CHAPTER IV

EXPERIMENTAL INVESTIGATION AND SOME RESULTS

The objective of the experiment was to find the characteristics of ohmic contact by chemical deposition. It is a low cost process and may replace metallization by evaporation in vacuum. For fabrication of silicon devices, it has become increasingly important to establish processes for obtaining electrical contacts to silicon with very low resistance ohmic contact.

4.1 <u>Preparing Ohmic Contacts</u>

The steps for fabrication of nickel, copper-silicon contacts were as follows;

1) Choose the silicon wafers, n-type and p-type.

   [carrier concentration 10^{14}-10^{19} cm^{-3}]

2) Initial cleaning of the silicon wafers.

   [Appendix A.1]

3) Grow initial silicon dioxide layer about 5000 Å thick

   [$T=1050^{o}C$-WetO_2 (1^{ℓ}/min), $T_{H_2O} = 80^{o}C$]

4) Clean the wafers.

   [Trichoroethylene, Acetone, and Deionized Water]

5) Photolitography at the front side with mask N<u>O</u> 1.

   [Using positive photoresis]

6) Etch silicon dioxide at the front side with buffered HF solution

   [Appendix A.2]

7) Clean the wafers with deionized water (For electroplated contact) or acetone, deionized water (For electroless plated contact).

8) Nickel or copper plating contact on the front side.

9) Scribe the wafer into small dies by scribing machine. [Appendix D.1]

10) Wire bonding with aluminium wire by ultrasonic wire bonder. [Appendix D.2]

11) Test the samples as shown in Fig.11.

12) Anneal in an oven at 120°c for 16 hours.

13) Test the samples again.

One of the ohmic contact testing procedure of the specimen was shown in Fig.7,8.

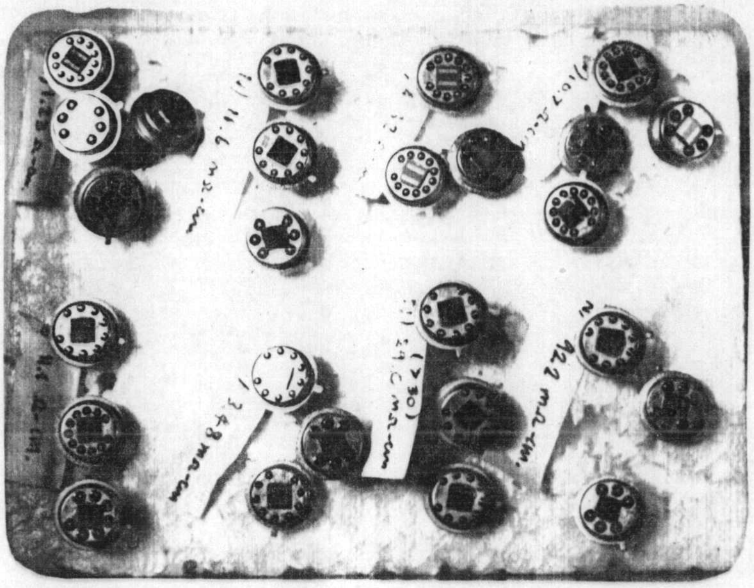


Fig.7 Ohmic contact testing specimen

4.1.1 Silicon Samples Data

The relevant wafers are single crystals of p-type and n-type silicon with the carrier concentration of 10^{14}-10^{19} cm^{-3}, and <111> orientation.

4.1.1.1) P-type silicon wafers having resistivities of 10-15mΩ-cm, 16-40 mΩ-cm, 90-110 mΩ-cm, 200-240 mΩ-cm, 4-5 Ω-cm, 9-10 Ω-cm and 11-12 Ω-cm were used.

4.1.1.2) N-type silicon wafers having resistivities of 10-20 mΩ-cm, 30-40 mΩ-cm, 90-100 mΩ -cm, 1-2 Ω-cm, 4-5 Ω-cm, 10-11 Ω-cm and 11-12 Ω-cm were used.

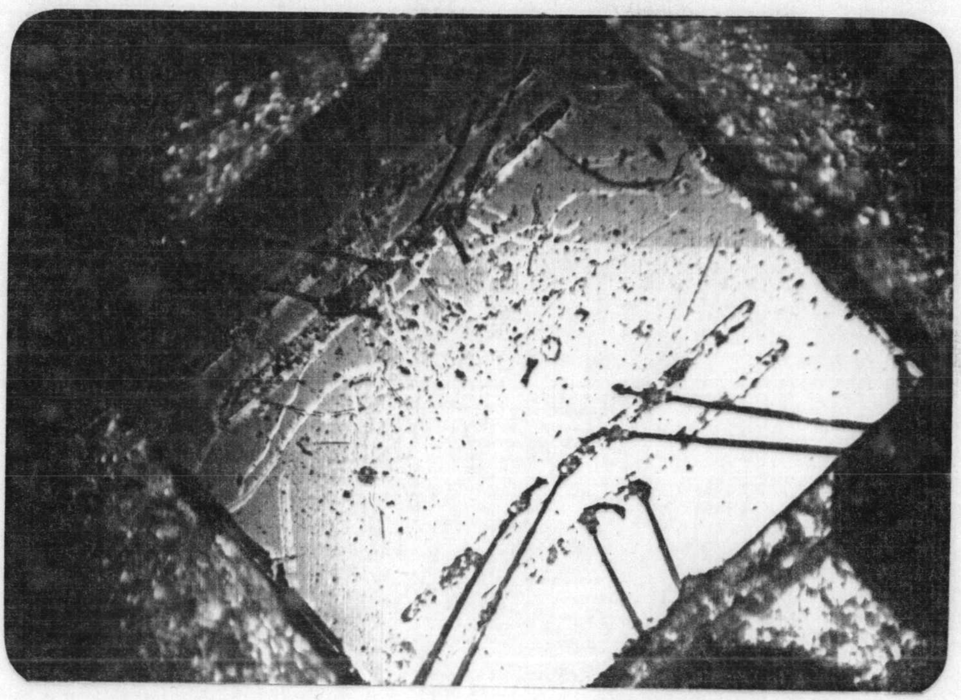


Fig. 8 Sample connected on the header.

4.1.2 Masking Pattern

Masking pattern for ohmic contact was shown in Fig.9.

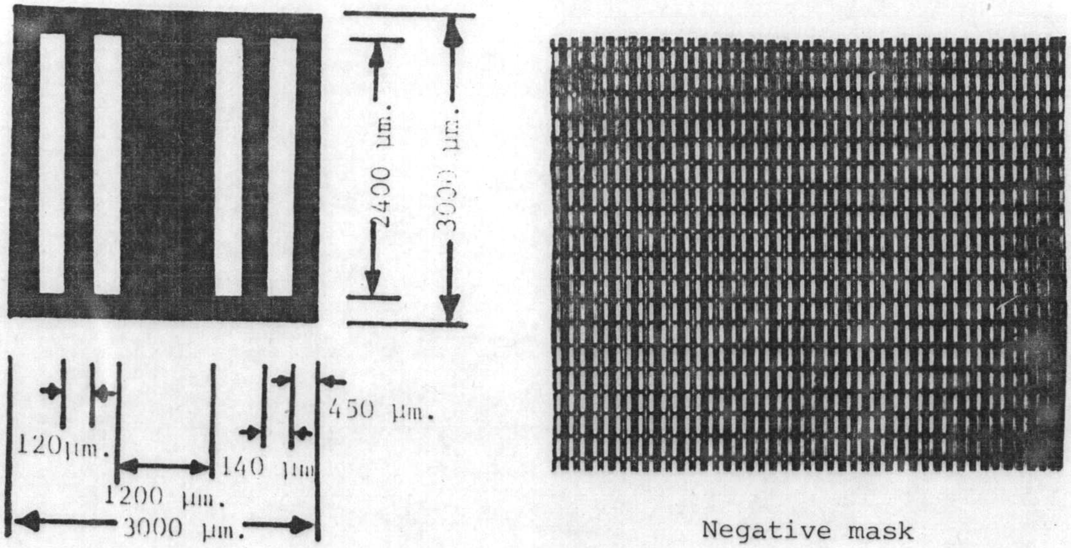


Fig. 9 Masking pattern No 1

4.1.3 Nickel, Copper Electroplating

4.1.3.1) Nickel electroplating

In order to study the characteristics of Ni-Si contacts, nickel is plated on various silicon wafers of a wide range resistivities, both p-type and n-type by electroplating technique.

Nickel is a white lustrous metal. It has mechanical strength, is fairly hard and at ordinary temperature is paramagnetic. It is hard to be oxidized even heated in air. Polished surfaces will, however, gradually be corroded upon heated atmospheric exposure.

Nickel is slowly soluble in hydrochloric and in dilute sulphuric acid. Dilute nitric acid rapidly attracks nickel and it may be deposited as a bright, semi-bright or dull coating on silicon wafers.

a) Plating equipment for nickel electroplating

The type of equipment plating is the simplest possible : D.C. power supply, tank, nickel solution, and nickel metal anodes (Fig. 10). The nickel anodes area should be approximately equal to or more than the cathode area.

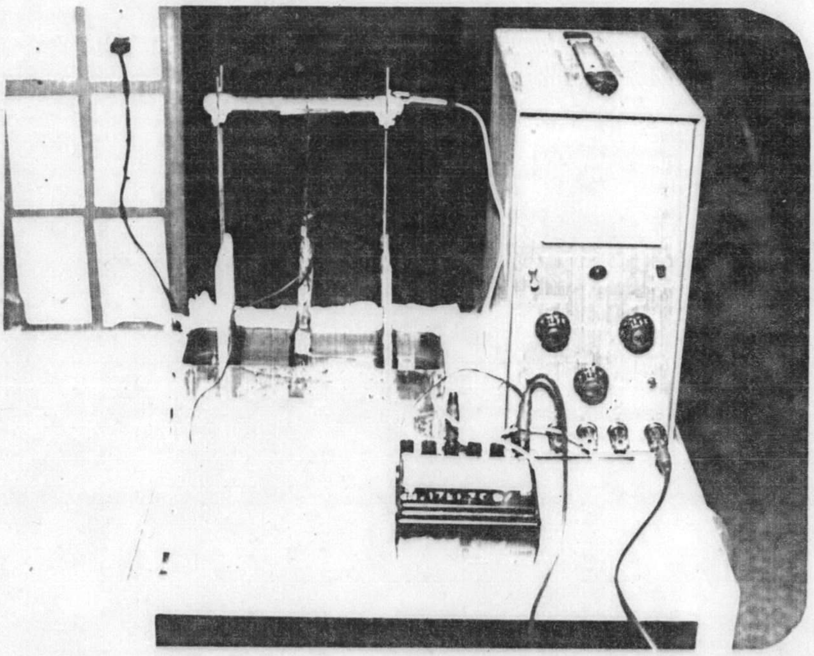


Fig. 10 Equipment of nickel electroplating

b) Preparation of nickel plating solution

The solution used for deposition was as follows;

Nickel chloride	19 g/l	Albo nickel solution
Boric acid	10 g/l	
Ammonium sulphate	14 g/l	

The commercial appellation of this solution is Albo nickel solution which is commonly available.

Albo nickel solution is dull nickel plating solutions that gives deposits of high quality and heavy deposition. It is worked at room temperature without heating agitation.

This Albo salt is soluble in deionized water (D.I. water) at temperature not above 40°C (100°F). The concentration of the solution must not exceed 125 g/l , and the solution is filtered into the plating tank.

c) Operating condition

Voltage	1.5 - 2.5 volts
Current density	10 - 15 mA/cm^2
Interelectrode distance	6 cm
pH Value	5.6 - 5.8
Temperature	15 - 20°C (60°- 70°F)
Time	1 - 3 minutes

If the pH value is too high, it can be corrected by careful addition of small quantities of hydrochloric or sulphuric acid. On the other hand when pH is too low, sodium hydroxide is added.

During the process, the supply voltage has to be increased slowly from zero up to 1.5 volts(for very good cleaning surface sample), or 2.5 volts (for fairly cleaning surface sample). In this process, the voltage is very important,because it controls time and current during nickel coating. Nickel electroplating solution can be used for quite a long time. It depends on pH value of the solution.

4.1.3.2) Copper electroplating

Copper is one of the few coloured metals. It is relatively soft and ductile. It has excellent electrical and thermal conductivity. On heating in air it oxidises quickly and polished surfaces are easily tarnished when exposed with various sulphur compounds and acids in the atmosphere.

a) Plating equipment for copper electroplating

The equipments are the same as nickel electroplating (Fig. 10) but the appropriate anodes and solution are replaced. The ratio of anode to cathode area should be increased to 2:1.

b) Preparation of copper electroplating

The solution used for deposition was as follows;

Copper cyanide	4 - 6 g/l	Zonax copper solution
Sodium cyanide	8 g/l	

These solutions are named commercially as "Zonax copper solution" which can be bought easily. The Zonax copper solution has the widest field of application and are the type most generally employed for commercial electroplating.

Appropriate amount of Zonax copper salts is dissolved in about half the final required volume of warm deionized water. The salts is gradaully added, and the solution is stirred until the Zonax copper salts is completely dissolved. The solution is filterred into the plating tank. Finally diluted with deionized water to the working level again stirring to ensure that the solution is thoroughly mixed.

During the preparation of this solution the operator must wear goggles , a face mask and other appropriate safety equipment to prevent contact with the solution.

c) Operating condition

Voltage	1 - 3.5 volts
Current density	8 - 10 mA/cm^2
Interelectrode distance	6 cm
pH Value	11.5 - 12.5
Temperature	50^oC (120^oF)
Time	1 - 3 minutes

In Zonax copper solution, if the pH value is too high it may be corrected by careful addition of small quantities of acetic acid. If the pH is too low, very small addition of ditute potassium or sodium hydroxide solution may be made.

4.2 Measurement on Ni-, Cu-Si Contacts

Contact resistivity, ρ_c, depends on doping level Of the semiconductor. Nickel and copper chemical deposition on silicon are measured by ρ_c. The relevant contacts are reported into two groups, one without annealing and the other annealing at 120^oC for 16 hours.

R_c and ρ_c can be calculated from R_1 and R_2 of the structure in Fig. 11 and can be used Eq. (2.6) and Eq. (2.10)

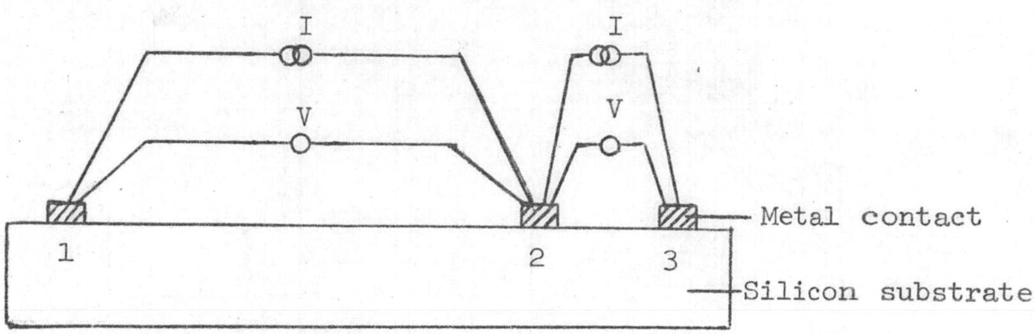
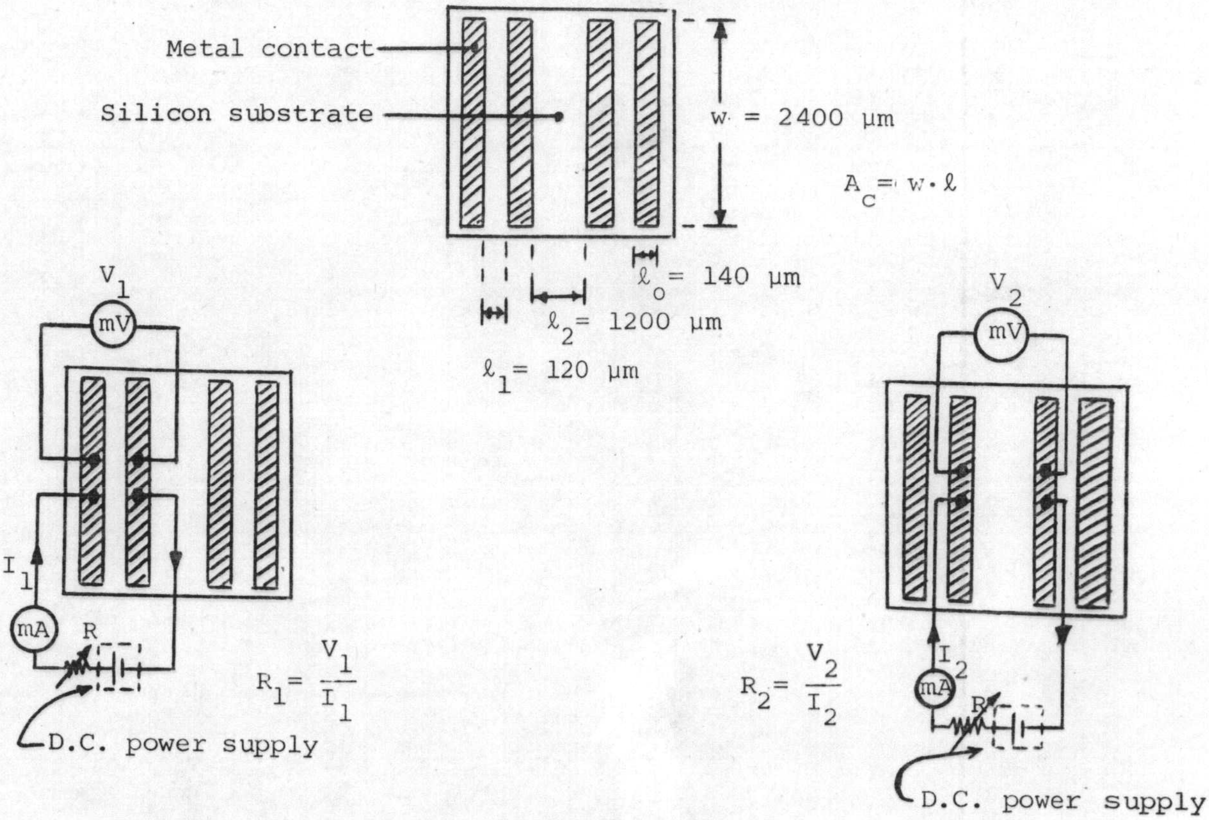


Fig. 11 Method measured contact resistance

For example, find the contact resistance, R_c, and contact resistivity, ρ_c, of Ni-pSi on 15.4 mΩ-cm silicon substate.

Fig.5, Fig.9 , and structure in Fig.11 as show in the following.



As shown in the upper figure, there are 3 contact strips for measurement of R_1, R_2 and the other one for the verification.

Using Eq. 2. 6 , for R_c, we have

$$R_c = \frac{R_2 \ell_1 - R_1 \ell_2}{2(\ell_1 - \ell_2)}$$

$$= \frac{(0.18\Omega)(120\mu m) - (0.2\Omega)(1200\mu m)}{2\left[(120\mu m) - (1200\mu m)\right]}$$

$$= 0.1\ \Omega$$

given in Eq.(2.10), thus

$$\rho_c = R_c \cdot A_c \qquad (A_c \text{ is the area contact})$$

$$= (0.1\Omega)(140\mu m \times 2400\mu m)$$

$$= 3.36\times10^{-4}\ \Omega\text{-cm}^2$$

The another results of the contact resistances and contact resistivities were in Table 1 and summarized in Appendix E.1.

Table 1 Experimental Results for Nickel, Copper-p-type, n-type silicon Contacts with Nonanneling and Annealing 16 hours at 120°C

Ni-Si Contacts

Substrate resistivity (Ω-cm)	Impurity concentration (cm^{-3})	I_1 (mA)	V_1 (mV)	R_1 (Ω)	I_2 (mA)	V_2 (mV)	R_2 (Ω)	R_c (Ω)	ρ_c (Ω-cm^2)
				Ni-pSi					
0.015	5.5×10^{18}	1.0	0.2	0.20	1.0	0.18	0.18	0.10	3.36×10^{-4}
0.100	3.0×10^{17}	8.8	4.69	0.53	5.8	5.26	0.90	0.24	8.06×10^{-4}
0.226	1.0×10^{17}	4.5	17.80	3.95	4.6	54.0	11.74	1.54	5.17×10^{-3}
4.5	3.0×10^{15}	0.2	1.92*	9600	0.2	1.92*	9600	4800	1.61×10
11.1	1.0×10^{15}	1.0	10.1*	10100	1.0	10.5*	10500	5030	1.69×10
				Ni-pSi (16 hr., 120°C annealing)					
0.015	5.5×10^{18}	3.5	0.47	0.13	4.9	0.3	0.06	0.06	2.28×10^{-4}
0.100	3.0×10^{17}	6.8	1.72	0.25	9.8	11.0	1.22	0.07	2.35×10^{-4}
0.226	1.0×10^{17}	8.1	30.4	3.75	8.0	91.7	11.46	1.45	4.87×10^{-3}
4.5	3.0×10^{15}	0.6	3.72*	6200	0.6	0.28*	460	3400	1.06×10
11.1	1.0×10^{15}	1.0	8.8*	8800	1.0	9.1*	9100	4380	1.47×10

Table 1 (Continued) Experimental Results for Nickel, Copper-p-type, n-type Silicon Contacts with Nonannealing and Annealing 16 hours at 120°C.

Ni-Si Contacts

Substrate resistivity (Ω-cm)	Impurity concentration (cm^{-3})	I_1 (mA)	V_1 (mV)	R_1 (Ω)	I_2 (mA)	V_2 (mV)	R_2 (Ω)	R_c (Ω)	ρ_c (Ω-cm^2)
				Ni-nSi					
0.012	2.5×10^{18}	9.5	15.0	1.58	9.4	7.7	0.82	0.83	2.75×10^{-3}
0.029	7.0×10^{17}	6.7	21.4	3.19	6.7	59.8	8.93	1.28	4.30×10^{-3}
1.23	3.5×10^{15}	1.0	11.9	11.9	1.0	8.0	8.0	6.17	2.07×10^{-2}
10.70	3.5×10^{14}	1.0	3.3*	3300	1.0	4.5*	4500	1580	5.30
11.10	3.0×10^{14}	1.0	4.33*	4330	1.0	4.79*	4790	2140	7.19
				Ni-nSi (16 hr., 120°C annealing)					
0.012	2.5×10^{18}	7.5	2.63	0.35	7.3	3.4	0.47	0.17	5.71×10^{-4}
0.029	7.0×10^{17}	3.8	9.4	2.48	3.9	10.8	2.77	1.22	4.09×10^{-3}
1.23	3.5×10^{15}	1.0	10.4	10.4	1.0	3.0	3.0	5.61	1.88×10^{-2}
10.70	3.5×10^{14}	1.0	3.9*	3900	1.0	0.42*	420	2140	7.19
11.10	3.0×10^{14}	1.0	5.15*	5150	1.0	5.61	5610	2550	8.56
				Cu-Si Contacts					
				Cu-pSi					
0.013	5.0×10^{18}	9.8	18.8	1.92	6.2	96.0	15.48	0.21	7.05×10^{-4}
0.226	2.0×10^{17}	5.1	6.42	1.26	5.1	20.13	3.95	0.48	1.61×10^{-3}
0.546	4.0×10^{16}	7.4	8.28	1.12	9.0	31.1	3.45	0.43	1.44×10^{-3}
4.5	3.0×10^{15}	1.0	0.42*	420	1.0	0.48*	480	210	7.05×10^{-1}
9.84	1.0×10^{15}	1.0	1.03*	1030	1.0	5.6*	5600	260	8.73×10^{-1}
				Cu-pSi (16 hr., 120°C annealing)					
0.013	5.0×10^{18}	7.1	12.7	1.78	7.1	108	15.9	0.14	4.70×10^{-4}
0.226	2.0×10^{17}	8.8	9.7	1.10	8.7	70.1	8.05	0.16	5.37×10^{-4}
0.546	4.0×10^{16}	8.6	13.3	1.45	8.6	87.5	10.17	0.29	9.74×10^{-4}
4.5	3.0×10^{15}	9.9	0.36*	36	9.8	0.53*	50	170	5.71×10^{-1}
9.84	1.0×10^{15}	1.0	1.2*	1200	1.0	7.5*	7500	250	8.40×10^{-1}

Table 1 (Continued) Experimental results for Nickel, Copper-p-type, n-type silicon contacts with nonannealing and annealing 16 hours at 120°C.

Cu-Si Contacts

Substrate resistivity (Ω-cm)	Impurity concentration (cm^{-3})	I_1 (mA)	V_1 (mV)	R_1 (Ω)	I_2 (mA)	V_2 (mV)	R_2 (Ω)	R_c (Ω)	ρ_c ($\Omega\text{-}cm^2$)
				Cu-nSi					
0.0116	$2.5\ 10^{18}$	81.0	28.2	0.35	79.0	82.2	1.04	0.14	$4.7\ 10^{-4}$
0.092	$7.0\ 10^{18}$	3.6	0.4*	110	3.6	0.66*	180	50	$1.68\ 10^{-1}$
1.23	$3.5\ 10^{15}$	1.0	0.81*	810	1.0	1.09*	1090	390	1.31
4.32	$9.0\ 10^{14}$	4.1	10.9*	2660	4.0	11.5*	2880	1320	4.43
			Cu-nSi (16 hr., 120°C annealing)						
0.0116	$2.5\ 10^{18}$	8.4	2.3	0.27	8.2	8.9	1.08	0.09	$3.02\ 10^{-4}$
0.092	$7.0\ 10^{18}$	8.0	0.71*	80	8.0	1.0*	125	37	$1.24\ 10^{-1}$
1.23	$3.5\ 10^{15}$	6.0	9.7*	1610	6.0	10.3*	1710	790	2.65
4.32	$9.0\ 10^{14}$	2.0	8.6*	4300	2.0	9.7*	4850	2120	7.12

* is Volt. dimension.