Gold Pre-tinning through Single Dynamic Wave Soldering for Pin Through-Hole and Surface Mount Components

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***Abstract*—** In the assembly of printed circuit boards (PCBs), most pin through-hole (PTH) components undergo hot-dip soldering or dual dynamic wave soldering to dissolve the gold (Au)-plated surface of the pin. A single dynamic wave soldering was used to investigate the effect of PCB thickness on the Au pre-tinning of an eight-pin connector. Au electroplated (non-pre-tinned) pins were inserted into two PCBs of different thicknesses (1.514 and 7.620 mm) and passed through single dynamic wave soldering. The Au concentration of the pins and the microstructure between the tin–lead solder and pins were studied using Scanning electron microscopy and energy-dispersive X-ray spectroscopy. No Au was found in the pins on the thin PCB (1.514 mm), but less than 3 wt% to 4 wt% Au was found in the thick PCB (7.620 mm), in accordance with IPC J-Standards. No Au was found on the terminals of the surface mount component.

***Keywords*—**Gold concentration, Intermetallic compound (IMC), Scanning electron microscope (SEM), Wave soldering.

I. INTRODUCTION

GOLD (Au) is widely used in electronic and microelectronic components (e.g., as coating on component pins and wire bonding of microchips). Using Au in electronics reduces electrical resistivity and contact resistance, facilitates thermal compression, and increases resistance to mechanical wear [1]. Electroplated Au is often used in electronic components (e.g., as an intermediate layer and finishing on connectors, terminations, and printed circuits). However, thick electroplated Au layers on component pins must be reduced before the assembly of printed circuit boards (PCBs) to avoid the embrittlement of intermetallic compounds (IMCs). IMC embrittlement weakens solder joints and possibly induces solder joint failure in electronic products [2]. Thus, this issue is a significant concern of engineers because they should be able to maintain product quality while reducing manufacturing cost.

Au layers with a thickness of 100 µin or above must be wicked away by molten solder before soldering, a process known as pre-tinning. Pre-tinning removes most or all of the Au layer and leaves a solderable nickel (Ni) finish for excellent bonding. If pre-tinning is not performed or found inadequate, such as when the initial Au layer is too thick, an $AuSn_4$ intermetallic layer forms between the Ni-plated part and the solder. Therefore, the solder joint becomes susceptible to failure because of embrittlement by the $AuSn_4$ intermetallic phase. As an extension of our previous research [3], single dynamic wave soldering was used to investigate the effect of PCB on the dissolution of Au on the pins of pin through-holes (PTHs). The proposed single dynamic wave solder method was extended to the pre-tinning of Au-plated terminals for surface mount components. Scanning electron microscopy (SEM) equipped with energy-dispersive X-ray (EDX) spectroscopy was used to analyze the microstructure and the presence of the material element in specimens. Wave soldering PTHs and pre-tinning surface mount components by using single dynamic wave solder have been conducted in the electronics industry. This implementation has significantly reduced the costs of the industry. The performance of the components in the PCB with the proposed method meets IPC J-Standards and satisfies customers. Therefore, the findings of this study are expected to provide a valuable reference for other areas of the electronics industry.

II. PROBLEM STATEMENT

Reducing manufacturing cycle time reduces costs. Typically, Au is pre-tinned by hot-dip and dual wave soldering before PCB assembly. In this study, single dynamic wave solder was used to (i) pre-tin and solder PTH components at a single step for two PCB thicknesses and (ii) pre-tin surface mount components. Au-plated pins were passed through single dynamic wave soldering. The Au layer of the pin was dissolved, and the molten solder filled the PCB hole and thus formed a joint between the pin and PCB. The Au pin connector (Fig. 1) was used to investigate the effect of PCB thickness on Au dissolution during wave soldering. However, surface mount components were inserted into the pallet and pre-tinned by single dynamic wave soldering. Fig. 2 shows a surface mount technology (SMT) component with two Au-plated terminals.

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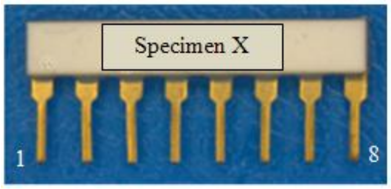
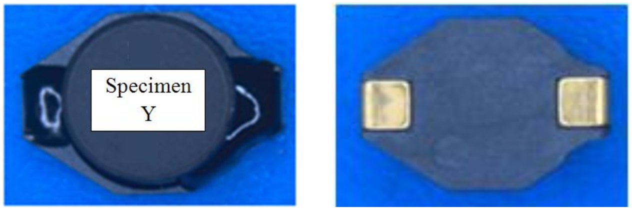


Fig. 1 8-Gold pin connector.



(a) Top view

(b) Bottom view-two gold terminals

Fig. 2: Surface mount component for gold removal.

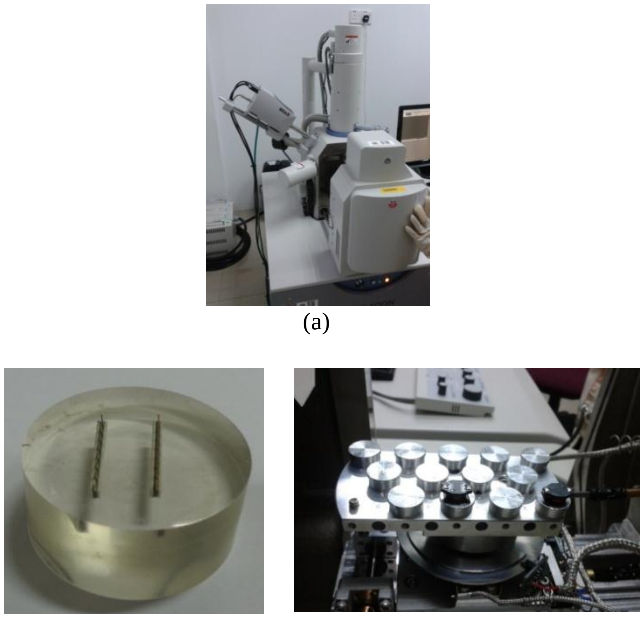
III. METHODOLOGY

This section describes the experiment procedures to investigate Au removal by single dynamic wave soldering. The wave soldering machine in the manufacturing line was used for two components during the experiment. The experiments were conducted to investigate (i) the effect of PCB thickness on the removal of PTH Au and (ii) the removal of Au from surface mount component terminals. Similar wave soldering procedures and SEM and EDX analyses were used in both cases

IV. SAMPLE PREPARATION

The standard parts of an eight-pin connector with an Au thickness <150 µin (3.80 µm) were used in the experiment (Fig. 1). Simply soldering these parts to a PCB with a lead–tin solder may embrittle the Au. Thus, the Au layer must be wicked away by molten tin before soldering, a process known as dynamic wave soldering. Dynamic wave solder removes most or all of the Au layer and leaves a solderable Ni finish for excellent bonding. J-STD-001 E states that 95% of Au thickness should be removed [4]. J-STD-001 also suggests that 3wt% to 4 wt% Au can embrittle solder [5]. Therefore, to obtain better pin joints, Au thickness should be less than the abovementioned values. Pin connectors were assembled onto two PCBs of different thicknesses (thin: 1.514 mm; thick: 7.620 mm). These pin connectors were sliced from the PCB after wave soldering to analyze the elements and microstructure. The part was cold-mounted for SEM and EDX analyses.

The terminals of the surface mount component were coated with 1.0 µm thick Au. Before PCB assembly, the Au surface must be wicked away from the PTH component. In this study, surface mount components were loaded onto the pallet and passed through single dynamic wave soldering. At this stage, the Au plate on the terminals was dissolved into the molten solder. The pre-tinned terminals were then examined by SEM and EDX. Fig. 3(a) shows the EDX machine used to analyze the microstructure and elements. Specimens of the pin connector and surface mount component are shown in Figs. 3(b) and 3(c).



(a)

(b)

(c)

Fig. 3: (a) EDX machine, (b) Pin connector in cold-mounting and (c) surface mount component

V. SINGLE DYNAMIC WAVE SOLDERING PROCESS

Single dynamic wave soldering was used for the pin connectors (pre-tinning and soldering) and surface mount components (pre-tinning) to reduce cycle time and manufacturing costs. As mentioned earlier, this study considered two components, each of which underwent the procedures shown in Figs. 4 and 5. Fig. 4 shows the single dynamic wave solder for PTH pre-tinning and soldering on the PCB. However, a specific pallet was used to carry the surface mount components (Fig. 5). The components were fitted into the holes without any tilting (as guided by a top catch fixture) to ensure the even pre-tinning of each terminal. The populated pallet was conveyed through dynamic wave solder (i.e., fluxing and soldering) and then washed with water to remove flux residue.

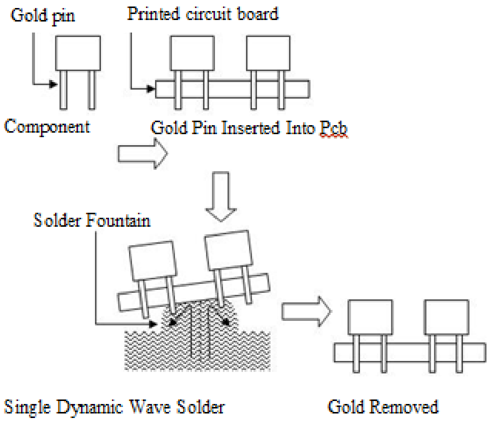


Fig. 4 Single dynamic wave soldering process for PTH component pre-tinning and soldering

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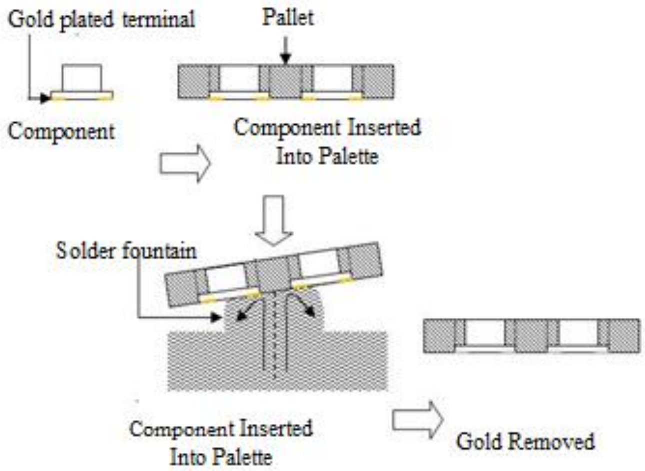


Fig. 5 Single dynamic wave soldering process for surface mount component pre-tinning

VI. PIN THROUGH HOLE COMPONENT (SPECIMEN X)

Before pre-tinning, the thickness of the Au-plated layer of the PTH pin was measured with an Alicona Infinite Focus microscope. The copper pin was plated with Ni and Au layers (Fig. 6). The thickness of the Au layer was measured at three random locations. The thicknesses of the Au layer are summarized in Table 1. The average thickness of the Au layer was 3.7234 µm. In this section, the PTH pin connector was inserted into a thin (0.0596 in or 1.5140 mm) and thick (0.30 in or 7.62 mm) PCB for single-step pre-tinning and soldering.

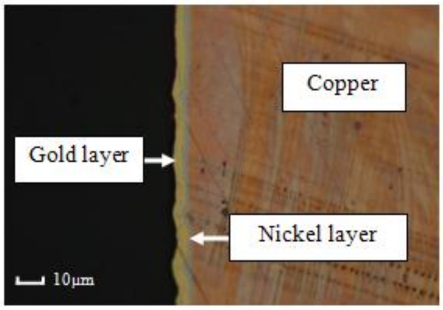


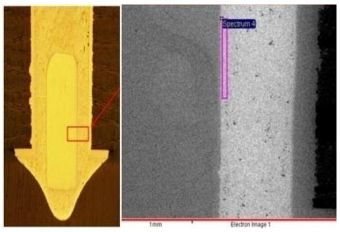
Fig. 6: Gold and nickel layer on the copper pin before wave soldering.

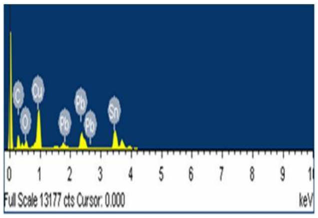
TABLE I
GOLD LAYER THICKNESS OF PTH PIN

Pin	Measurement of gold layer (µm) 1	2	3	Average (µm)
1	3.0811	3.0811	3.5987	3.2536
2	3.2568	2.5876	3.3679	3.0708
3	4.6535	4.2650	3.4395	4.1193
4	3.9898	3.0955	3.8797	3.6550
5	4.3750	3.5839	4.4911	4.1500
6	3.9623	3.1698	3.7972	3.6431
7	4.9990	3.6281	4.4586	4.3619
8	3.2331	3.5083	3.8599	3.5338
Average gold thickness for specimen X				3.7234

The cold-mounted part was analyzed by SEM and EDX. The presence of elements in the wave-soldered part was examined according to the spectrum of the EDX result. Both the thin and thick PCBs were analyzed after the pins were wave-soldered onto the PCBs. Figs. 7 and 8 show the microstructure and EDX results of the pin soldered onto the thin PCB. The microstructure of the soldered pin showed that the solder completely filled the PCB hole and that the pin perfectly joined with the PCB. The selected pin region (Figs. 7 and 8) were analyzed by the EDX machine. Metallic elements tin (Sn) and lead (Pb) were found in the pin joint of the thin PCB, but not Au. The pin joint had high Sn content derived from the Sn63Pb37 solder material. These results show that the Au layer was successfully dissolved by the single dynamic wave soldering of the thin PCB (0.0596 in or 1.5140 mm thick).

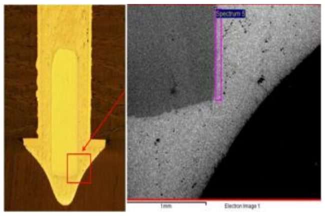
J-STD-001 [5] states that, the Au layer should be less than 3wt% to 4 wt% to avoid embrittling the solder joint. Only a small percentage of Au was found in the middle regions of the pin joint as observed in the EDX spectra (Figs. 9–11). This result may have been caused by the thick PCB, which had a deeper PCB hole than the thin PCB. However, Au was not found at the bottom region of the pin joint, although it was identified in the middle region of the assembled pin joint (<3 wt %). Therefore, the pre-tinning and soldering of the thick PCB (0.30 in or 7.62 mm) met the J-Standard (minimum Au of <3wt% to 4 wt %). Thus, using single dynamic wave soldering in PCB assembly (as a substitute for dual wave soldering) may reduce manufacturing cost and shorten process steps.

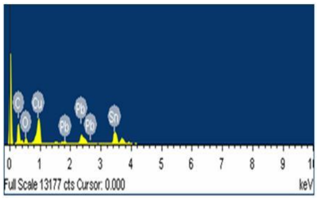




Element	Weight %	Atomic %
C K	7.33	32.80
O K	5.96	20.05
Cu L	28.49	24.11
Sn L	41.03	18.59
Pb M	17.19	4.46
Totals	100.00	

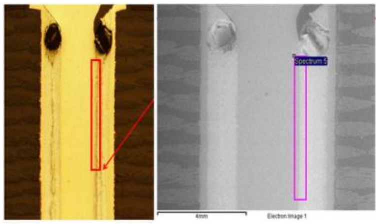
Fig. 7: Middle region of pin for thin PCB.

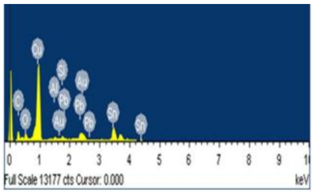




Element	Weight %	Atomic %
C K	14.71	51.26
O K	6.00	15.71
Cu L	23.89	15.74
Sn L	40.49	14.28
Pb M	14.90	3.01
Totals	100.00	

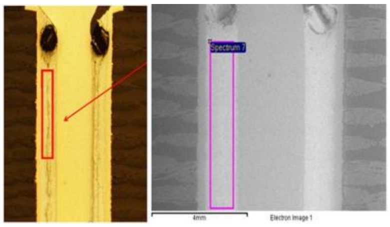
Fig. 8: Bottom region of pin for thin PCB.

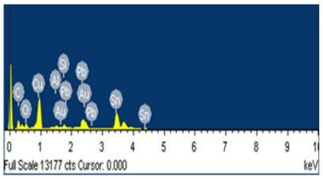




Element	Weight %	Atomic %
C K	6.07	27.18
O K	3.60	12.09
Al K	0.72	1.43
Si K	0.96	1.84
Cu L	49.11	41.55
Sn L	29.10	13.18
Au M	**1.14**	**0.31**
Pb M	9.29	2.41
Totals	100.00	

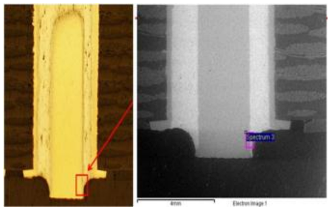
Fig. 9: Middle region of pin for thick PCB (Right side).

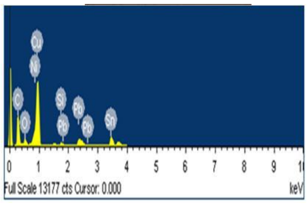




Element	Weight %	Atomic %
C K	5.64	27.08
O K	4.94	17.82
Al K	0.72	1.53
Si K	1.10	2.27
Cu L	28.23	25.64
Sn L	43.93	21.35
Au M	**1.18**	**0.35**
Pb M	14.26	3.97
Totals	100.00	

Fig. 10: Middle region of pin for thick PCB (Left side).





Element	Weight %	Atomic %
C K	19.76	57.73
O K	3.40	7.45
Si K	0.71	0.88
Ni L	5.64	3.37
Cu L	41.95	23.16
Sn L	20.35	6.02
Pb M	8.20	1.39
Totals	100.00	

Fig. 11: Bottom region of pin for thick PCB.

VII. SURFACE MOUNT COMPONENT (SPECIMEN Y)

The proposed method was extended to the pre-tinning of the surface mount component by using single dynamic wave soldering. Similarly, the Au-plated part of the component must be wicked away to avoid embrittlement. In the earlier SMT assembly, the component parts are pre-tinned by the vendor. This step increases manufacturing cost. To minimize manufacturing cost, single dynamic wave solder was used to pre-tin the Au-plated terminals of the surface mount component (Fig. 12). The pre-tinned component terminals were examined by SEM and EDX. Two components were used in this study (Fig. 13). Each terminal was evaluated at different spots and in its entirety. The EDX spectra show the presence of metal elements.

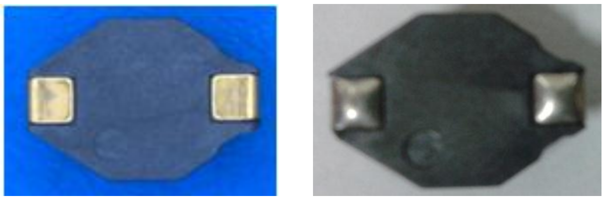
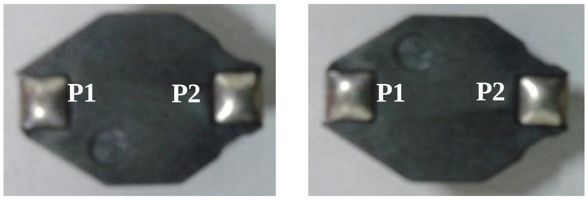

(a) Before pre-tinning (b) After pre-tinning

Fig. 12: Terminals of component before and after pre-tinning.



Component-1 Component-2

Fig. 13: Two components to investigate the gold thickness after wave soldering.

Four spots on the terminal P1 surface were evaluated (Fig. 14). The results of the elemental analysis of each point are presented in Figs. 15–19 and 21–25. The EDX spectra showed the presence of metallic elements on the terminal, such as Sn and Pb. Au was not observed after the terminals were pre-tinned by single dynamic wave soldering. A similar finding was revealed for the full area analysis: no Au was found on the pre-tinned surface. The microstructure morphology also shows the homogeneous distribution of Pb and Sn on the terminal. The white spot denotes high Pb content (Figs. 14 and 20). Conversely, the dark area denotes high Sn content. Terminal P2 of component 1 also had similar microstructure morphology. No Au was found in the pre-tinned terminals with the proposed wave soldering. This method has been used in the electronics industry to pre-tin surface mount components with reduced manufacturing costs.

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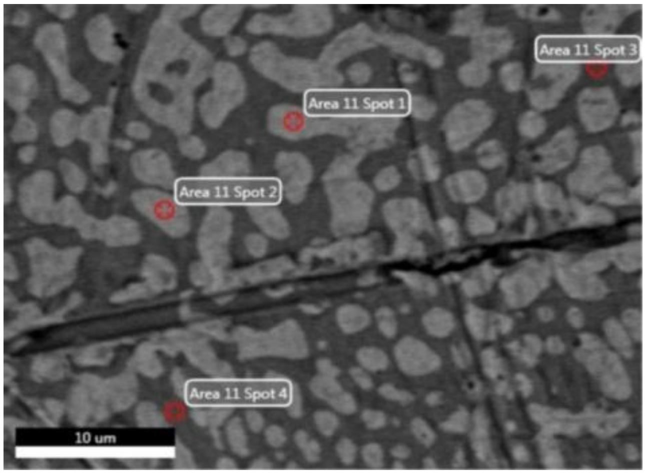
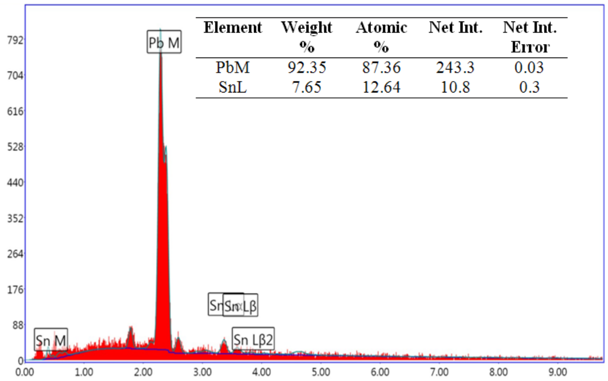
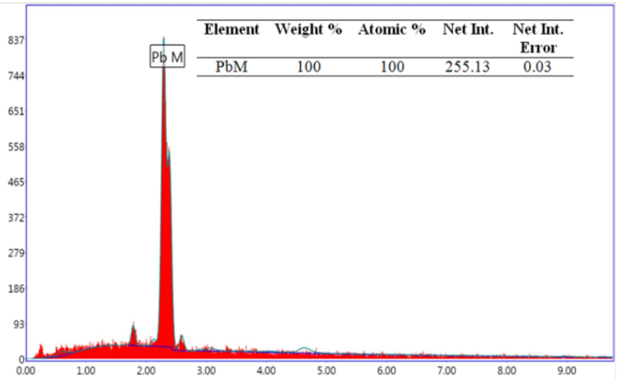


Fig. 14: 4 Spots on component 1 at terminal P1.



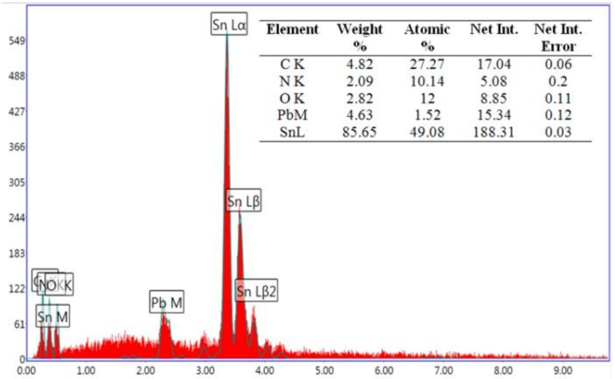
Element	Weight %	Atomic %	Net Int.	Net Int. Error
PbM	92.35	87.36	243.3	0.03
SnL	7.65	12.64	10.8	0.3

Fig. 15: Spot 1.



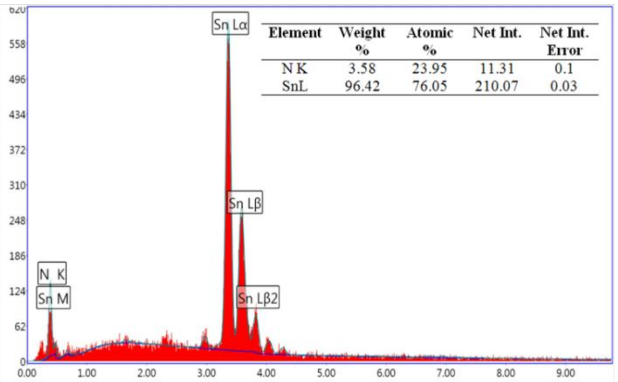
Element	Weight %	Atomic %	Net Int.	Net Int. Error
PbM	100	100	255.13	0.03

Fig. 16: Spot 2.



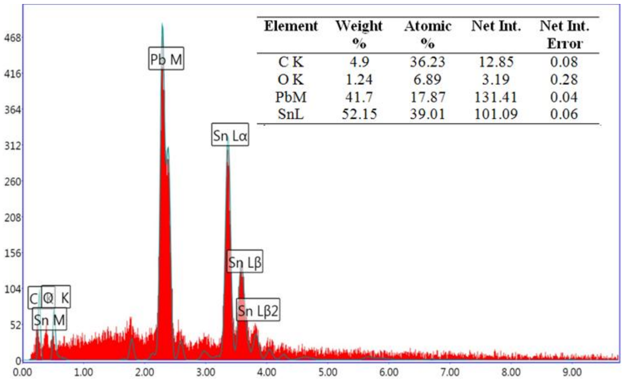
Element	Weight %	Atomic %	Net Int.	Net Int. Error
C K	4.82	27.27	17.04	0.06
N K	2.09	10.14	5.08	0.2
O K	2.82	12	8.85	0.11
PbM	4.63	1.52	15.34	0.12
SnL	85.65	49.08	188.31	0.03

Fig. 17: Spot 3



Element	Weight %	Atomic %	Net Int.	Net Int. Error
N K	3.58	23.95	11.31	0.1
SnL	96.42	76.05	210.07	0.03

Fig. 18: Spot 4.



Element	Weight %	Atomic %	Net Int.	Net Int. Error
C K	4.9	36.23	12.85	0.08
O K	1.24	6.89	3.19	0.28
PbM	41.7	17.87	131.41	0.04
SnL	52.15	39.01	101.09	0.06

Fig. 19: Full area analysis.

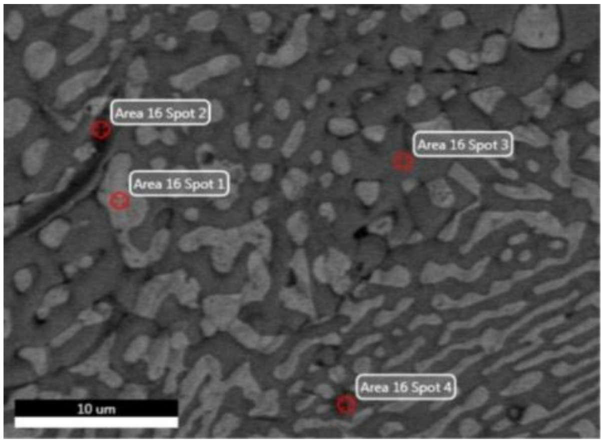
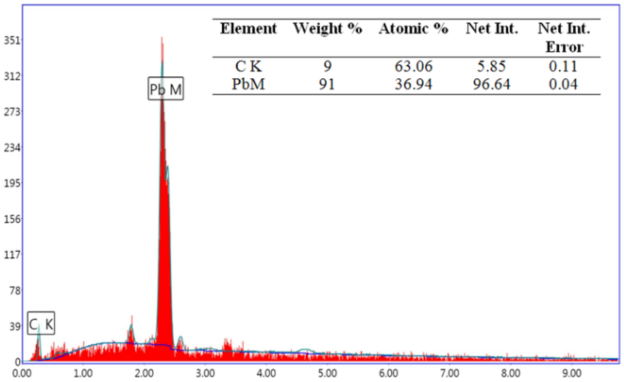
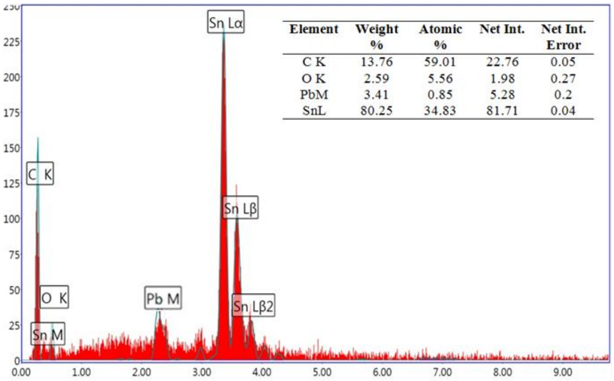


Fig. 20: Four spots on terminal P2 of component 1.



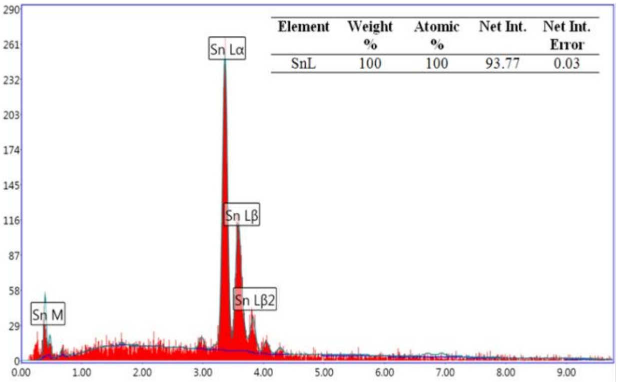
Element	Weight %	Atomic %	Net Int.	Net Int. Error
C K	9	63.06	5.85	0.11
PbM	91	36.94	96.64	0.04

Fig.21: Spot 1



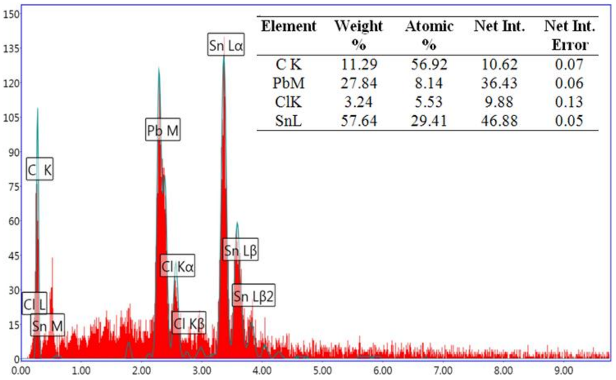
Element	Weight %	Atomic %	Net Int.	Net Int. Error
C K	13.76	59.01	22.76	0.05
O K	2.59	5.56	1.98	0.27
PbM	3.41	0.85	5.28	0.2
SnL	80.25	34.83	81.71	0.04

Fig. 22: Spot 2



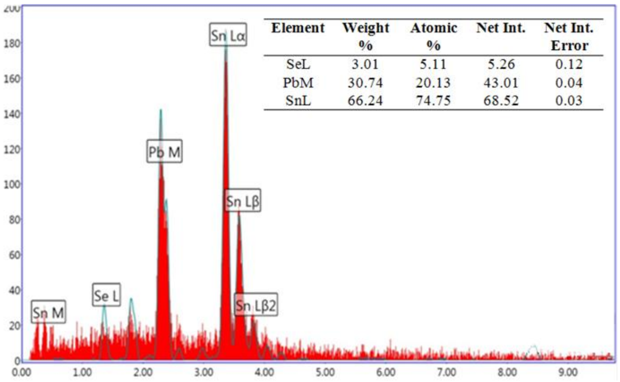
Element	Weight %	Atomic %	Net Int.	Net Int. Error
SnL	100	100	93.77	0.03

Fig. 23: Spot 3



Element	Weight %	Atomic %	Net Int.	Net Int. Error
C K	11.29	56.92	10.62	0.07
PbM	27.84	8.14	36.43	0.06
ClK	3.24	5.53	9.88	0.13
SnL	57.64	29.41	46.88	0.05

Fig. 24: Spot 4



Element	Weight %	Atomic %	Net Int.	Net Int. Error
SeL	3.01	5.11	5.26	0.12
PbM	30.74	20.13	43.01	0.04
SnL	66.24	74.75	68.52	0.03

Fig. 25: Full area analysis.

VIII. CONCLUSION

Single dynamic wave soldering was used to pre-tin and solder PTH components in a single step. The results show that single dynamic wave soldering is adequate and applicable for the pre-tinning and soldering of Au-plated pin connectors. The Au layer on the pin of a thin PCB (1.514 mm) was dissolved into the molten solder after wave soldering. No Au was found in the EDX spectrum. However, the proportion of Au in the thick PCB (7.62 mm) met IPC J-STD-001 [4]. Thus, double hot-dip is unnecessary (even with an Au thickness of ≥100 µin/2.54 µm) if the PCB thickness is equal to or less than 7.62 mm (0.30 in). With these desired results, we propose to IPC that IPC J-STD-001 (page 9, clause 4.5.1a), as a global standard for electronic industries, be modified according to our findings. Before this study, we were unaware of the proposed method and completely followed IPC J-STD-001 standards.

The proposed single dynamic wave soldering was successfully used to pre-tin surface mount components. EDX results showed no traces of Au on the component terminals. The proposed pre-tinning method excellently performed with the SMT component. The Au layer of component terminals was completely dissolved. The proposed method enables the industry to achieve pre-tinning targets and reduce process steps compared with the double hot-dip method. Thus, the proposed single dynamic wave soldering is suitable for pre-tinning SMT components because of its excellent performance. Compared with dual wave soldering, the proposed method enables the industry to reduce costs and time during PCB assembly.

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