The Study of the Nitrogen Effect for Wave Soldering Process

Han-Na Noh*, Jae-Chan Kim, Dong-Woon Park, Il-Je Cho, Min-Jin Oh
LG Electronics
19-1 Cheongho-ri, Jinwuy-myun, Pyeongtaek-si, Gyeonggi-do, Korea
* Corresponding Author, myanya99@lge.com, +82 31 660 7394

Abstract

Recently, with significant increasing of solder manufacturing cost due to raw materials, electronics makers are also faced with the same difficulty. And they are finding solutions that save cost by reducing the dross. This paper describes the implementation of a wave soldering system using inert gas. The system based on the PSA-generated nitrogen with residual oxygen levels of 100ppm has low maintenance cost and is very simple to retrofit. In this study, technical results and economic benefits are analyzed by feasibility and actual test. To analyze the effects of comparing nitrogen wave soldering with conventional air condition, we have evaluated the wettability of assemblies, dross and solder joint reliability. The inert wave soldering system shows significant dross reduction and its wettability is better than conventional. Also SEM analysis from solder joint shows good results.

1. Introduction

New packaging technologies are evolving toward smaller, thinner and more powerful devices. Despite the predicted elimination of the wave soldering process, this soldering technique continues to be widely used. [1, 2] The use of pin-through hole components and the overall cost effectiveness of the process maintain its viability. So as the pressure to reduce cost and improve quality increases in electronic manufacturing, assemblers using wave soldering must consider innovations to meet these challenges.

One option is to adopt an inert wave soldering system. The main benefit of nitrogen in wave soldering processes is the reduction in the generation of dross. [3, 4, 5] Dross is the silvery sludge that covers the surface of the solder pot. The wave chute area is critical for dross generation because of the agitation of the molten solder. Nitrogen is a better heat conductor than air. This fact offers the great advantage that lower process temperatures may be applied and therefore the impact on assemblies and components is reduced. Furthermore, due to the shielding gas atmosphere, a significant reduction of oxidation in wave soldering is achieved, along with a decrease of dross creation. Lowering dross generation saves money and lessens maintenance requirements. Reducing dross on the surface of flowing waves improves wetting to the solderable surfaces. So the method enables a reduction of dross and provides good quality of assemblies while minimizing investment and maintaining low operating costs. .

Inerting the wave soldering system may be done in a number of different ways. One is available that only protects the solder pot area by installing a cover, which effectively closes off the soldering environment. Such method enables a dross reduction and provides higher quality while minimizing investment and maintaining low operation costs. These systems can be retrofitted with used soldering machines. Some wave solder machines inert the tunnel leading to the solder pot as well, to prevent oxidation from forming on the solderable surfaces during preheating. In the full tunnel system, the dross generation is lower and capital costs are higher than localized inert system.

This paper describes the implementation of the localized inert system with lower investment cost and simple retrofitting. Our goals were to reduce the losses associated with dross generation and reduce touch-up. Additionally, an increase in quality and reliability of the assembly would be another benefit. As the pressure to reduce cost in the industry is continuously increasing, the ultimate decision to use nitrogen should be based on investment cost vs. benefit analysis which goes beyond the unit cost of nitrogen itself. Testing is recommended for that purpose.

2. Experiments

In this study, we divided experimentation into feasibility tests in the laboratory and trial production to evaluate the effect of the inert system on wave soldering. In detail, these were the wetting characteristic and solder joint microstructure with evaluation of dross generation for the economic feasibility.

2.1 Feasibility test

We have studied dross generation through inspection in the laboratory. We evaluated the effect of atmosphere on the rate of dross generation under three different environmental conditions: ambient atmosphere, nitrogen atmosphere without enclosure, nitrogen atmosphere with enclosure. In this test, we used membrane-generated nitrogen to make an inert gas suitable for laboratory on a small scale. To maintain and seal the inert atmosphere we used an enclosure for the solder pot. The test conditions used for analysis of the dross generation are seen below.

Table 1 - Test condition used for analysis of the dross generation

Solder pot	N_2 generator		Test time	Measuring of dross
Temp.	Flow rate	O_2 PPM		
260℃	3ℓ/min	20000	360min	Each hour

2.2. Trial production

2.2.1. Implementation of the localized inert system

Figure 1 illustrates schematics of retrofit inert system. The retrofit system selected is described and its implementation is detailed. The system consists of three parts: N2 nozzle, cover and N2 generator:

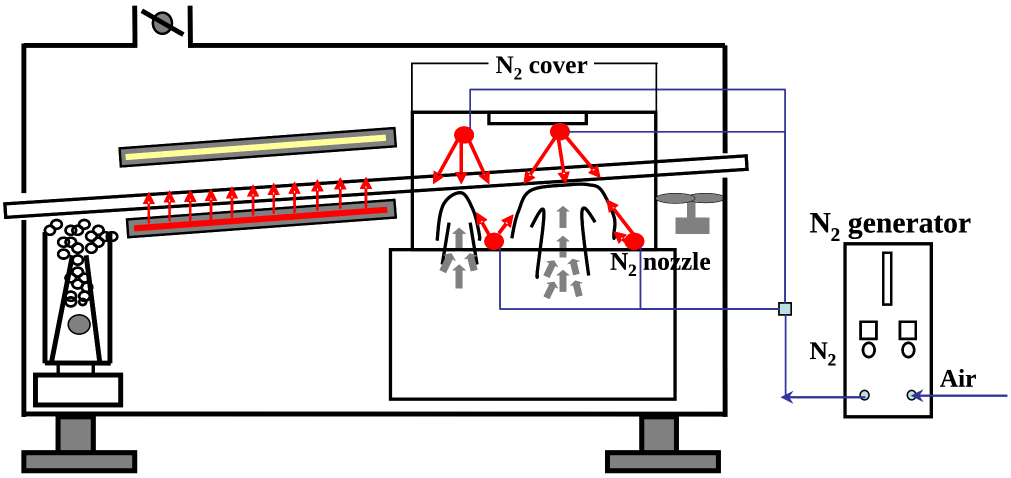


Figure1 - Schematic of the localized inert system.

1) N2 nozzle

The N2 nozzle is comprised of 2 pipes and 2 porous filters with 10um diameter pores which are enclosed in a frame. The nitrogen system is one that diffuses nitrogen along each side of the flowing waves and on the top of the enclosure. The PCB is an integral part of the inert system as it acts as a seal over the waves. When the PCB reached the waves, the volume underneath the PCB is instantly purged with nitrogen diffused from the N_2 filters. So with the nitrogen gas bled at printed circuit board/ solder wave interface a low oxygen content atmosphere can be expected at interface.

2) Enclosure (cover)

The system requires the enclosure and curtains to maintain an inert atmosphere. Through these systems nitrogen is trapped and a low oxygen content atmosphere can be expected.

3) Generator

We used PSA-generated nitrogen with a house nitrogen line. It was known as PSA type generator offers much higher purity nitrogen than membrane type, so we selected PSA type generator to produce high purity nitrogen and to meet mass-production. In this study, an air compressor should not be required if the assembly facility can provide high enough pressure and flow from its house line. The oxygen level in the inert system is maintained at around 100ppm and the flow rate is about 6lube.

2.2.2. Wettability

The choice of flux directly influences solderability of the assemblies as well as the resulting cleanliness after soldering. Comparing wetting force for different fluxes in air and nitrogen again yields results indicating that nitrogen coverage can improve the process. In this study, we selected 2 fluxes with 14.5% and 10% solids, respectively and evaluated the influence of the solid contents of flux on the wettability in the inert system. We evaluated the wettability on the basis of IPC standard. Inspection has been done with an optical microscope at a magnification of 50X-100X.

2.2.3. Inter-metallic compounds analysis

The micro-structure of the component was compared to those investigated in ambient and inert wave soldering. SEM analysis from solder joints was accomplished to compare inter-metallic compound (IMC) layers.

3. Result

3.1. Feasibility test

Figure 2 shows the rate of dross generation under three different conditions. In the inert system with enclosure, the rate of dross generation has been established at 34%. We found that the dross generation has been reduced by 62% in comparison with a normal air atmosphere. From this result, the use of the nitrogen largely eliminates the dross generation. Especially, we observed that the higher nitrogen atmosphere the more the rate of dross generation is reduced.

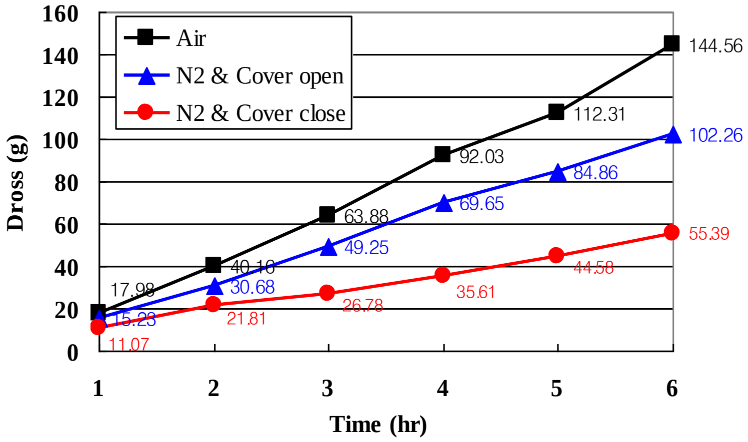


Figure 2 - The rate of dross generation under different conditions

3.2.1. Implementation of the localized inert system

Solderability of solder alloys depends very much on its fluidity or surface tension for it to adhere and solder onto the substrate that needs to be soldered. In this process, Sn-3.0Ag-0.5Cu alloy has run successfully at 249℃ with minimal or no blow-holes, insufficient solders, bridging or excessive solders in comparison with normal wave soldering because the enclosure minimized any drop in temperature.

3.2.2. Wettability

Figure 3, 4, 5 shows the impact of nitrogen atmosphere on wettability. In a comparison of wetting states under conventional wave soldering, the assembly with inert soldering had better wetting characteristics. We observed that solder joints with conventional soldering show hole filling is not complete. The wettability of assembly using flux with 10% solid contents was similar with the samples with 14.5% solids. Even with reducined solid content of flux, the wettability of assembly has been accomplished successfully. From these result we find the use of nitrogen generally allows the use of milder fluxes than would be tolerable in air. This is a well-established fact.

Condition	Solid contents	Part N/B				
		IC7	L1	CE1	IC2	Trans
Air	14.5%					
N2	14.5%					
	10%					

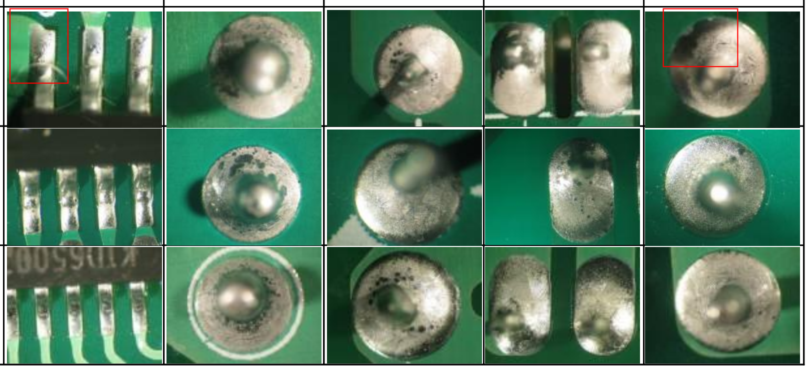


Figure 3 - The bottom pad wettability of assemblies under different conditions

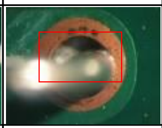
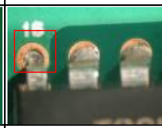
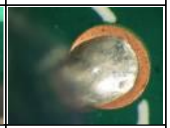
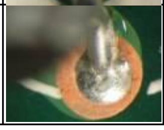
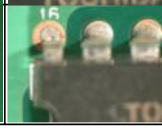
Condition	Solid contents	Part N/B				
		CE18	FUSE2	IC2	IC13	LED201
Air	14.5%					
N2	14.5%					
	10%					

Figure 4 - The top pad wettability of assemblies under different conditions.

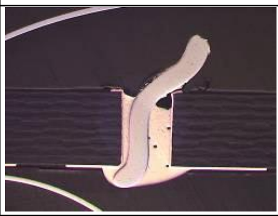
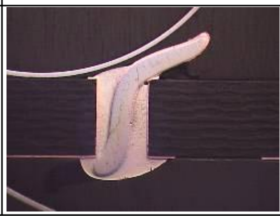
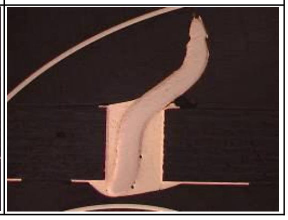
Condition	Air	N2	
Solid content of flux	14.5%	14.5%	10%
X-section image			

Figure 5 – X-section images of assembly under different conditions.

3.2.3. Dross generation

The results shown in figure 5 indicate a definite decrease in dross generation with an increase in purity of nitrogen. After six months of operation of the inert system the amount dross generated at 99.99%, 99%, 97%, were 475g/hr, 341g/hr, 240g/hr, respectively. The rate of dross generation with 99.99% nitrogen purity has been established at an average of 19%. In normal ambient atmosphere under the same soldering conditions the figure established is at 37%. We find that the dross formation has been reduced by 50%. The 100ppm (99.99%) ROL nitrogen feed results in a 30,000ppm (97%) soldering environment, which produced high quality solder joint with dramatic dross reductions. High purity nitrogen is necessary in wave soldering.

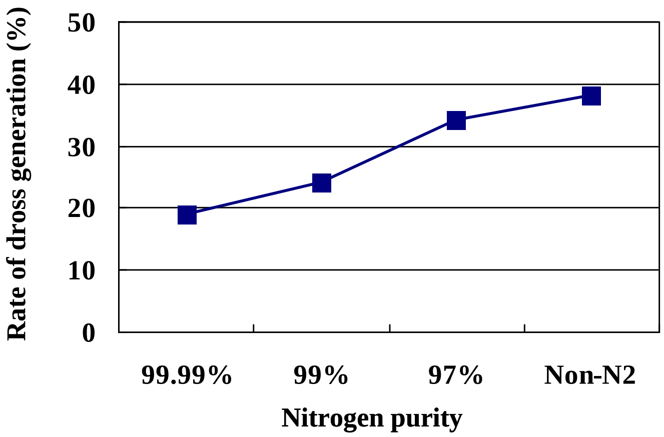


Figure 6- The rate of nitrogen generation according to nitrogen purity

3.2.4. Inter-metallic compound analysis

The microstructure at the interface between Sn-3.0Ag-0.5Cu solder and Sn-plated component was analyzed by optical and scanning electron microscopy. It was clear that the inter-metallic compound was formed at the interface, and in comparison to sample with conventional soldering operation, inert soldering should exhibit more homogeneous and uniform thickness of IMC layer. In this case, by reducing oxidation and increasing surface tension, faster wetting is obtained. As a result, the reliability of the solder joint was increased in an inert system.

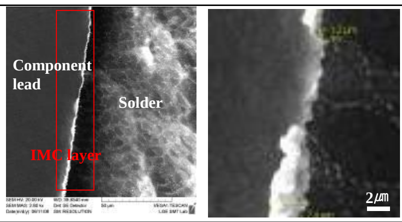
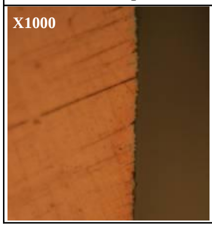
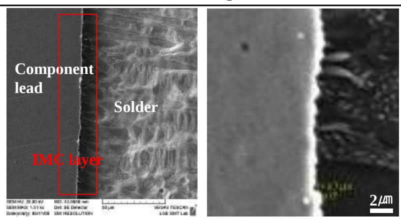
Conventional wave soldering		
OM Image	**SEM Images**	**Thickness of IMC layer**
		-IMC Layer ~ 0.7 ~3 ㎛
N_2 wave soldering		
OM Image	**SEM Images**	**Thickness of IMC layer**
		-IMC Layer ~ 1㎛

Figure 7 - The images of inter-metallic compound (IMC) thickness

Summary

This paper describes the implementation of a Nitrogen inerting retrofit system in a high volume, mixed-assembly plant where consumer products are manufactured. The conversion of existing wave soldering equipment to nitrogen was very simple to retrofit. The system based on the PSA-generated nitrogen with residual oxygen levels of 100ppm lowers dross production, helping assemblers realize a considerable operational cost savings. By reducing oxidation, wettability and reliability of the joint were improved. In on going work, we will measure the bonding strength of solder joints after thermal shock test and analyze the failure modes to evaluate the reliability of the solder joints.

Reference

[1] M.Theriault, P.Wolff, R.Passman and K.Redwitz; Proceedings of Nepcon west 1999.

[2] M.Theriault, P.Blostein; Nitrogen and soldering: Reviewing the issue of inerting.

[3]Chrys Shea, Thomas J.Chinnici and Kathleen Stillings; Effects of reduced purity nitrogen in the inert wave soldering environment, Siemens information and communication networks, Inc.

[4] Website: http://www.tequipment.net/pdf/Hakko

[5] Website: http://smt.pennnet.com/display_article

[6] Chrys Shea, Gary Shipe; Optimizing the inert soldering environment with the use of hot nitrogen knives. Nepcon West'98.

[7] M. Theriault, P Blostein; Reducing the cost of inert soldering. Circuit assembly magazine, July 1998, pages 46-52.

[8] IPC-A-610D

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Introduction

- **New packaging technologies are evolving toward smaller, thinner and more powerful devices.**

- **Despite the predicted decrease of the wave soldering applications, this soldering technique continues to be widely used.**

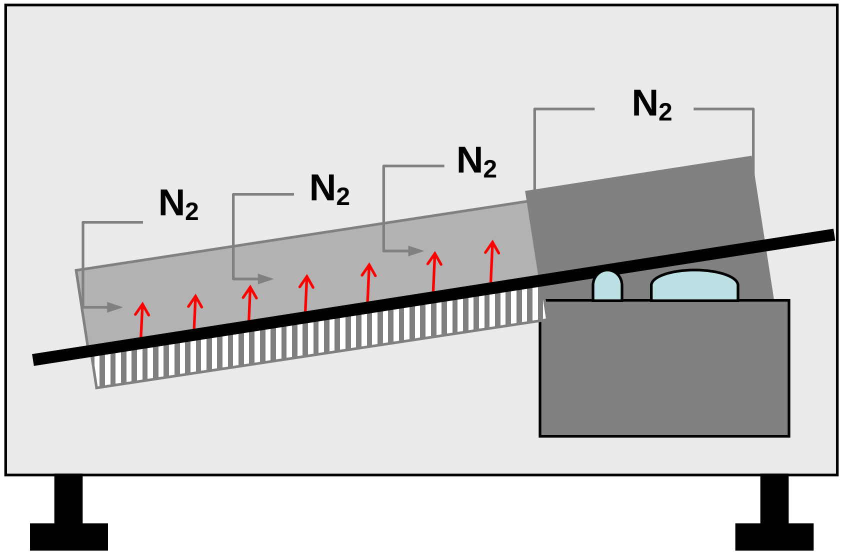
- **The use of pin-through hole components and the overall cost effectiveness of the process maintain its viability.**

- **The pressure to reduce cost and improve quality increases in electronic manufacturing, recently assemblers using wave soldering must consider innovations due to meet these challenges.**

Introduction

➢ **The inert wave soldering system**

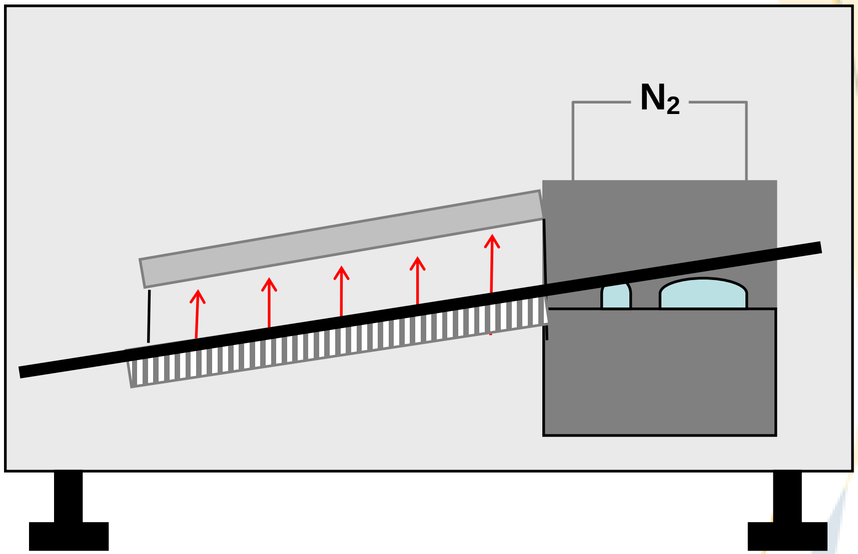
Full-tunnel inert system



• Inert tunnels are offered in different lengths and designs.

• Lower the dross generation than localized inert system

Localized inert system



• System is available that not only protect the solder pot area but also with a blanket of nitrogen gas bled over the wave.

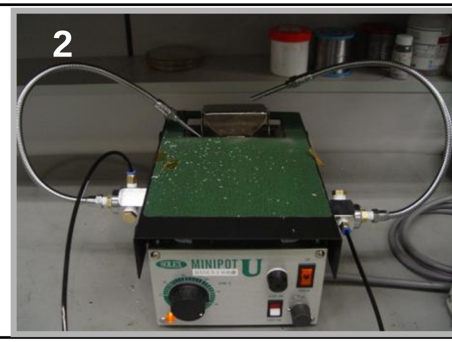
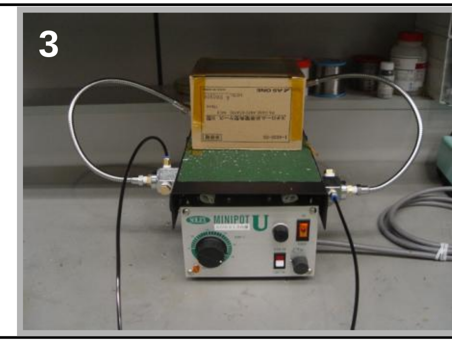
• Investment and maintenance costs are lower than full tunnel inert system

Experiment

➢ Test conditions used for analysis of the dross generation

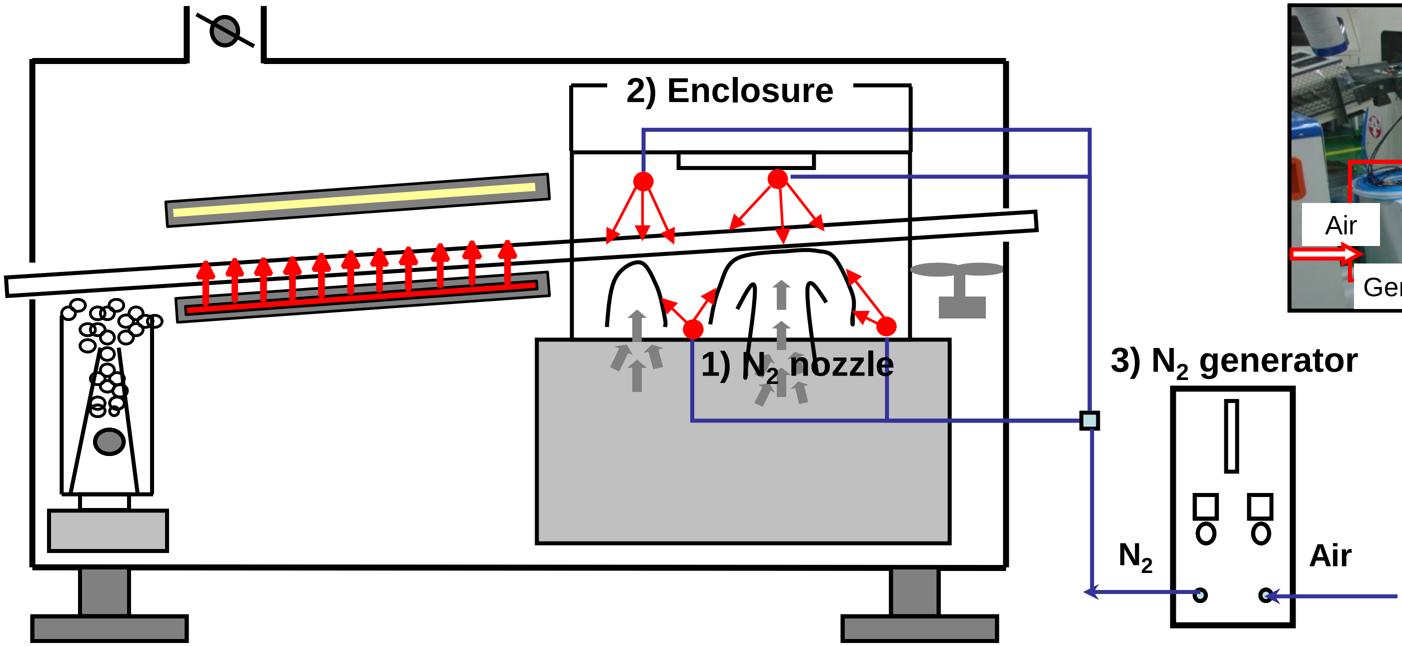
Solder pot	N_2 generator		Test time	Measuring of dross generation
Temperature	Flow rate	O_2 PPM		
260℃	3ℓ/min	20,000	360min	Each hour

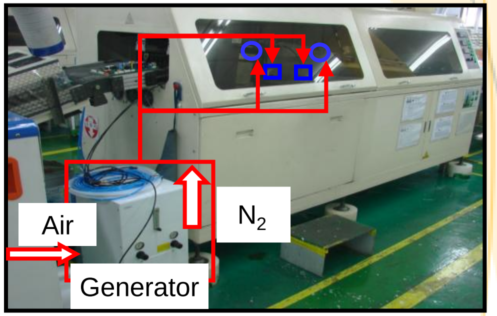
We evaluated the effect of atmosphere on the rate of dross generation under three different environmental conditions

		
Ambient atmosphere	Nitrogen atmosphere without enclosure	Nitrogen atmosphere with enclosure.

Experiment

➢ **Implementation of the localized inert system**





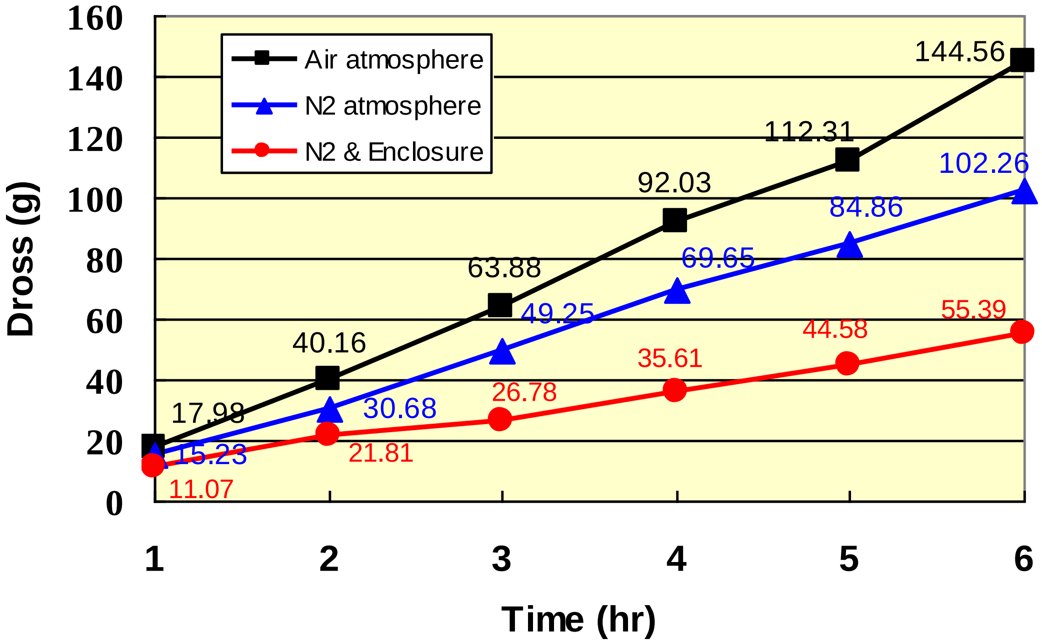
1) N_2 nozzle : 2 pipes and 2 porous filters with 10um diameter

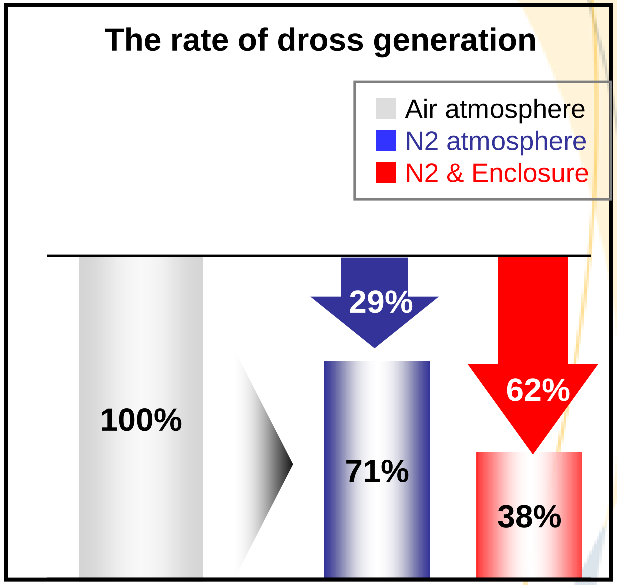
2) Enclosure : Minimize of heating energy loss and lower the temperature on soldering

3) N_2 generator : PSA-generated nitrogen system using air pressure in the assembly line

Results

➢ **The rate of dross generation under different conditions**



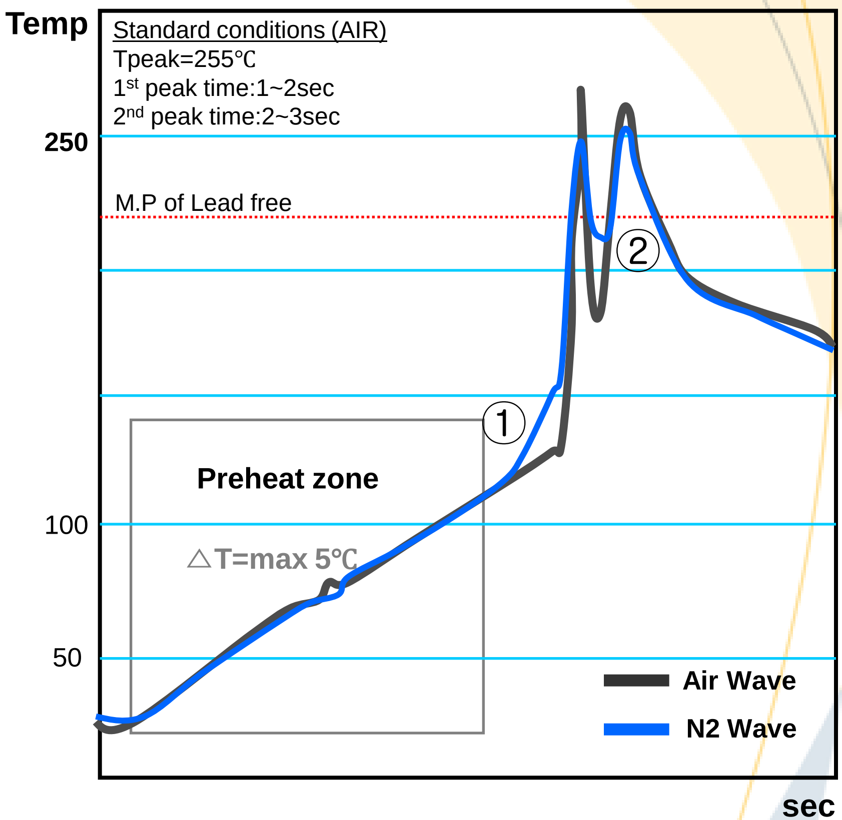


- **The use of the nitrogen largely decrease the dross generation.**
- **The more nitrogen atmosphere promote well, the more the rate of dross generation become reduced.**

Results

➢ **Process conditions**

	Air wave soldering	N2 wave soldering
Preheat Temp.	96 ℃	93 ℃
Solder pot Temp.	258 ℃	249 ℃
Dip time	3.3 sec	3.5 sec

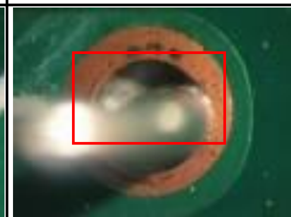
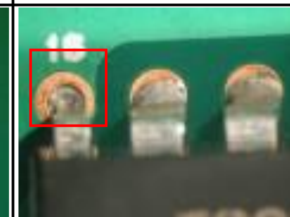
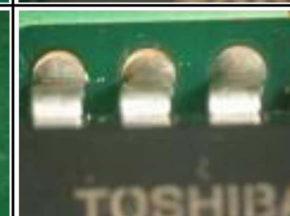


•**Heat shock was decreased by the effect of heat tunnel between pre-heater and solder pot. (①)**

•**Sn-3.0Ag-0.5Cu alloy has run successfully at 249℃ ,in comparison with conventional wave soldering, because the enclosure had influenced on minimizing of the temperature drop. (②)**

Results

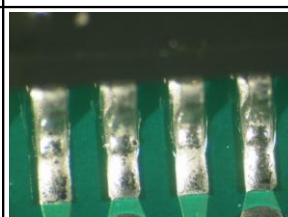
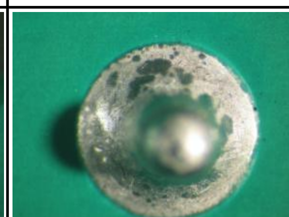
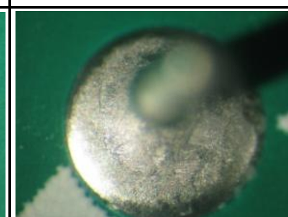
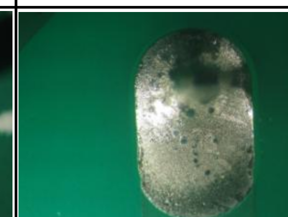
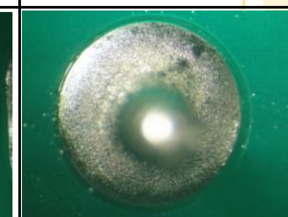
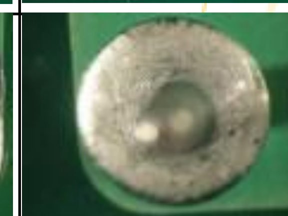
➢ **The wettability on the top side of assemblies under different conditions**

Condition	Solid contents	Part N/B				
		CE18	FUSE2	IC2	IC13	LED201
Air	14.5%					
N2	14.5%					
	10%					

- **We could observed that solder joint with conventional wave soldering where hole filling is not complete.**
- **The wettability of assembly using flux with 10% solid contents was similar with the former samples with 14.5%.**

Results

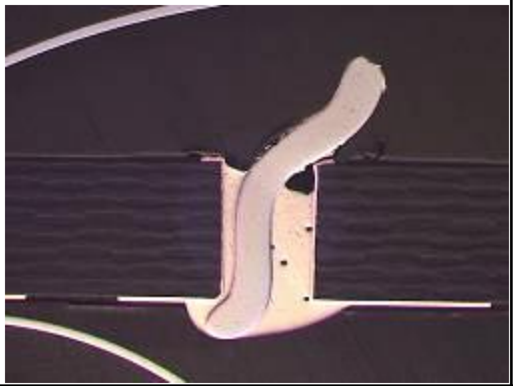
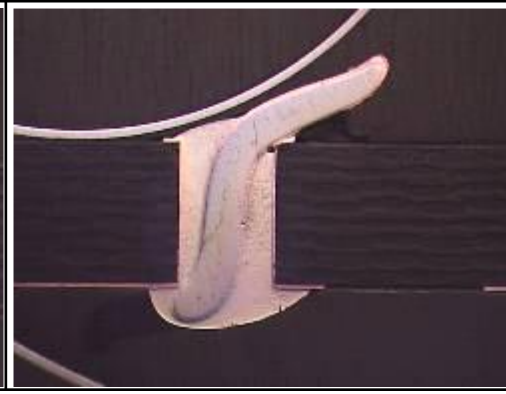
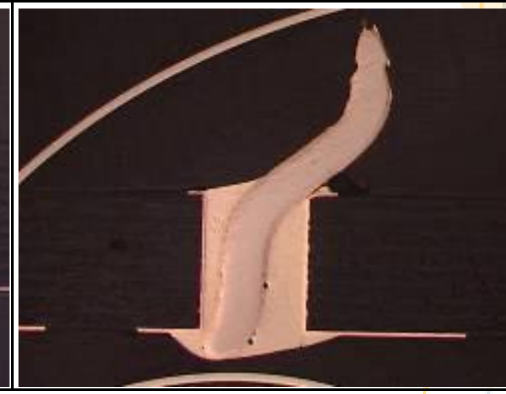
➢ **The wettability on the bottom side of assemblies under different conditions**

Condition	Solid contents	Part N/B				
		IC7	L1	CE1	IC2	Trans
Air	14.5%					
N2	14.5%					
	10%					

- **The wettability of assembly using flux with 10% solid contents was similar with the former samples with 14.5%.**

Results

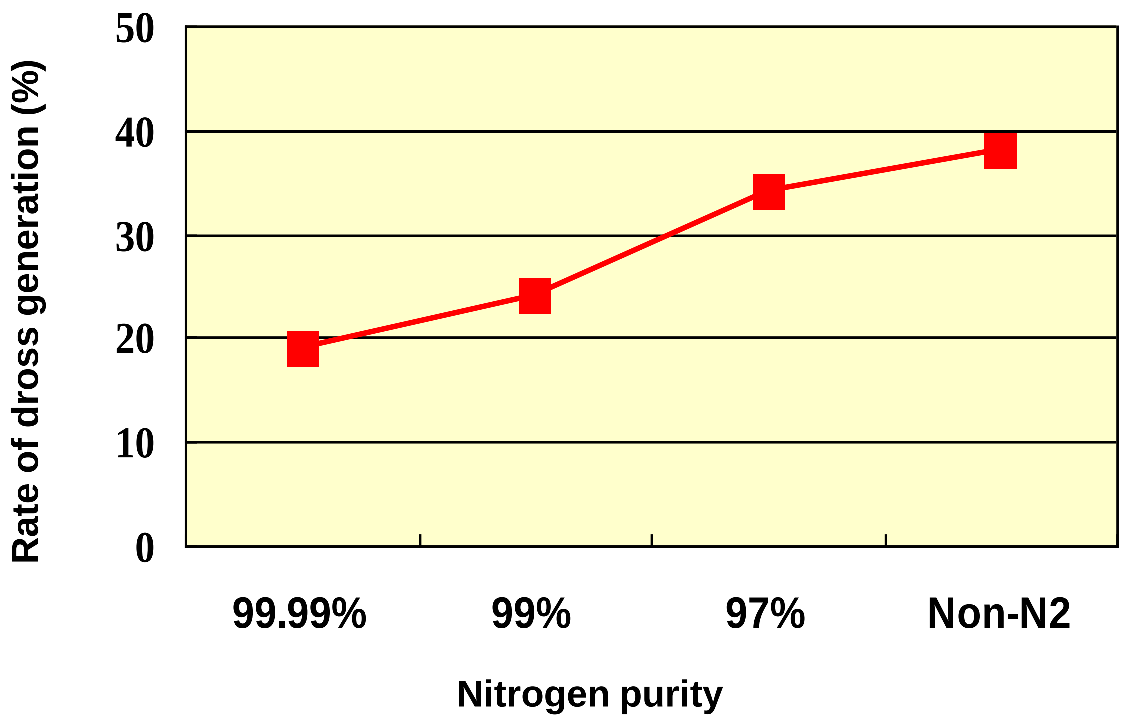
➢ **X-section images of assemblies under different conditions**

Condition	Air wave soldering	N2 wave soldering	
Solid contents	14.5%	14.5%	10%
X-section image			

- **Comparison of wetting states under conventional wave soldering, the assembly with inert soldering had better wetting characteristics.**
- **The use of nitrogen in lead-free soldering allows the use of milder fluxes although with the insufficient wetting conditions.**

Results

➢ **The rate of nitrogen generation according to nitrogen purity**

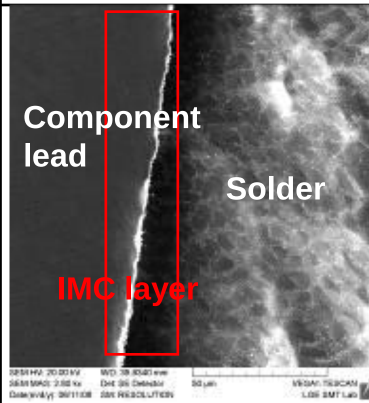
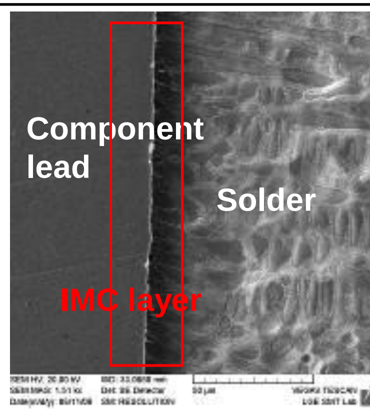
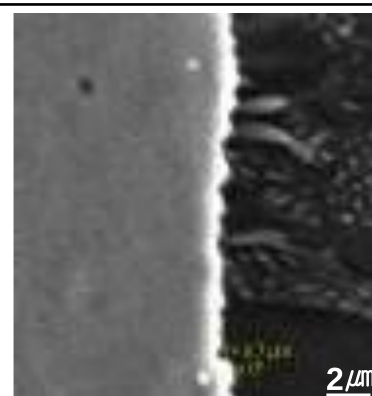


•Given that the 100ppm (99.99%) ROL nitrogen feed results in 30,000ppm (97%) soldering environment, which produced high quality solder joint with dramatic dross reductions.

•High purity nitrogen is necessary in wave soldering.

Results

- Inter-metallic compounds analysis

Conventional wave soldering		
OM Image	**SEM Images**	**Thickness of IMC layer**
	 	-IMC Layer ~ 0.7 ~3 ㎛
N_2 wave soldering		
OM Image	**SEM Images**	**Thickness of IMC layer**
	 	-IMC Layer ~ 1㎛ -Homogeneous and uniform thickness of IMC layer

Summary

- This paper describes on the implementation of inerting retrofit system at a high volume, mixed-assembly line where consumer products are manufactured.

- The conversion of existing wave soldering equipment to nitrogen was very simple to retrofit.

- The system based on the PSA-generated nitrogen with residual oxygen levels of 100ppm lowers dross production, helping assemblers realize a considerable operational cost savings under the increase of solder prices.

- By reducing oxidation, wettability and reliability of the joint were improved.