EVALUATION ON SURFACE ROUGHNESS RATE FOR SILVER NANO-PARTICLES REINFORCED EPOXY CONDUCTIVE INK

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ABSTRACT: This paper presents an analysis of silver nanoparticles-filled epoxy conductive ink. The evaluated parameter is the surface roughness. The surface roughness of the sample can be identified by using portable contact profilometer. The measurement of the surface roughness is taken in vertical and horizontal directions of the sample. From all the obtained data, it can be concluded that samples with lower filler percentage have consistent average value of surface roughness, Ra and smooth surface. Meanwhile, for the samples with high percentage of filler have inconsistent surface irregularities that contributed to rougher surface.

KEYWORDS: *Silver Nanoparticles; Conductive Ink; Surface Roughness*

1.0 INTRODUCTION

Conductive ink, which is a printed ink that can conduct electricity have been in some conversations for a few years because of its applications in printed electronics (PE) and flexible electronics (FE). It has the ability to print circuits on paper or some form of flexible surface through the inkjet printing technology. Although the early growth of the printed electronics industry is not as drastic as expected, there are some great demands to use these products (conductive inks) in daily activities such as cell phones, displays, smart wearable, lighting, small packaging, labels, shipping, storage and many more [1-4].

Troubleshooting problems in the characterization of conductive ink is to fabricate conductive ink which has high conductivity tracks or patterns. This experiment investigates conductive ink characterization related to the formulation of ink loading and preparation method of the ink samples [2].

The objective of this study is to investigate the surface roughness measurement of silver nanoparticles-filled epoxy conductive ink with contact profilometer, and to evaluate the results in relation with the composition of ink loading [3-4].

2.0 RESEARCH METHODOLOGY

2.1 Samples Preparation

Firstly, samples of silver nanoparticles-filled epoxy conductive ink were fabricated. They consisted of silver nanoparticles acted as the filler element, epoxy as the binder and hardener. The materials were weighed based on the values of mass as in Table 1. The loading of hardener was 30 % of amount of the binder loading while the total value of mass as indicated in the table only included

the total sum of filler and binder loading. The total mass of the sample was set at the beginning of experiment.

Table 2.1: Composition of Ink Loading

Sample	Filler		Binder		Hardener (g)	Total (g)
	(%)	(g)	(%)	(g)		
1	10	0.2	90	1.8	0.54	2
2	20	0.4	80	1.6	0.48	2
3	30	0.6	70	1.4	0.42	2
4	40	0.8	60	1.2	0.36	2
5	50	1.0	50	1.0	0.30	2
6	60	1.2	40	0.8	0.24	2
7	70	1.4	30	0.6	0.18	2
8	80	1.6	20	0.4	0.12	2
9	90	1.8	10	0.2	0.06	2

After they were weighed, all three materials were mixed in a beaker and stirred for 10 minutes by using glass rod in the same direction and at consistent speed. After stirring process completed, the mixture was deposited onto the glass slide by applying doctor-blading method with 0.5 cm of width gap. Then, the sample was placed in an oven with the temperature of 160 °C for 60 minutes in order to preserve the adhesion between the ink and substrate. The sample was put aside until it fully dried.

2.2 Surface Roughness Measurement

The study of surface roughness was carried out by using contact profilometer after the sample sheet resistivity and microstructure were evaluated. The apparatus is shown in Figure 1.

Figure 1: Contact Profilometer

Each substrate has two samples of ink layers located side by side that was labelled as Position A and Position B and illustrates in Figure 2.

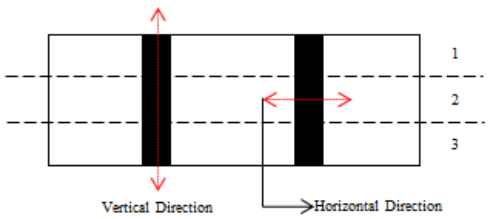

Figure 2: Region and Direction of Measurement

For the purpose of this study, three readings of surface roughness were taken at each constructed points on the sample in vertical and horizontal directions. The results of measurement were recorded into table of data.

3.0 RESULTS AND DISCUSSION

3.1 Results of Surface Roughness

The results of surface roughness in vertical and horizontal directions are shown in the Tables 2 and 3, respectively. All other parameters are remained constant so that only the surface roughness effect can be obtained.

From the table of results in both directions, the values of surface roughness for the sample of 10% of filler until 50% of filler were below 1.9 μm with the lowest value of Ra in vertical direction was 0.091 μm and in horizontal direction was 0.115 μm. The highest value of Ra from 10% of filler until 50% of filler in vertical direction was 1.803 μm and for the horizontal direction; the highest Ra value was 1.606 μm.

For 60% onwards, the values of surface roughness in both directions surpassed 2.0 μm with the highest value of Ra was 7.017 μm in vertical direction and 6.276 μm in horizontal direction.

In vertical direction, surface roughness with the most stable consistency was exhibited from the graph of 50% of filler since there was less differences between the taken data. The rest of the samples of 60% - 80% of filler displayed irregular consistency among the recorded data. The concentration of calculated average values was low, thus that the average value was uncertain.

For horizontal direction, surface roughness with the most stable consistency was contributed from 10% - 70% of filler and 90% of filler. It proved with the high value of calculated average values concentration, thus that the average value was certain. Surface irregularities for sample with 80% of filler were not consistent as the data displayed the most obvious differences.

Table 2: Vertical Results

% of Filler	Position	Surface Roughness (μm)								
		Point 1	Average	Total Average	Point 2	Average	Total Average	Point 3	Average	Total Average
10	A	0.249	0.235	0.281	0.259	0.273	0.276	0.108	0.099	0.114
		0.208			0.279			0.099		
		0.247			0.280			0.091		
	B	0.344	0.328		0.271	0.279		0.124	0.129	
		0.330			0.277			0.112		
		0.310			0.290			0.150		
20	A	0.784	0.834	0.689	0.295	0.290	0.229	0.124	0.141	0.111
		0.880			0.292			0.178		
		0.839			0.284			0.121		
	B	0.537	0.544		0.190	0.168		0.090	0.081	
		0.548			0.164			0.081		
		0.546			0.150			0.071		
30	A	0.922	0.909	0.686	0.933	0.910	1.033	1.803	1.746	1.097
		0.916			0.915			1.696		

		0.889			0.883			1.738		
	B	0.482			1.171			0.483		
		0.459	0.463		1.128	1.156		0.435	0.447	
		0.448			1.169			0.424		
40	A	0.696		0.561	0.398		0.364	0.306		0.300
		0.807	0.768		0.411	0.426		0.323	0.317	
		0.801			0.469			0.321		
	B	0.320			0.311			0.293		
		0.370	0.354		0.291	0.302		0.257	0.282	
		0.371			0.303			0.297		
50	A	0.285		0.245	0.247		0.240	0.367		0.383
		0.285	0.286		0.240	0.241		0.385	0.383	
		0.288			0.237			0.396		
	B	0.205			0.239			0.367		
		0.203	0.204		0.240	0.239		0.385	0.383	
		0.203			0.237			0.396		
60	A	3.409		4.264	2.709		4.006	2.300		2.319
		3.547	3.509		2.724	2.726		2.407	2.349	
		3.570			2.745			2.341		
	B	5.048			5.270			2.323		
		5.023	5.020		5.283	5.286		2.276	2.288	
		4.989			5.306			2.266		
70	A	3.977		4.434	5.014		3.736	2.890		3.257
		3.669	3.753		4.992	4.981		2.852	2.850	
		3.613			4.938			2.807		
	B	5.045			2.463			3.707		
		5.226	5.114		2.502	2.490		3.657	3.665	
		5.071			2.506			3.631		
80	A	5.266		4.299	3.509		3.461	2.271		2.169
		5.370	5.378		3.387	3.397		2.260	2.254	
		5.499			3.294			2.232		
	B	3.146			3.628			2.020		
		3.166	3.220		3.541	3.526		2.088	2.084	
		3.349			3.409			2.145		
90	A	5.220		5.721	5.192		5.890	4.700		5.716
		5.151	5.199		5.644	5.477		4.352	4.490	
		5.226			5.596			4.417		
	B	6.240			6.248			6.890		
		6.170	6.242		6.276	6.303		6.921	6.943	
		6.316			6.384			7.017		

Table 3: Horizontal Results

% of Fill	Position	Surface Roughness (μm)								
		Point 1	Average	Total Average	Point 2	Average	Total Average	Point 3	Average	Total Average A
10	A	0.202	0.189	0.215	0.189	0.190	0.228	0.115	0.121	0.121
		0.181			0.170			0.124		
		0.184			0.212			0.125		
	B	0.256	0.241		0.277	0.266		0.120	0.120	
		0.235			0.258			0.121		
		0.233			0.264			0.118		
20	A	0.828	0.830	0.943	1.450	1.450	1.507	1.116	1.116	1.135
		0.825			1.454			1.122		
		0.836			1.445			1.111		
	B	1.058	1.056		1.554	1.565		1.151	1.154	
		1.052			1.572			1.161		
		1.059			1.569			1.149		
30	A	1.288	1.327	0.952	1.597	1.568	1.506	1.155	1.149	1.116
		1.343			1.603			1.136		
		1.349			1.503			1.155		
	B	0.586	0.578		1.439	1.444		1.078	1.084	
		0.575			1.436			1.092		
		0.572			1.456			1.082		
40	A	0.493	0.497	0.469	0.222	0.221	0.228	0.336	0.339	0.340
		0.496			0.218			0.349		
		0.501			0.224			0.333		
	B	0.437	0.441		0.230	0.234		0.337	0.340	
		0.444			0.239			0.339		
		0.441			0.234			0.343		
50	A	0.385	0.373	0.502	0.458	0.463	0.439	1.587	1.595	1.071
		0.367			0.459			1.606		
		0.366			0.473			1.591		
	B	0.754	0.631		0.367	0.415		0.530	0.547	
		0.539			0.405			0.556		
		0.601			0.472			0.554		
60	A	4.108	4.185	4.238	3.228	3.218	3.546	2.840	2.774	3.186
		4.213			3.209			2.713		
		4.235			3.218			2.769		
	B	4.299	4.291		3.865	3.873		3.592	3.597	
		4.314			3.887			3.596		
		4.261			3.866			3.604		
70	A	3.502	3.510	3.516	4.666	4.686	4.393	4.428	4.464	4.132
		3.507			4.691			4.491		
		3.521			4.700			4.473		
	B	3.535	3.523		4.091	4.101		3.735	3.800	
		3.531			4.117			3.744		
		3.502			4.095			3.920		
80	A	5.266	5.287	4.335	3.212	3.215	3.366	3.849	3.859	3.740

		5.226			3.221			3.855		
		5.370			3.213			3.873		
	B	3.409			3.541			3.628		
		3.349	3.382		3.509	3.516		3.620	3.621	
		3.387			3.499			3.614		
90	A	4.288			4.948			5.018		
		4.212	4.194		5.166	5.076		5.151	5.026	
		4.083		4.765	5.114		5.279	4.910		5.641
	B	5.288			5.465			6.240		
		5.335	5.335		5.493	5.483		6.248	6.255	
		5.382			5.490			6.276		

3.2 Relationship between Surface Roughness and Sample Composition

The total average values of surface roughness were in the range of 0.1 μm up to 1.2 μm and the total average values between horizontal direction and vertical direction showed small differences. The difference indicated of even spreading of ink which made the surface has stable consistency of irregularities. On top of that, the ink can be distributed evenly was contributed from low concentration of sample texture. Low viscosity ink made the printing activity became easier to carry out.

Apart from that, the sample texture with low viscosity can be relate to the composition between the elements in the sample, in which the ratio of binder and hardener was higher than the ratio of filler.

Moreover, the total average values of surface roughness were in the range of 2 – 5.9 μm with the highest value was 5.890 μm. It was resulted from 90% of filler and the lowest value of 2.169 μm was resulted from 80% of filler. Both conditions were occurred in vertical direction. High total average value of surface roughness can be presumed from higher ratio of filler to the binder and hardener. In addition, the filler in the form of silver flake made the assumption was strongly accepted.

As the sample had high composition of filler, the texture had high viscosity and became more concentrated. Thus, printing process required extra work than usual to enable even ink covering on. It contributed to the rougher surface.

4.0 CONCLUSIONS

This study was carried out to examine the surface roughness of silver nanoparticles-filled epoxy conductive ink. The contact profilometer was used to measure the surface roughness value of the sample.

From the results obtained from measurement through contact profilometer, the samples with lower filler percentage had consistent irregularities and smooth surface. Meanwhile, the samples with high percentage of filler had inconsistent surface irregularities that contributed to rougher surface. In conclusion, the samples with high filler percentage generated higher value of surface roughness and vice versa.

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