (20:1 DI water:ammonium hydroxide (NH_4OH) spray for 30 seconds, followed by a nitrogen dry, optional), metal evaporation, liftoff soak, O_2 strip, and anneal (optional), for the 2-step depositions a second metal evaporation (optional), and for a PdGe sample (#21) a second anneal. Metal pad dimension were 100 x 50 microns. Evaporation took place in a CVC electron-beam evaporation system with a base pressure below $5x10^{-7}$ Torr. Oven Anneals were in a Blue-M convection oven. The Rapid Thermal Anneal (RTA) was performed in an Addax AET system. Both were performed in a forming gas environment.

The substrates used for <u>bond pad</u> metal adhesion in this study were GaAs (100) wafers and GaAs wafers coated with silicon nitride. On those samples which were electroplated, the process included a TiAu seed layer evaporation, a six micron thick plating resist, O_2 plasma descum, electroplating, solvent strip, and seed layer removal etch. While the bond pad metal adhesion study was conducted using mechanical GaAs substrates with a non-isolated mask designs, the subsequent electrical performance material was run on doped epitaxial substrates with electrically isolated features.

Evaluation of the candidate metal schemes was made in three ways: Atomic Force Microscopy (AFM) imaging [6,7], surface roughness, and wire bond pull testing.

The surface roughness of each sample was characterized using a Digital Instruments Dimension 3000 System Atomic Force Microscope (AFM) operating in tapping mode with silicon nitride tips in a class 100 clean room. The root mean square (RMS) roughness values were taken from points inside a 5x5 micron area using built-in software. AFM is a clean, non destructive evaluation tool, which allowed monitoring the samples before they were submitted for wire bond pull testing.

Wire bond pull testing was performed on the samples following MIL-STD-883-D, 2011.7 for flat loop, double bond test condition D in order to give quantitative values for comparison. A minimum of 20 wire bond loops were made by wedge bonding 25 micron diameter gold wire. The force in grams required to break the wire loop when using the Unitek Micropull III system, was recorded for each loop. Commonly used parameters for standard manufacturable wire bonding processes were used. Some samples did not have metal surfaces suitable for bonding. The average and standard deviation of the wire pull test values for the 'as-received' parts for which bonding was possible are reported in table 3. Enough wire bonds were made to comprise a sample study for pulling at least twenty bonds at four different time intervals (initial, 6, 16, and 60 hours) with aging at 250 ^{o} C in air.

Results and Discussion

A.) GeNiAu alloy contacts

All the one-step deposition GeNiAu alloys contact metals (samples 1, 2, 14, and 17) exhibited poor to fair wire bonding pull test values (below 5.0 grams). The addition of TiPtAu (#17) gave better results than sample #1, but was still below the targeted 6.0 gram force pull strength values for this application. The two-step deposition with the added TiPtAu (sample #18), however, improved the wire bonding results dramatically, achieving 8.0 gram force average. In figure 2, the pull test values for sample #18 are plotted. Note that the second deposition in sample #18 is not followed by an anneal, and in surface morphology looks very much like the TiPtAu alone, sample #4. The RMS values for #18 and #4 were 4.94 and 3.37 respectively. The corresponding average in 'as-received' pull testing for sample #4 was 4.7 gram force. AFM images of sample #4, TiPtAu, is shown in figure 3. AFM image of sample #18, TiPtAu deposited of GeNiAu, is shown for comparison in figure 4. Both exhibited relatively smooth surfaces which were expected to be good for wire bonding. Performing the 20:1 oxide removal clean prior to the metal evaporations was found to be critical.

B.) BeAu contact alloys

Samples #3, 13, 15, and 16 constituted the BeAu alloys included in the study. In-situ deposition of TiPtAu makes the BeAu contacts bondable (samples 15 and 16), but there is little difference in bond strength between in-situ and ex-situ addition of TiPtAu, in contrast to GeNiAu contacts. RMS roughness values for samples #15 and #16 were 4.0 and 4.1, while bond strength values of 6.4 and 6.6 gram force were obtained. Both values were above the targeted 6.0 value.

C.) PdGeAu contacts

In order to lower the contact resistance below the value obtained from our GeNiAu components, other candidate materials and processes were considered. A low temperature process GePdAu scheme[8] which passed initial screening for other application in the CSRL was included in the study. The annealing temperature and process cycle were also included as variables in the study. Like the BeAu samples, large metal roughness resulted in unbondable surfaces. The low temperature n-ohmic contact material PdGeAu appeared very rough after anneal. The surface appearance of sample #19, one which was not bondable, is illustrated in Figure 5. TiPtAu deposited over the PdGeAu, sample #21, improved the surface roughness enough to make bonding possible. Samples #21, seen in Figure 6, achieved a pull strength average value of 6.9. RMS roughness values were 40.3 and 14.2 for #19 and #21 respectively.

D.) Bond Pad Metals on Silicon Nitride or GaAs

Beryllium 2%-gold followed by gold plating has been a common p-type contact and bond pad scheme in use for some time at Sandia's CSRL, but recently evaluation of the adhesion to silicon nitride was included in this study since it showed promise in the device prototype evaluation. High pull strength values were obtained from this entire group that utilized Ti as an adhesion layer without subsequent high temperature anneals. Measurements indicated that strong bonds could be obtained on both the GaAs and Si_3N_4 substrate surfaces. Thicker plating decreased the bond strength values. The best sample in the group was sample #10, TiPtAu on GaAs which exhibited a very high bond strength average of 7.7 grams. The inclusion of Pt under the gold offers advantages for applications where solder attach might also be used.

E.) Aging at 250 ^{o} C

In order to understand the wire bond pull strength changes which might be caused by various curing and temperature cycling in assembly, packaging, and use, an aging study at 250 ^{o} C in air was conducted on all the samples. Pull tests were made as-received, after 6 hours, 16 hours and

60 hours. Very little degradation was found to occur in the wire bond -to- bond pad metal interface during aging at 250 ° C in air after 60 hours. Figure 6 plots the averages for ten different ohmic contact metal samples after the aging. Figure 7 plots the averages for six bond pad metal samples after the aging. There is some indication that separation occurred between contact metal and the bond pad metal in two-step depositions, but that the likelihood of this separation decreased with increased aging time. In no instance did the aging result in bond pad metal separating or peeling from the insulating substrate or dielectric during the bond wire pull testing. Samples #18 (GeAu/NiAu with separate deposition of TiPtAu) and #21 (PdGeAu/TiPtAu with oven anneal) in particular maintained high bond strengths throughout all pull testing.

F.) General Observations.

In general, high RMS roughness correlated well with bond strength from the pull tests. RMS roughness is interpreted as evidence of ohmic contact reaction with GaAs. One well known result of such a reaction is the formation of AuGa phases which have been observed at the surface of the contact metal. We speculate that the presence of Ga on the contact surface is related to poor metal adhesion which results in poor bond strength.

Conclusions

1.) Good metal adhesion, morphology, and bondability were achieved by adding a separate TiPtAu bond pad layer over both GeNiAu and BeAu contact metals. Very high wire bond strength were obtained which did not degrade when subjected to longer times at 250° C in air. Most of the alloys that used titanium for adhesion, whether plated gold, on GaAs, or on Si_3N_4 demonstrated good wire bondability and adhesion. 2.) PdGeAu with a TiPtAu overlay also showed promise as an alternative n-ohmic contact 3.) Performing the 20:1 oxide removal clean prior to all metal evaporations was found to be critical.

Acknowledgments

The authors would like to thank Leonardo Griego for his work on the Atomic Force Microscope, Jeanne Sergeant for her processing expertise, and Katherine Myers for her work on wire bonding and pull testing.

References

1 R.H. Cox and H. Strack, Solid State Electronics, 10 (1967) 1213.

2 N. Braslau, J.B. Gunn and J. L. Staples, Sol. Stat. Electronic. 10 (1967) 381.

3 V.L. Rideout, Solid State Electronics, 14 (1987) 541.

4 V. Malina, K. Vogel, J. Zelinka, Semicond. Sci. Technology. 3 (1988) 1015. [BeAu]

5 R.D.Briggs, A.J. Howard, A.G. Baca and M.J. Hafich, Proceedings of ICMCTF (1996) H6.06.

6 A.J. Howard, A.G.Baca, R.J. Shul, J.C. Zolper, M.E. Shirwin, D.J. Rieger, Proceedings of the International Workshop on Characterization, NIST, Githersburg, MD (1996) 654.

7 A.G.Baca, A.J. Howard, R. J. Shul, M.E. Sherwin, J.C. Zolper, D.J. Rieger, Non-destructive GaAs IC Process Characaterization and Monitoring by Atomic Force Microscopy, *Semiconductor Fabtech, Issue No. 3*, Digital Instrument, Santa Barbara, CA (1995).

8 L.C. Wang, P.H. Hao, B.J. Wu, Appl. Phys. Lett. 67, (1995), 509.

Table 1. Contact Metal Alloy Summary

#	Clean	Metal deposition thickness in nm	Contact Anneal Temperature in ^{o} C and time	Second Anneal	RMS in nm
1	20:1	26 Ge:54 Au/ 15 Ni:200 Au (Standard GeNiAu)	RTA 360		3.5
2		26 Ge:54 Au/ 15 Ni:200 Au	RTA 360		33.0
14	20:1	50 Ni:26 Ge:54 Au/ 30 Pd:400 Au	RTA 420 90 sec		11.3
17	20:1	GeNiAu/ 50 Ti:50 Pt:400 Au	RTA 360		5.5
18	20:1	GeNiAu/ 50 Ti:50 Pt:400 Au	RTA 360	none	4.9
3	20:1	300 Be 2% Au (Standard BeAu)	RTA 360		4.0
13	20:1	BeAu/ 10 Ti:30 Pd:100 Au	RTA 420 90 sec		8.9
15	20:1	BeAu/ 50 Ti:50 Pt:400 Au	RTA 360		4.0
16	20:1	BeAu/ 50 Ti:50 Pt:400 Au	RTA 360	none	4.1
4	20:1	50 Ti:50 Pt:400 Au	RTA 360		3.4
19	20:1	10 Pd:50 Ge:120 Au	Oven 175 60 min		40.3
20	20:1	10 Pd:50 Ge:300 Au	Oven 175 60 min		16.4
21	20:1	10 Pd:50 Ge:300 Au/ 50 Ti:50 Pt:400 Au	Oven 175 60 min		20.3
22	20:1	10 Pd:50 Ge:30 Au/ 50 Ti:50 Pt:400 Au	Oven 175 60 min	2 RTA's 420 90	16.3 21.4

Table 2. Bond Pad Metal Alloys

Sample #	Clean	Metal thickness on substrate thickness in nm (No Anneal)	RMS in nm
5		50 Ti:700 Au on 400 Si_3N_4	6.6
6		50 Ti:50 Pt 700 Au on 400 Si_3N_4	10.5
7		50 Ti:100 Au (seed)/2 micron Au plate on 400 Si_3N_4	85
8		50 Ti:100 Au (seed)/5 micron Au plate on 400 Si_3N_4	240
9	20:1	50 Ti:700 Au on GaAs	6.4
10	20:1	50 Ti:50 Pt:700 Au on GaAs	11.0
11	20:1	50 Ti:100 Au (seed)/2 micron Au plate on GaAs	94
12		50 Ti 100 Au (seed)/5 micron Au plate on GaAs	127

Table 3. Gram force required to break wire bond

Sample	Number of bonds	Average force in grams to break wirebonds	Standard deviation
1	60	2.4	1.1
2		unable to bond, metal lifing	
14	20	2.9	1.9
17	20	4.7	.7
18	20	8.0	2.1
3		unable to bond	
13		unable to bond	
15	20	6.4	.6
16	20	6.6	1.2
4	60	6.8	1.7
19	20	.9	.3
20	20	unable to bond	
21	20	6.9	1.2
22	20	unable to bond	
5	60	7.3	1.7
6	60	7.0	1.9
7	40	7.4	2.1
8	60	7.0	1.6
9	60	7.6	2.1
10	60	7.7	2.0
11	40	7.1	1.8
12	40	5.3	2.2

List of Figures

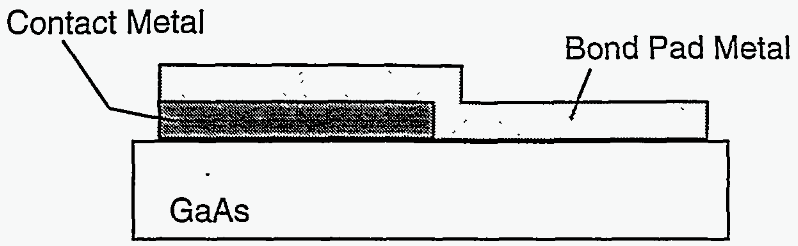

Figure 1. Cross sectional view drawing showing contact metal and bond pad metal topology.

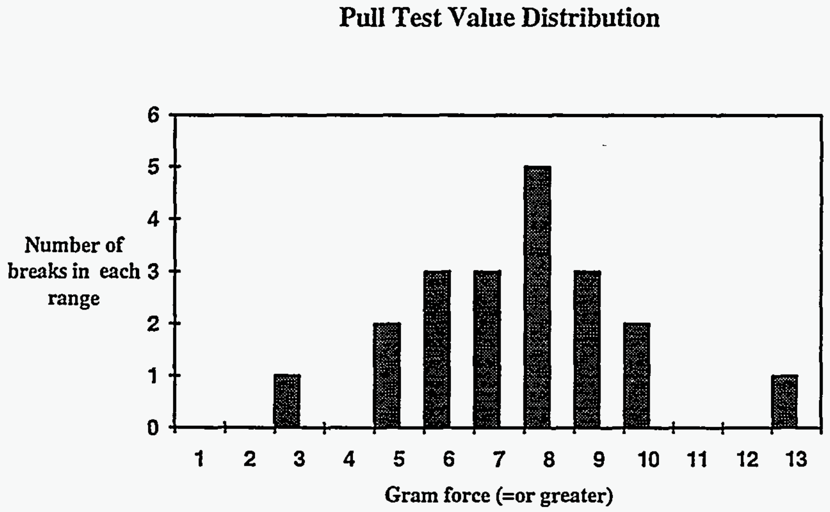

Figure 2. Pull Test Value Distibution for sample #18, GeAu/NiAu with separate TiPtAu deposition. Sample Size =20.

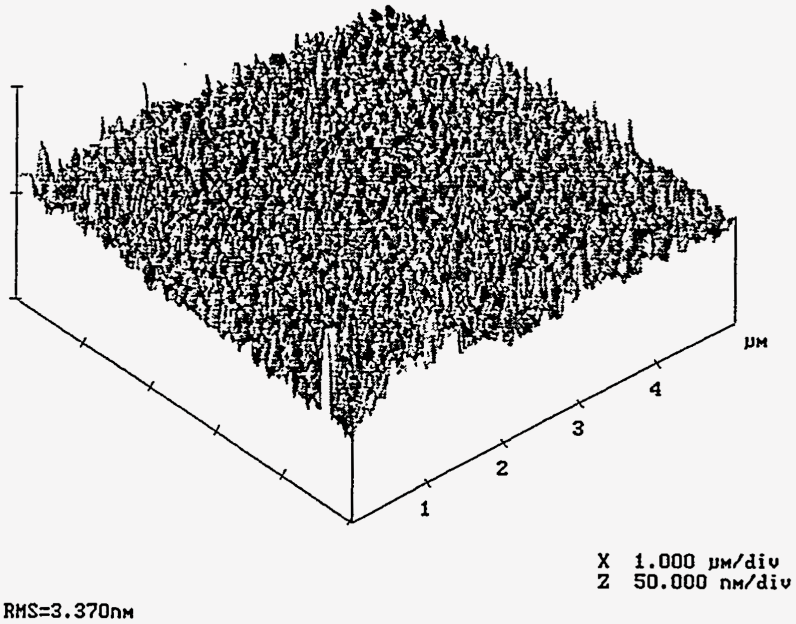

Figure 3. Atomic Force Microscope Image of Sample #4.

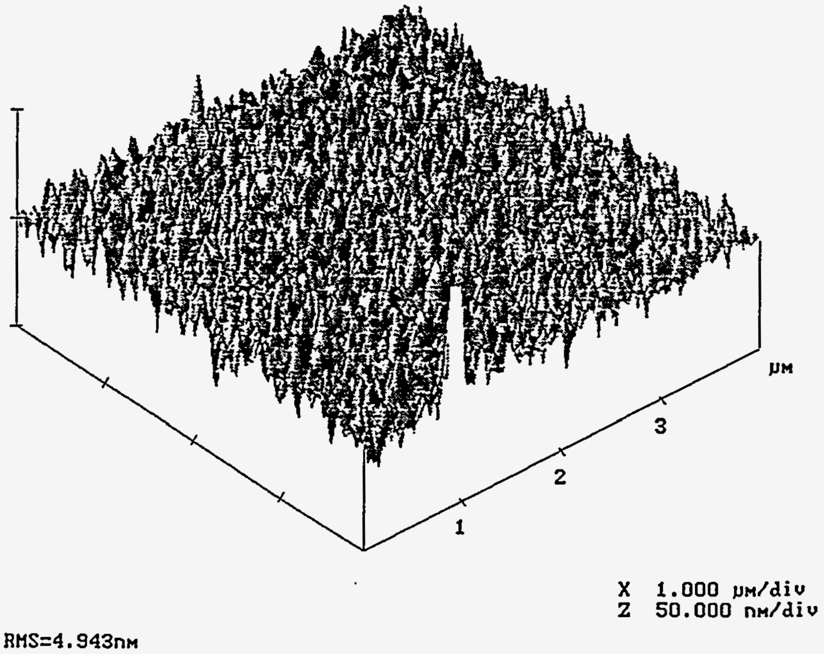

Figure 4. Atomic Force Microscope Image of Sample #18.

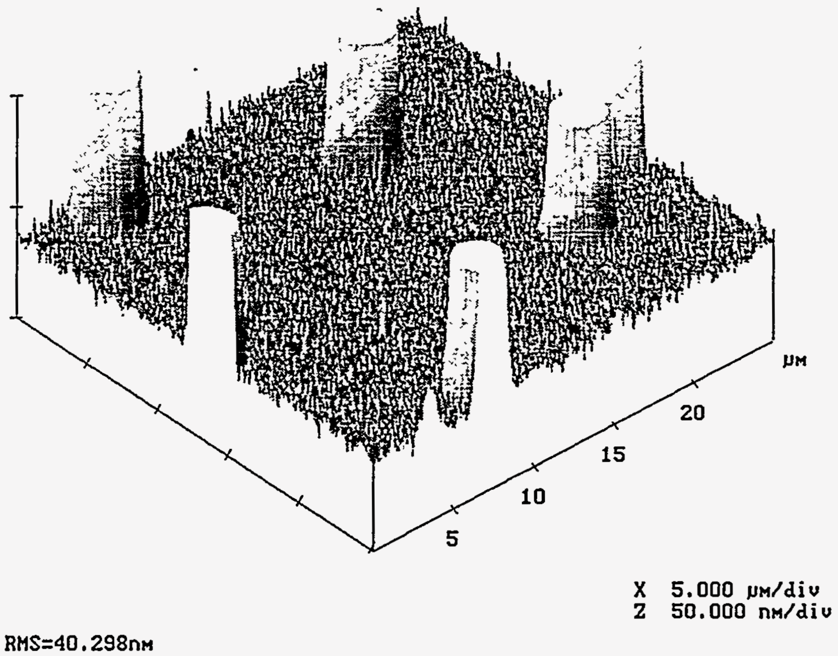

Figure 5. Atomic Force Microscope Image of Sample #19.

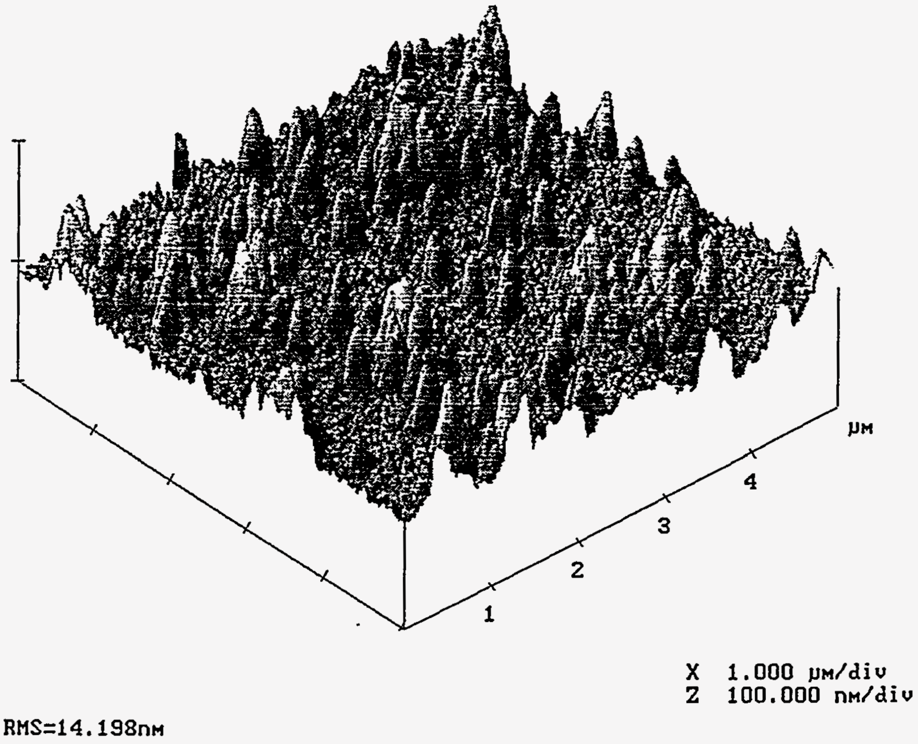

Figure 6 Atomic Force Microscope Image of Sample #21.

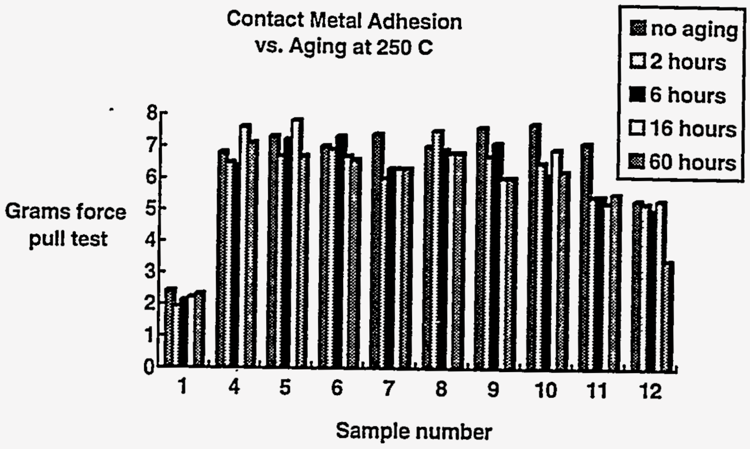

Figure 7. Ohmic Contact Metal Adhesion vs. Aging at 250 ° C.

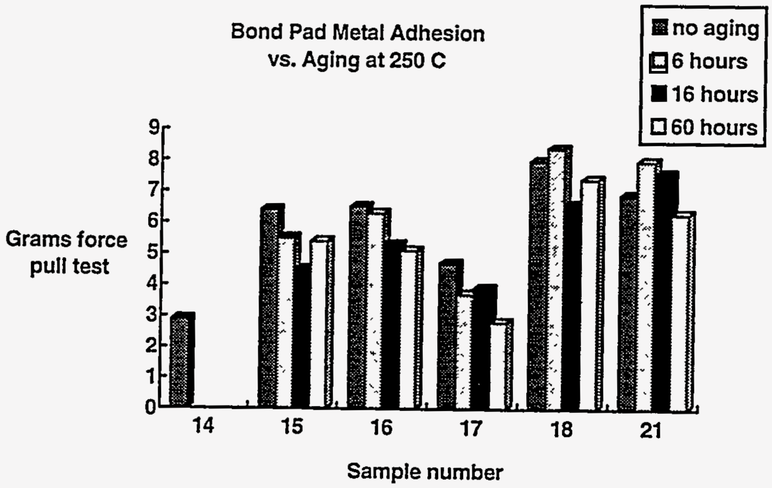

Figure 8. Bond Pad Metal Adhesion vs. Aging at 250 ° C.