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RESEARCH ARTICLE

Analysis of Electrical Properties the Sn-Bi and the Sn-Bi-Al as Environmentally Friendly Solder Material

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Abstract

Analysis of electrical properties the Sn-Bi and Sn-Bi-Al have been done. This research conducted to analysis the electrical properties for the Sn-Bi alloys with varied on Bi content and for the Sn-52Bi-Al alloys with varied on Al content. The measurement of electrical properties was conducted by LCR (inductance-capacitance-resistance) method. The results form measurement was compared to calculations. The Sn-Bi alloys showed increased in their specific electrical resistance from the alloy without Bi content to the alloy with 30 wt% of Bi, in the other hand at 52 wt% of Bi showed decreased in specific electrical resistance and increase at 70 wt% of Bi. The results showed increased in concentration of Al in alloys, the specific electrical resistance decreased.

Introduction:-

The Sn-Pb based solder material are still used in electronical manufacturing until now (T,Paul Vianco). Nevertheless, by its toxicity the Sn-Pb alloy become be abandoned. In 2006, the Waste Electrical and Electronic Equipment release the prohibition regulation uses the Sn-Pb based solder material (Yan Yanfu et.al,2007). The Pb element is the source of toxicity. Development in order to replace the Pb element has been done, such as Sn-Cu, Sn-Zn, Sn-Bi, Sn-In, dan Sn-Ag-CuL. Zhang, X. Y).The Sn-Bi alloy has promising to change the Sn-Pb, while the Sn and Bi are group of heavy metal but they don't toxic. Electrical properties of solder material had a low electrical resistance and had a high electrical conductivity. The Sn and Bi elements have adequate electrical properties. The Sn electrical resistance at $1.29x10^{-6}$ ohm.m, the Bi element electrical resistance at $0.0282x10^{-6}$ ohm.m. In this study conducted to show the Bi element behavior to the Sn. The lowest electrical resistance in Sn-Bi alloy then added by the Al element. The Al as a filler had good electrical properties with low electrical resistance at $0.0282x10^{-6}$ ohm.m. The Al element also used as superconductor material (Anwar,F.2010).

Experiment:-

The solder material alloys were composed with pure metal of Sn, Bi and Al according to Table 1. The metals were melted at 600 ^{o}C for the Sn-Bi alloys and for the Sn-Bi-Al alloys were melted at 800 ^{o}C.

Table 1.Composition of Sn-xBi and Sn-52Bi-xAl.

Sample	wt%		
	Sn	Bi	Al
Sn-0Bi	20.06	0	-
Sn-10Bi	17.94	2.1	-
Sn-30Bi	14.07	6.01	-
Sn-52Bi	9.6	10.42	-
Sn-52Bi-0.05Al	3.6999	4.0082	0.001
Sn-52Bi-0.11Al	3.6955	4.0035	0.0023
Sn-52Bi-0.14Al	3.6926	4.0003	0.003
Sn-52Bi-0.19Al	3.6882	3.9955	0.004
Sn-52Bi-0.25Al	3.6855	3.9926	0.0051
Sn-70Bi	6.04	14.08	-

LCR method resulted material electrical impedance, capacitance and resistance. The specific electrical resistance determined by Equation 1

$$\rho = \left(\frac{A}{L}\right)R \text{ .... } 1$$

where:

ρ = specific electrical resistance (ohm.m)

A = sample cross section area (m^2)

L = sample thickness (m)

The electrical conductivity determined by Equation 2 that derived from Equation 1.

$$\sigma = \frac{1}{\rho} \text{ ....}2$$

where:

$\sigma =$ electrical conductivity (1/ohm.m=mho)

The results from measurement were comparable to the results from calculation. The calculations were determined by Equation 3 and Equation 4.

$$Z = \sqrt{R_s^2 + \left(\frac{1}{2\pi fC}\right)} \text{ (Sutrisno)...}3$$

$$G_S = \frac{1}{R_S} \text{ (Sutrisno)} \qquad (4)$$

where:

Z = impedance (ohm)

G_S = conductance (Siemens)

Results and Discussions:-

Results the melting point temperature of Sn-Bi and Sn-Bi-Al by DSC tabulated in Table 2.

Tabel. 3.Melting point temperature of the Sn-xBi and the Sn-52Bi-xAl

Sample	Melting point	
	[C]	[K]
Sn-0Bi	235.1	508.1
Sn-10Bi	220.39	493.39
Sn-30Bi	143.43	416.43
Sn-52Bi	142.28	415.28
	190.12	463.12
Sn-52Bi-0.05Al	144.38	417.38
Sn-52Bi-0.11Al	143.44	416.44
Sn-52Bi-0.14Al	145.05	418.05
Sn-52Bi-0.19Al	144.54	417.54
Sn-52Bi-0.25Al	144.6	417.6
Sn-70Bi	143.74	416.74

The Sn-52Bi showed the lowest melting point at 124.28 ^{o}C. This alloy composition was added by Al element. The electrical properties was done by LCR with frequency ranged from 1 Hz to 1000 Hz. The measurement results of impedance (Z), capacitance (C) and conductance (G) also conductance calculation ((Gs)*) of Sn-52Bi tabulated in Table 4.

Table.4. Impedance (Z), capacitance (C) and conductance (G) also conductance calculation ((Gs)*) value of the Sn-52Bi.

%Wt.	Freq.	Z(ohm)	Cs(F)	Rs(ohm)	G(S)	G(S)*	ΔG
Bi	Hz	Ohm	Farad	ohm	Siemens	Siemens	%
	1	0.0131	1674.2	0.0131	76.526	76.5287	0.0035
	1.995	0.0132	1922.4	0.0132	75.91	75.9129	0.0038
	3.981	0.0131	6795.2	0.0131	76.26	76.2602	0.0003
	7.943	0.0131	4313.4	0.0131	76.052	76.0514	-0.0008
	15.85	0.0131	90.845	0.0131	76.54	76.5462	0.0081
52	31.62	0.0135	65.221	0.0135	73.894	73.8989	0.0066
	60	0.0135	2.3405	0.0135	73.807	74.3329	0.7125
	125.9	0.0125	2.9294	0.0125	79.975	80.0705	0.1194
	251.2	0.0136	0.3638	0.0135	73.068	74.2942	1.6782
	501.2	0.0132	0.3746	0.0132	75.662	75.9763	0.4154
	1000	0.0128	0.089	0.0127	77.166	78.6968	1.9838

The results of specific electrical resistance (ρ) and electrical conductance (σ)of the Sn-52Bi tabulated in Table.5

Table.5. Specific electrical resistance and conductance of the Sn-52Bi.

%Wt.	Freq.	Rs(ohm)	ρ	σ
Bi	Hz	ohm	ohm.m	1/ohm.m
	1	0.0131	0.0014	727.4291
	1.995	0.0132	0.0014	721.5757
	3.981	0.0131	0.0014	724.8773
	7.943	0.0131	0.0014	722.8927
	15.85	0.0131	0.0014	727.5962
52	31.62	0.0135	0.0014	702.4325
	60	0.0135	0.0014	706.5574
	125.9	0.0125	0.0013	761.0951
	251.2	0.0135	0.0014	706.1899
	501.2	0.0132	0.0014	722.1787
	1000	0.0127	0.0013	748.0378

Table 6 was calculated from averaging the value from table 5.

Table 6. Electrical conductance calculation specific electrical resistance and electrical conductance Sn-52Bi.

%Wt.	Rs(ohm)	G(S)	G(S)*	ΔG	P	σ
Bi	Ohm	Siemens	Siemens	%	ohm.m	1/(ohm.m)
52	0.0131	75.8964	76.2335	0.4443	0.0014	724.6239

Table 7. Impedance (Zs), capacitance (Cs) and conductance (Gs) also conductance calculation ((Gs)*) value of the Sn-52Bi-0.05Al.

%Wt.	Freq.	Z	Cs	Rs	G(S)	G(S)*	ΔG
Al	Hz	Ohm	Farad	Ohm	siemens	siemens	%
	1	0.0098	2543.8	0.0098	102.14	102.144	0.0039
	1.995	0.0098	2267.9	0.0098	102.14	102.1388	0.0012
	3.981	0.0098	2193.1	0.0098	102.43	102.4265	0.0034
	7.943	0.0098	768.13	0.0098	102.08	102.0773	0.0027
0.05	15.85	0.0097	212.72	0.0097	103.21	103.212	0.0019
	31.62	0.0093	8.8971	0.0093	107.43	107.8272	0.3697
	60	0.0091	2.3906	0.009	109.64	111.3139	1.5268
	125.9	0.0091	0.4713	0.0087	105.06	115.0629	9.5211
	251.2	0.0096	0.2342	0.0092	100.3	109.031	8.7049
	501.2	0.0095	0.1928	0.0093	103.75	106.9759	3.1093
	1000	0.0095	0.086	0.0093	103.35	107.4414	3.9588

The results of specific electrical resistance (ρ) and electrical conductance (σ) of the Sn-52Bi-0.05Al tabulated in Table.8

Table 8. Specific electrical resistance and conductance of the Sn-52Bi-0.05Al.

%Wt.	Freq.	Rs	ρ	Σ
Al	Hz	ohm	ohm-m	1/ohm.m
	1	0.0098	0.00035	2847.417
	1.995	0.0098	0.00035	2847.272
	3.981	0.0098	0.00035	2855.292
	7.943	0.0098	0.00035	2845.557
0.05	15.85	0.0097	0.00035	2877.188
	31.62	0.0093	0.00033	3005.844
	60	0.009	0.00032	3103.043
	125.9	0.0087	0.00031	3207.55
	251.2	0.0092	0.00033	3039.404
	501.2	0.0093	0.00034	2982.114
	1000	0.0093	0.00033	2995.09

Table 9. The electrical resistance, specific electrical resistance and electrical conductance value of Sn-52Bi-xAl alloys.

%Wt.Al	Rs	ρ	σ
	ohm	Ohm.mtr	Mho
0	0.0131	0.0014	724.6239
0.05	0.00943	0.00034	2964.16
0.11	0.01305	0.00141	711.23
0.14	0.01093	0.00124	807.74
0.19	0.01842	0.00194	516.72
0.25	0.01204	0.00156	640.87

Measurement showed, the frequency not significantly influenced the electrical impedance and resistance, that can be ignored. The frequency influenced on capacitance value. The specific electrical resistance value depends to the resistance. Similarly,the electrical conductivity value that only depends to the specific electrical resistance.

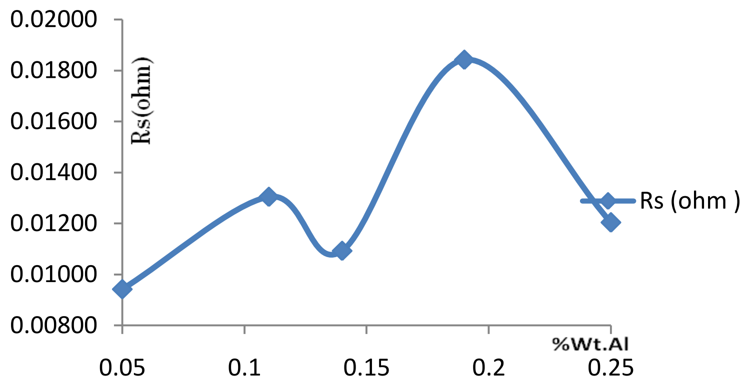

Figure 1. Correlations of the Al compositions to the electrical resistance.

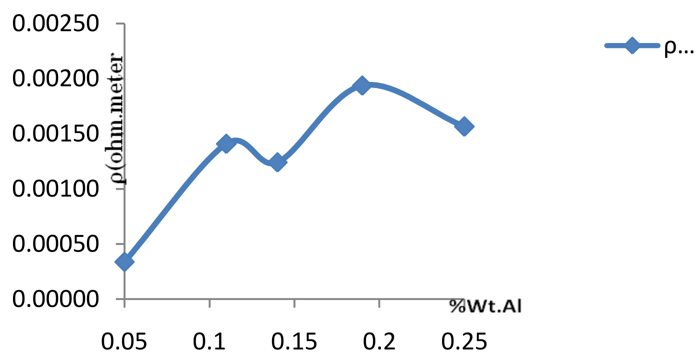

Figure 2. Correlations of the Al compositions to the specific electrical resistance.

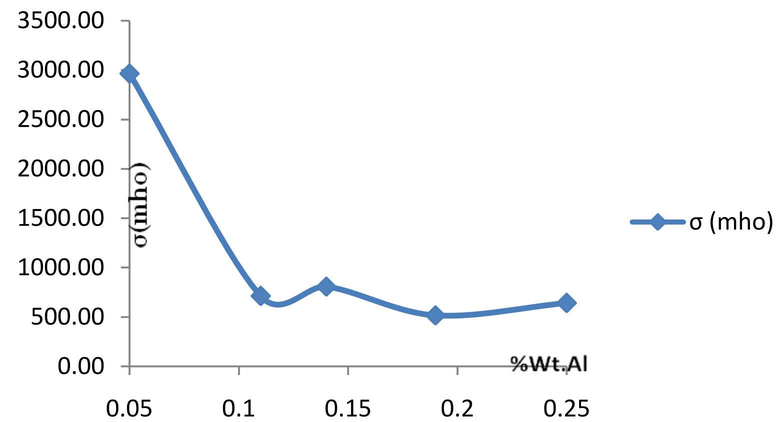

Figure 3. Correlations of the Al compositions to the electrical conductance

Figure 1, Figre 2, and Figure 3 showed the correlations of Al composition on alloy to the electrical resistance, specific electrical resistance and electrical conductivity. The statistical fitting on all the figures tabulated in Table 10.

Table 10. Fitting equation on electrical resistance, specific electrical resistance and electrical conductivity.

Parameter	R^2	R	Equation
Rs(Ohm)	0.705	0.8396	y = -7.704x3 + 3.098x2 - 0.319x + 0.018
ρ(Ohm.m)	0.901	0.9492	y = -0.182x3 + 0.019x2 + 0.014x - 0.000
σ(Mho)	0.978	0.9889	y = -99153x3 + 56934x2 - 10555x + 6920.

Table 10 showed the significant correlation between the Al composition in the alloy to electrical resistance, specific electrical resistance and electrical conductivity marked by the correlation coefficient value at 0.8396, 0.9492 and 0.9889.

Conclucions:-

Measurement of the electrical properties of Sn-52Bi-xAl has been done. The conclusion from the results of measurement and calculation are:

- The lowest melting point of Sn-Bi alloyswas in the Sn-52Bi at the eutectic with melting point at 142.28^0C and at the eutectoid with melting point at 190.12^0C.
- The composition Sn-52Bi-0.05Al showed the lowest electrical resistance and specific electrical resistance with value at 0.00943 ohm and 0.00034 ohm.m, respectively. The electrical conductivity of Sn-52Bi-0.05Al showed the highest with value at 2964.16 Mho.

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