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ELECTRICAL MEASUREMENT OF
PLATING THICKNESS

By J. B. Mustapha

Published December 1978

Final Report

Prepared for the United States Department of Energy
Under Contract Number DE-AC04-76-DP00613.

**Kansas City
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Final Report
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A resistance-measuring system using a commercial microhmmeter and four-point probes effectively determines the thickness of copper foil and plating on samples with surface dimensions large in comparison to probe spacing. Individual probe-calibration conductance curves are required. Although comparable in resolution to beta-backscatter measurements, the measuring system is faster, easier to calibrate, less expensive, and requires less operator training time.

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SUMMARY

This study evaluates a resistance-measuring system which effectively determines the thickness of copper foil and copper plating on 7.09-g-clad (0.25 ounce) and 28.35-g-clad (1 ounce) printed circuit board material by measuring the sheet resistance as a function of a specified distance on the copper surface. Resistance values were converted to conductance to take advantage of the linear relationship between the conductance values and the corresponding material thickness. Commercial equipment was utilized throughout the investigation.

The resistance-measuring method is superior to the beta-backscatter method in terms of simplicity, time, calibration, and cost. The resolution of the two systems is comparable, and the resistance-measuring system is highly accurate as compared to other methods now employed for measuring plating thickness, including beta backscatter.

The system requires that a calibration chart be developed for each measuring probe. In addition, the planar dimensions of the material to be measured should be large in comparison to the spacing between the probes.

DISCUSSION

SCOPE AND PURPOSE

The purpose of this project was to evaluate conductance values, calculated from resistance measurements, as a means of nondestructively measuring the thickness of copper foil and copper plating. Particular emphasis was given to the evaluation of copper plating on 28.35-g-clad (1 ounce) printed circuit board material. The study was made to determine specific calibration curves for this method of measurement, and to establish confidence levels for the use of the technology in making both in-process and quality-acceptance measurements.

The project was established at the encouragement of engineers at Sandia Laboratories, Livermore and Albuquerque (SLL and SLA) because of the potential advantages of this method of measurement over other methods now in use or proposed.

PRIOR WORK

An investigation into the use of conductance for the thickness gaging of metal surfaces has been previously reported.¹

ACTIVITY

Figure 1 shows the equipment setup, and Figure 2 shows a close-up of a probe positioned to make a resistance measurement on clad material. A functionally equivalent set of equipment was acquired by personnel at SLL and material samples were exchanged with Bendix in a joint effort to establish the accuracy and adequacy of this technology for measuring plating thickness. The investigation was aided by computerized mathematical-model data.

Each probe consists of four in-line, spring-loaded tips, symmetrically spaced from a perpendicular center line. Current is applied through the two outer tips, while the voltage drop is measured across the two inner tips. The resulting resistance is displayed on a digital microhmmeter and recorded on the tape of a digital recorder. The dimensional spacing for each four-point probe is shown in Table 1.

The investigation consisted of collecting data to determine, empirically, the relationship between plating thickness and resistance. Samples of copper foil were measured for both resistance and thickness. Figures 3 and 4 show plots of the resulting hyperbolic relationship for two of the probes.

Figure 1. Microresistance-Measuring-Equipment Setup

Figure 2. Four-Point 0.025 Probe Being Used for Microresistance Measurement of 28.35-g-Clad (1 Ounce) Copper-Plated Printed Circuit Board

Table 1. Dimensional Spacing of Four-Point Probe Tips

Probe Designation	Dimension Between Tips			
	Outer, Current Tips		Inner, Voltage-Drop Tips	
	mm	Inch	mm	Inch
0.025	1.90	0.075	0.64	0.025
0.0625	4.76	0.1875	1.59	0.0625
0.170	6.35	0.250	4.32	0.170

The determined resistance values were converted to conductance values, and the resulting linear relationship is shown in Figure 5. Because of the convenience of using a linear curve for both calibration and normal operation, conductance was adopted and used throughout the study. Comparative measured values obtained by Bendix and SLL for the copper-foil samples are listed in Table 2.

Two additional groups of samples were prepared and evaluated at both Bendix and SLL in a manner similar to that previously described for evaluating copper foil. One group consisted of eleven samples of electroplated copper on 7.09-g-clad (0.25 ounce) printed circuit board material, while the other group consisted of fourteen samples of copper plating on 28.35-g-clad (1 ounce) material.

Tables 3 and 4 show the values obtained by both Bendix and SLL for these two groups of samples, while Figure 6 graphically illustrates the relationship of the data. As indicated by the figure, there was a difference in the slopes of the Bendix and SLL curves. This difference proved to be reasonably consistent throughout the study.

Despite the differences between the Bendix and SLL data, the high degree of correlation within the individual sets of samples implies that the differences are fixed and constant. This correlation offers the possibility of using resistance-measuring technology for the gaging of plating thickness provided that a calibration curve is developed for each combination of measuring instrument and probe.

The results of plating-thickness measurements, by both beta-backscatter and cross-sectioning methods, confirmed the hyperbolic relationship between resistance and thickness, provided that the measured surface is large in comparison to the probe dimensions.

Figure 3. Thickness-Versus-Resistance Relationship for Copper-Foil Samples, Using the 0.0625 Probe (Bendix Data)

As the probe approaches an edge, or as the thickness becomes significant in comparison to the probe spacing, departures from the ideal curve can be expected. The distance that the probe should be kept from an edge was not determined in this study.

ACCOMPLISHMENTS

A four-point microresistance-measuring system which was investigated as a method for making nondestructive thickness measurements of copper foil and copper plating was found to be simpler, faster, easier to calibrate, and less expensive than a beta-backscatter system. The \$2000 cost of a resistance-measuring system is approximately one-half that of a basic beta-backscatter tester. The resolution of the two systems is comparable.

Figure 4. Thickness-Versus-Resistance Relationship for Copper-Foil Samples, Using the 0.170 Probe (Bendix Data)

Use of the resistance-measuring system requires that a calibration chart be developed for each individual probe, and that the material to be measured approach an infinite-surface plane in relation to the spacing of the probe elements in order to realize the highly accurate measurement capability.

FUTURE WORK

The recommendation is made that the microresistance plating-thickness-measuring technology be transferred to production testing of copper plating.

The further recommendation is offered that future investigation into making electrical measurements of plating thickness include aluminum and other materials, and that the study be oriented toward determining the width and depth of printed-wiring-board circuit paths.

Figure 5. Thickness-Versus-Conductance Relationship for Copper-Foil Samples (Bendix Data)

Table 2. Comparison Between Bendix and SLL Data for Copper-Foil Samples

Sample	Resistance Measurement for Indicated Probe				Thickness Measurement	
	0.170 Probe		0.0625 Probe		Physical Gaging by Bendix (mm; 0.001 Inch)	Beta Backscatter by SLL (mm; 0.001 Inch)
	Bendix ($\mu\Omega$)	SLL ($\mu\Omega$)	Bendix ($\mu\Omega$)	SLL ($\mu\Omega$)		
1	258	255	109	102	0.038 (1.49)	0.035 (1.39)
2	195	191	81	75	0.051 (1.99)	0.047 (1.83)
3	125	122	52	45	0.076 (2.99)	0.069 (2.73)
4	100	97	42	34	0.095 (3.74)	0.117 (4.60)
5	40	37	16	13	0.239 (9.39)	

Table 3. Comparison Between Resistance Measurements (With Calculated Conductance Values) Made by Bendix and SLL on 7.09-g-Clad (0.25 Ounce) Copper-Plated Samples

Sample	Measured Thickness			Data Obtained by Indicated Facility			
				Resistance		Conductance	
				Bendix ($\mu\Omega$)	SLL ($\mu\Omega$)	Bendix (kS)	SLL (kS)
	mm	0.001 In.	Probe				
1	0.007	0.268	0.170	2076	2113	0.5	0.5
			0.0625	871	849	1.1	1.2
			0.025	836	850	1.2	1.2
2	0.014	0.536	0.170	1019	937	1.0	1.1
			0.0625	427	386	2.3	2.6
			0.025	415	388	2.4	2.6
3	0.021	0.836	0.170	532	488	1.9	2.0
			0.0625	223	196	4.5	5.1
			0.025	216	198	4.6	5.1
4	0.032	1.270	0.170	355	324	2.8	3.1
			0.0625	151	123	6.6	8.1
			0.025	144	125	6.9	8.0
5	0.041	1.620	0.170	266	223	3.8	4.5
			0.0625	114	83	8.8	12.0
			0.025	110	84	9.1	11.9
6	0.060	2.380	0.170	176	154	5.7	6.5
			0.0625	74	56	13.5	17.9
			0.025	71	58	14.1	17.2
7	0.083	3.250	0.170	128	106	7.8	9.4
			0.0625	54	36	18.5	27.8
			0.025	52	38	19.2	26.3

Table 3 Continued. Comparison Between Resistance Measurements (With Calculated Conductance Values) Made by Bendix and SLL on 7.09-g-Clad (0.25 Ounce) Copper-Plated Samples

Sample	Measured Thickness			Data Obtained by Indicated Facility			
				Resistance		Conductance	
				Bendix ($\mu\Omega$)	SLL ($\mu\Omega$)	Bendix (kS)	SLL (kS)
	mm	0.001 In.	Probe				
8	0.139	5.480	0.170	81	57	12.3	17.5
			0.0625	34	17	29.4	58.8
			0.025	32	20	31.3	50.0
9	0.176	6.910	0.170	59	47	17.0	21.3
			0.0625	27	12	37.0	83.3
			0.025	24	14	41.7	71.4
10	0.215	8.480	0.170	51	35	19.6	28.6
			0.0625	21	9	47.6	111.1
			0.025	20	9	50.0	111.1
11	0.405	15.940	0.170	26	14	38.5	71.4
			0.0625	12	2	83.3	500.0
			0.025	11	0	90.9	

Table 4. Comparison Between Resistance Measurements (With Calculated Conductance Values) Made by Bendix and SLL on 28.35-g-Clad (1 Ounce) Copper-Plated Samples

Sample	Measured Thickness			Data Obtained by Indicated Facility			
				Resistance		Conductance	
	mm	0.001 In.	Probe	Bendix ($\mu\Omega$)	SLL ($\mu\Omega$)	Bendix (kS)	SLL (kS)
1	0.036	1.42	0.170	266	256	3.76	3.91
			0.0625	112	96	8.93	10.42
			0.025	102	99	9.80	10.10
2	0.040	1.58	0.170	231	221	4.33	4.52
			0.0625	97	82	10.31	12.20
			0.025	59	84	16.95	11.90
3	0.046	1.83	0.170	201	191	4.98	5.24
			0.0625	84	69	11.90	14.49
			0.025	39	71	25.64	14.08
4	0.049	1.93	0.170	195	183	5.13	5.46
			0.0625	83	66	12.05	15.15
			0.025	39	68	25.64	14.71
5	0.054	2.11	0.170	175	165	5.71	6.06
			0.0625	74	60	13.51	16.67
			0.025	27	61	37.04	16.39
6	0.057	2.23	0.170	169	157	5.92	6.37
			0.0625	71	56	14.08	17.86
			0.025	34	58	29.41	17.24
7	0.062	2.46	0.170	157	144	6.37	6.94
			0.0625	66	50	15.15	20.00
			0.025	33	52	30.30	19.23

Table 4 Continued. Comparison Between Resistance Measurements (With Calculated Conductance Values) Made by Bendix and SLL on 28.35-g-Clad (1 Ounce) Copper-Plated Samples

Sample	Measured Thickness			Data Obtained by Indicated Facility			
				Resistance		Conductance	
	mm	0.001 In.	Probe	Bendix ($\mu\Omega$)	SLL ($\mu\Omega$)	Bendix (kS)	SLL (kS)
8	0.069	2.72	0.170	141	130	7.09	7.69
			0.0625	59	44	16.95	22.73
			0.025	29	45	34.48	22.22
9	0.070	2.76	0.170	138	125	7.25	8.00
			0.0625	58	43	17.24	23.26
			0.025	25	45	40.00	22.22
10	0.078	3.08	0.170	124	110	8.06	9.09
			0.0625	52	37	19.23	27.03
			0.025	26	40	38.46	25.00
11	0.085	3.35	0.170	114	101	8.77	9.90
			0.0625	48	33	20.83	30.30
			0.025	17	35	58.82	28.57
12	0.083	3.27	0.170	118	105	8.47	9.52
			0.0625	50	35	20.00	28.57
			0.025	19	36	52.63	27.78
13	0.088	3.46	0.170	113	102	8.85	9.80
			0.0625	48	33	20.83	30.30
			0.025	14	35	71.43	28.57
14	0.094	3.72	0.170	104	91	9.62	10.99
			0.0625	43	30	23.26	33.33
			0.025	11	31	90.91	32.26

Figure 6. Comparison Between Thickness-Versus-Conductance Results Obtained by Bendix and SLL From 7.09-g-Clad (0.25 Ounce) Copper-Plated Samples

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¹J. W. Hill, *Measuring Penetration Depth of Electron Beam Welds* (Final Report). Bendix Kansas City: BDX-613-1353, August, 1975 (Available from NTIS).

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