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# **Controlled Atmospheres for Soldering Processes**

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# Controlled Atmospheres for Soldering Processes

## Abstract

The global regulation of chlorofluorocarbons has challenged researchers to find alternative solvents and processes. The electronics assembly and packaging industry, being a principal user of CFCs, is making considerable progress towards eliminating these ozone-depleting solvents. Our research has focused on investigating the use of inert atmospheres for reflow soldering processes. Specifically, the effect of oxygen in solder reflow atmospheres has been studied with both traditional rosin-based and low-residue solder pastes that require no cleaning at all. The data shows the presence of air in a solder reflow atmosphere causes oxidation of tin-lead alloy systems used for electronic soldering. Studies have also shown that oxidation can occur in atmospheres with low partial pressures of oxygen. These surface oxides are predominantly Sn(II) and Sn(IV) oxides, and are known to inhibit solder wetting.

Inert soldering atmospheres, by excluding oxygen as a process variable, have proved to effect a decrease in the component-solder joint wetting angle and also to increase wetting force in wetting balance measurements. Production tests showed that a significant reduction in subjective, noncritical-type defects can be achieved when nitrogen is used in reflow soldering.<sup>1</sup> Inert atmospheres have also been demonstrated to be effective at reducing the amount of solder paste residue remaining after solder reflow. When a nitrogen atmosphere is used in conjunction with a low-residue solder paste, the amount of vehicle remaining as residue is reduced by 35%. Thus, inert atmospheres have been shown to complement traditional solder pastes as well as the new flux and vehicle chemistries found in no-clean reflow soldering processes.

## Perspective on Alternatives to Chlorofluorocarbon Cleaning

In the mid-eighties, atmosphere scientists predicted a 2% reduction in stratospheric ozone over the next fifty years. These predictions led to the adoption of the Montreal Protocol in 1987. The Protocol is an international treaty, ratified by all major producing nations, designed to protect the stratospheric ozone layer by controlling the production and consumption of ozone-depleting chemicals. The original Protocol restrictions required a 50% global reduction in fully halogenated solvents by the year 2000 and restricted 1992 halon production at 1986 levels. Among the restricted chemicals is Freon 113. Freons are used in the electronics assembly industry to remove solder paste residues and other foreign matter left behind from the solder attachment operation. In 1989, atmospheric studies indicated that there already exists a 2% global ozone reduction, and a 1.5%–3.0% reduction in the mid-latitudes over North America. This sobering data led to a reconvening of industrialized nations, and in June 1990 Parties to the Protocol voted to phase out previously controlled chemicals by the year 2000 and to control other halogenated chemicals such as 1,1,1-trichloroethane, carbon tetrachloride, and methylene chloride.<sup>2</sup> This motion required CFC users to accelerate their timetables for identifying replacement products and processes. These restrictions have created a renewed interest in the development of new electronic assembly cleaning solvents and alternative PCB manufacturing processes.

The Environmental Protection Agency (EPA)/Department of Defense (DOD)/Institute for Packaging and Interconnecting (IPC) Ad Hoc Solvents Working Group was formed to investigate the use of chlorofluorocarbon alternatives. In Phase 1 of their work, the Group set cleaning benchmarks by evaluating the ability of Freon-113 to efficiently clean mildly activated rosin solder paste formulations. The committee agreed to accept alternative solvents that performed as well as or better than the established benchmarks. The Ad Hoc Group's evaluation of alternative solvents is defined as Phase II testing, and is currently ongoing. In Phase III, alternative processes, including no cleaning at all, are being evaluated against the Phase 1 benchmark results. There are several promising chlorofluorocarbon alternatives that have been demonstrated to be as effective as CFC-113 for the cleaning

of electronic assemblies. There are advantages and disadvantages to each of these CFC solvent alternatives. Some options currently available to the industry are:

- (1) Hydrochlorofluorocarbons (HCFC 123 and HCFC 141b mixtures) serve as drop-in substitutes for traditional halogenated cleaning solvents. H-CFCs are combined with methanol and stabilized with nitromethane to afford a bipolar solvent mixture. H-CFCs have an Ozone Depletion Factor of 0.07 versus 0.7–1.0 for Freons. Incorporation of hydrogen into the Freon structure decreases the stability of the molecule, resulting in atmospheric decomposition at an altitude below the ozone layer.
- (2) Semi-aqueous cleaning methods employ terpene-based, aromatic, or hydrocarbon-based solvents, which do not deplete stratospheric ozone. They do not require the use of new solder paste chemistries, and have proved to be a superior cleaning solvent. However, their use requires properly designed cleaning equipment because the solvent mist is flammable, and the solvents are classified as volatile organic compounds (VOC) by the Occupational Health and Safety Association (OSHA).
- (3) Aqueous cleaning of water-soluble wave soldering fluxes has been demonstrated to be successful, and water-soluble solder paste formulations are currently available. Aqueous cleaning systems require saponifiers and surfactants to increase the surface tension of the liquid and achieve acceptable results. Heavy metal contamination of wastewater effluent is an environmental issue which must be addressed when using this approach.
- (4) No-clean, low-residue fluxes have been successfully employed in wave soldering processes. Research continues for the development and refinement of no-clean reflow soldering processes. Considerable cost-savings can be realized, making no-clean soldering a desirable option.

Elimination of the cleaning step in the manufacturing process can result in reduced production costs and capital expenditures related to cleaning solvents and equipment. Furthermore, environmental and safety problems associated with alternative cleaning solvents can be mitigated. The key technical hurdle which must be overcome before this process will be accepted by the Ad Hoc Group as a viable alternative to chlorofluorocarbon cleaning is to develop a process that affords benign residues on the surface of the printed circuit board. Conductive residues migrate under electrical bias, resulting in electrical failure of the assembly. The residues must also be minimized to allow for in-circuit testing of the circuit, and to afford an aesthetic final product. To overcome these hurdles, the use of controlled soldering atmospheres will likely be required.

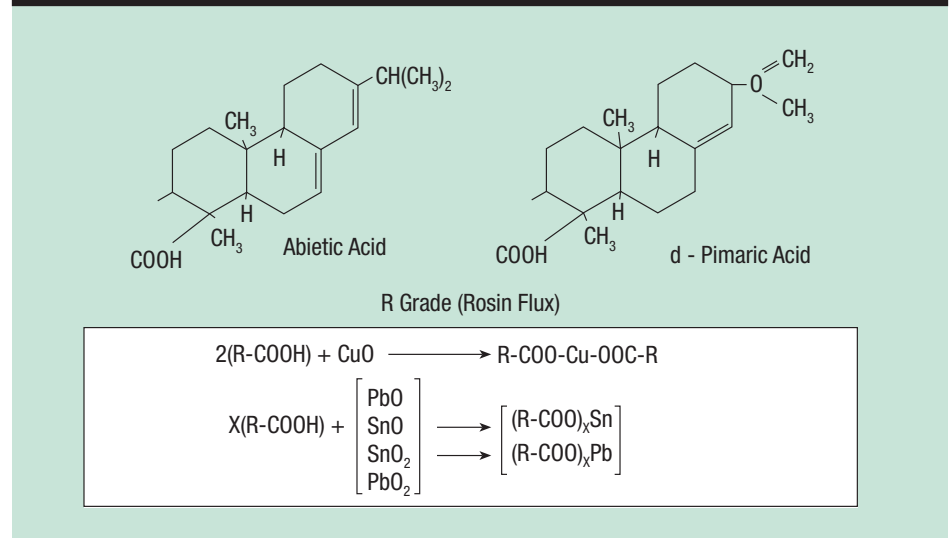
### Rosin Mildly Activated (RMA) Solder Paste Chemistry

The traditional reflow soldering process utilizes a solder paste containing 88% to 92% metal powder. The most common solder alloys used are a eutectic Sn 63-Pb 37 (m.p. 183°C), and a Sn 60-Pb 40 near-eutectic alloy (m.p. 186°C). The powdered metal alloy,

upon reflow, functions as the electrical and mechanical interconnect from IC package to the signal network. The balance of the paste composition is a mixture of rosin flux and activators. It is this nonmetal component of solder paste that requires cleaning from the circuit board surface. The solder paste activators provide primary oxide reduction to promote wetting and are typically selected from aliphatic and aromatic carboxylic acids, aliphatic amines, and amine hydrochloride salts. The rosin flux serves to provide secondary oxide reduction for wetting, to suspend the metal powder, to control the thixotropy and rheology of the formulation, to protect the metal from ambient oxidation and oxidation during reflow, and to encapsulate the post-anneal mobile ionic residues.

Rosin is obtained from pine trees and consists of several rosin acids, and over 100 nonfluxing compounds, including rosin acid esters, fatty acid esters, diterpene aldehydes and alcohols, and hydrocarbons. The major components of unmodified rosin are: abietic acid, isopimaric acid, pimaric acid, dihydroabietic acid, and dehydroabietic acid.<sup>3</sup> The reactive site for oxide reduction is the carboxyl group. The reduction of metal oxides by the acid carboxyl group results in formation of a tin abietate complex. A general fluxing reaction is shown in Figure 1. These metal soaps are insoluble in water or alcohol cleaning solutions.

Figure 1: Solder Paste Chemistry



## Low-Residue, No-Clean Solder Paste Chemistry

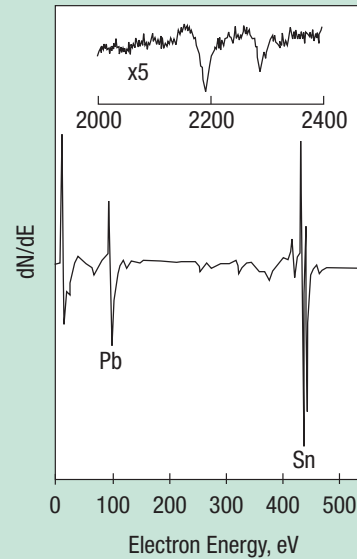
There are an increasing number of low-residue, no-clean solder pastes available to the electronics industry. The paste composition is considerably different from traditional rosin-based paste formulations. These pastes typically contain higher metal powder loading, with flux formulations blended to minimize and/or camouflage paste residues. The flux consists of selected mono- and di-carboxylic acids in concentrations ideally designed to react stoichiometrically with the solder oxides present on the alloy spheres and circuit lands. This is done to minimize free acid that can cause corrosion and reliability problems. Therefore, low-residue paste formulations offer lower fluxing activity and decreased ability to protect the solder from ambient and process oxidation. Solder reflow processes conducted in an inert, non-oxygen-containing atmosphere can afford superior results by eliminating both solder and vehicle oxidation. Aspects of solder oxidation and solder wetting were investigated to understand the fundamental benefits of inert soldering atmospheres for traditional electronic assembly and with no-clean soldering as an alternative to chlorofluorocarbon cleaning processes.

## Oxidation of Tin-Lead Solders

The oxidation and behavior of the tin-lead alloy system has been studied extensively by many researchers. In this section, some relevant studies pertaining to in situ surface oxidation of solder are presented. The research was conducted at ambient and moderate temperatures, in air and low oxygen partial pressures. These conditions are within the process envelope of electronic soldering, and the results afford an understanding of the oxidation potential of tin-lead alloys during reflow under air and inert atmospheres.

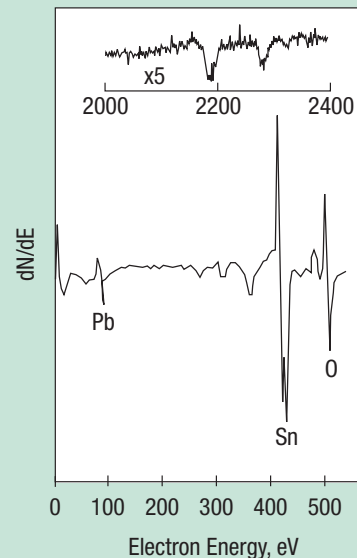
Frankenthal and Siconolfi investigated the surface composition of 60:40 tin-lead solder, and the composition of the oxide film that forms during ambient and low pressure oxidation using Auger electron spectroscopy.<sup>4</sup> The Auger electron spectra of the alloy before and after exposure to air or to oxygen at pressures as low as 1 millipascal (mPa) are shown in Figures 2 and 3, respectively. The main spectral changes observed during oxidation over this pressure range are a merger of the Pb 90/94 eV doublet into one broad peak of

Figure 2: Auger Electron Spectrum of 60:40 Sn/Pb Alloy After Oxide Sputter Etched



Frankenthal and Siconolfi AES study of tin-lead alloys

Figure 3: Auger Electron Spectrum of 60:40 Sn/Pb Alloy After Exposure to Ambient Air



Frankenthal and Siconolfi AES study of tin-lead alloys

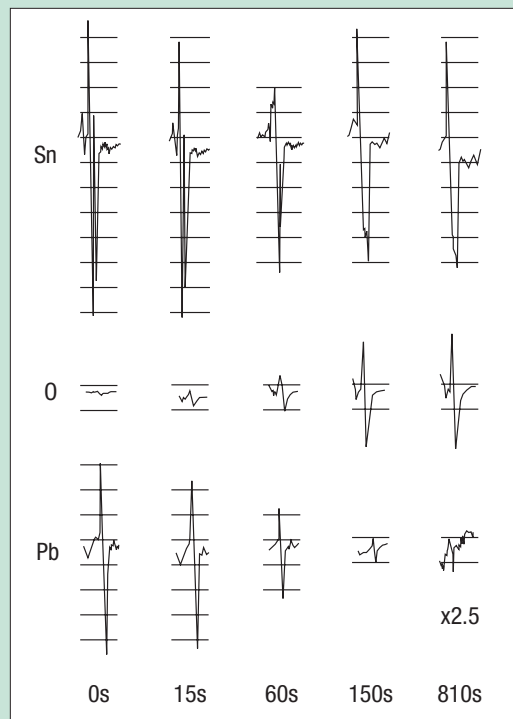
greatly diminished height, a decrease in the height of the high energy lead peaks, and a change in the height and position of the main tin peaks.

Oxidation of the individual metals shows similar changes. However, the decrease in height accompanying the merger of the 90 and 94 eV lead peaks is much less for oxidation of the metal than for oxidation of the alloy—40% and 70% decreases for the metal and alloy, respectively. From the data it is concluded that the oxide film is a mixture of tin oxide and lead oxide with the tin oxide being the predominant constituent. The Auger electron spectra do not allow the differentiation between SnO and SnO<sub>2</sub> and between PbO and PbO<sub>2</sub>.

In another experiment, the sputtered alloy surface was exposed to a residual pressure of air of less than 10<sup>-5</sup> pascal (Pa) for various periods of time. The changes in shape and height of the lead and the tin peaks as oxidation proceeded may be followed in Figure 4. It is observed that the tin peaks change shape, while the lead 90/94 eV doublet only decreases in height. Thus, at these very low pressures of oxygen, only a tin oxide forms on the surface. This oxide covers the lead in the alloy so that the lead peaks are attenuated in height.

Thermodynamically, the formation of a tin oxide is preferred, the standard free energies of formation of SnO, SnO<sub>2</sub>, PbO, and PbO<sub>2</sub> being -257, -518, -180, and -218 kJ/mol, respectively.<sup>5</sup> The differences in oxidation behavior between the very low oxygen pressure environment and the higher oxygen pressure ones are of kinetic origin.

**Figure 4: Auger Electron Spectra of 60:40 Sn/Pb Alloy After Exposure to Low Oxygen Pressures**



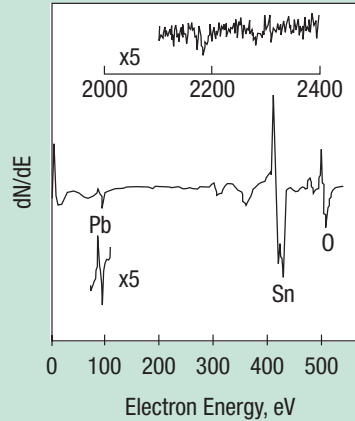
Frankenthal and Siconolfi AES study of tin-lead alloys

Oxide	$\Delta G_f^0$
SnO	-257 kJ/mol
SnO <sub>2</sub>	-518 kJ/mol
PbO	-180 kJ/mol
PbO <sub>2</sub>	-218 kJ/mol

Thermodynamic Properties of Tin-Lead Alloys  
Standard Free Energies of Oxide Formation

At the higher pressures, the rate of oxidation is sufficiently fast that the available tin is rapidly consumed, and oxidation of lead follows. At sufficiently low partial pressures of oxygen, the rate of oxidation is slower than the rate of tin diffusion from the bulk of the alloy to its surface. Thus, there is always a sufficient supply of tin for the oxidation reaction, and the lead remains in the metallic state. This interpretation was verified by Frankenthal and Siconolfi in an experiment in which the alloy was oxidized at an elevated temperature (130°C) in an oxygen partial pressure of the order of 1 Pa. At room temperature and this pressure, the rate of tin diffusion in the alloy is sufficiently slow that lead is oxidized after the tin is depleted. However, in the spectrum obtained from the specimen oxidized at 130°C, the Pb 90/94 eV doublet is clearly resolved (Figure 5), indicating that lead has not been oxidized.

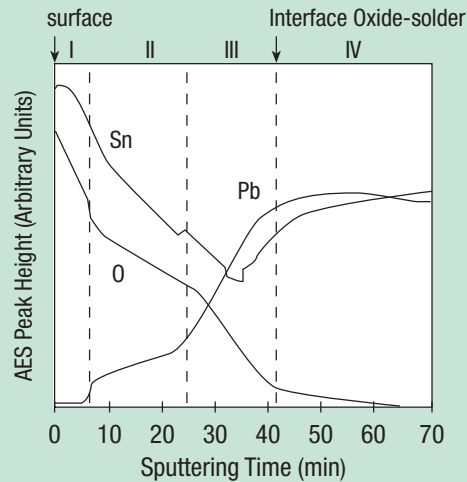
**Figure 5: Auger Electron Spectrum of 60:40 Sn/Pb Alloy Oxidized at 130°C**



Frankenthal and Siconolfi AES study of tin-lead alloys

This description was further supported by de Kluzenaar, who conducted an Auger study of the composition of oxide films on molten soft solder as a function of oxidation time.<sup>6</sup> In this experimentation, depth profiles were measured of oxide films formed at 250°C in air after 2, 4, 8, 15, 30, 60, 120, 240, and 480 minutes. Changes in the alloy surface are shown in Figure 6. de Kluzenaar compared the complete Auger spectra at various depth with those of the pure elements and pure oxides to determine the mixture of compounds present at various depths. The data describes the four regions of the oxide layer:

**Figure 6: Auger Electron Spectrum of 60:40 Sn/Pb Alloy Oxidized at 250°C for 15 minutes**



E. E. de Kluzenaar  
Surface Oxidation of Molten Soft Solder

- Region I: An outer layer of tin oxide
- Region II: A layer consisting of tin oxide and metallic lead
- Region III: A transition layer consisting of tin oxide, metallic tin and lead
- Region IV: An underlying layer of original alloy composition

The studies of Frankenthal and Siconolfi, and de Kluzenaar were conducted under conditions (time, temperature, oxygen concentration) representative of either a solder reflow process or a storage environment. In general, it has been shown that oxidation of solder can occur in air and low oxygen concentrations, and that the formation of tin oxide is preferred if the diffusion time for Sn is short compared to the rate of oxidation.

## Wetting Theory

Wetting is a surface phenomenon in which surface energy is an important consideration. The surface tension of the liquid and the tension of the interface between the solid and liquid metal determine whether or not the solid will be wetted. The free energy of a surface is expressed in units of work, ergs/cm<sup>2</sup>; thus surface energy and surface tension are used interchangeably.

The wetting of a solid surface by a liquid is determined by the surface tension,  $\gamma$ . This can be derived thermodynamically from the change in the Gibbs free energy, (G), of a system, when the surface area, (A), is varied:

For a system at constant temperature (T), and pressure (P),

$$\gamma = \left( \frac{\delta G}{\delta A} \right)_{P, T, n}$$

In the case of a liquid droplet on a flat surface, three tensions describe the system:

$\gamma_l$  = surface tension of the liquid;

$\gamma_s$  = surface tension of the solid;

$\gamma_{ls}$  = surface tension of the liquid-solid interface;

$\theta$  = angle between surface and liquid tangential line

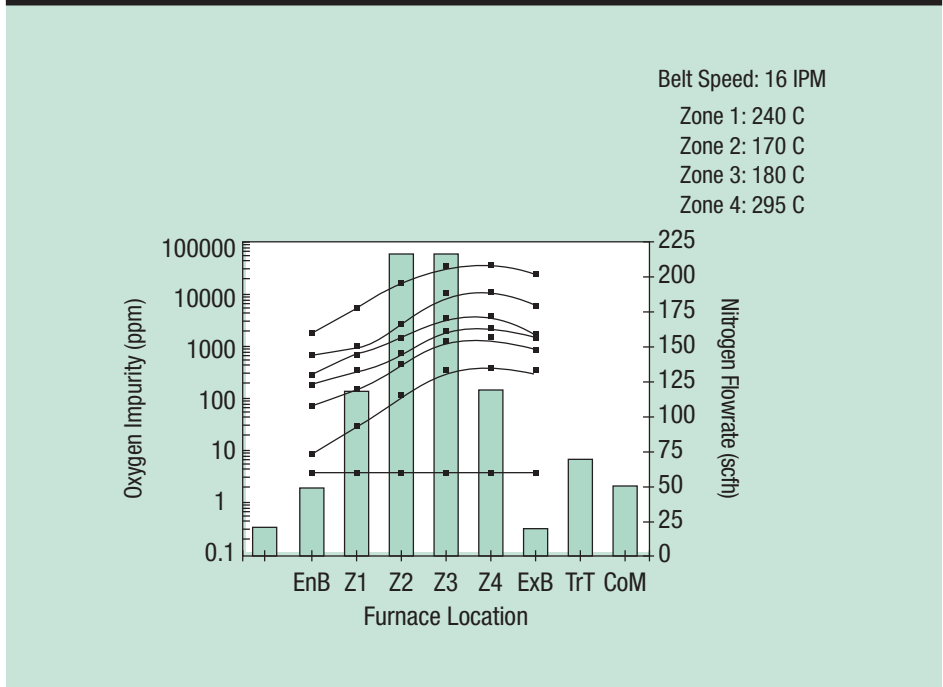
The condition for equilibrium is minimum total free energy, and a negative G results in wetting. Thus,

$$-\left( \frac{\delta G}{\delta A} \right)_{P, T, n} = \gamma_s - (\gamma_{ls} + \gamma_l \cos\theta)$$

Therefore for wetting to occur;

$$\gamma_s - (\gamma_{ls} + \gamma_l \cos\theta) > 0 \quad \text{or} \quad \gamma_s > \gamma_{ls} + \gamma_l \cos\theta$$

**Figure 7: Oxygen Impurity Mapping Oxygen Profiles From 4 ppm to 41000 ppm**



The surface tensions of oxides are distinctly lower than the values for corresponding metals.<sup>7</sup> From the theory, it is impossible to wet the surface of a solid metal when it is oxidized. To raise the coefficient of wetting, it is necessary to increase the surface tension of the liquid-solid interface by removing the oxides with chemical fluxes and by preventing reoxidation of molten metal after the oxide reduction chemistry.

## Effects of Inert Gas Soldering on Solder Wetting

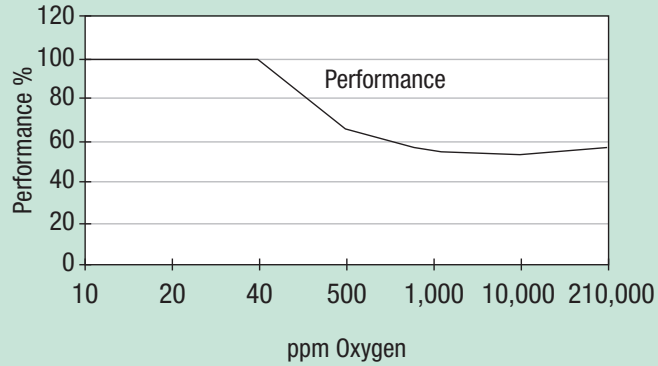
In electronics assembly, solder paste is melted in a low temperature “reflow” process over a four- to seven-minute period. The peak temperature is typically around 215°C, and the time during which the tin-lead solder is liquidus ranges from 30 seconds to ninety seconds. The research reviewed indicates that when reflow soldering is carried out in air, the oxygen in the air reacts with both the molten and solid solder to form predominantly tin (II) and tin (IV) metal oxides. These oxides hinder the solder reflow process by decreasing the wetting force of the molten solder and increasing its viscosity, thereby decreasing solder affinity between component leads and solder coated lands.

Several oxygen-containing nitrogen reflow atmospheres were evaluated to study the effect of residual oxygen on solder fillet-component wetting angle. In a separate study, the effects of oxygen concentration on solder-component wetting force were evaluated. Figure 7 illustrates the oxygen profiles with respect to temperature established in an infrared reflow furnace for this study. Measurements of the wetting angle between the solidified solder and ceramic chip capacitors were taken from cross sections of components. The measurements showed a favorable correlation between oxygen concentration in the reflow atmosphere and the solder fillet-land wetting angle. The qualification guidelines were taken from Lea.<sup>8</sup>

Oxygen Level	Wetting Angle	Qualification
4 ppm	20 degrees	excellent
400 ppm	20 degrees	excellent
1000 ppm	20 degrees	excellent
2000 ppm	27 degrees	very good
4000 ppm	35 degrees	good
10,000 ppm	>35 degrees	good
41,000 ppm	36 degrees	good

Preliminary results from wetting balance measurement performed under the controlled atmosphere conditions of a glove-box apparatus indicate that atmospheres containing low oxygen levels improved wetting force, wetting time, and the standard deviation between measurements. For an RMA assembly flux, wetting time increased by 50%, and wetting force increased by 11% in a 7 ppm O<sub>2</sub> nitrogen atmosphere versus air. For a low solids assembly flux, wetting performance drops with oxygen impurities greater than 40 ppm.<sup>9</sup> Figure 8 illustrates the wettability performance versus oxygen concentration of a copper test coupon. The test was performed using a GEC Meniscograph which measures the interfacial force between molten solder and the test specimen to be soldered.

**Figure 8: Atmosphere Effects on Copper Wettability Wetting Performance**

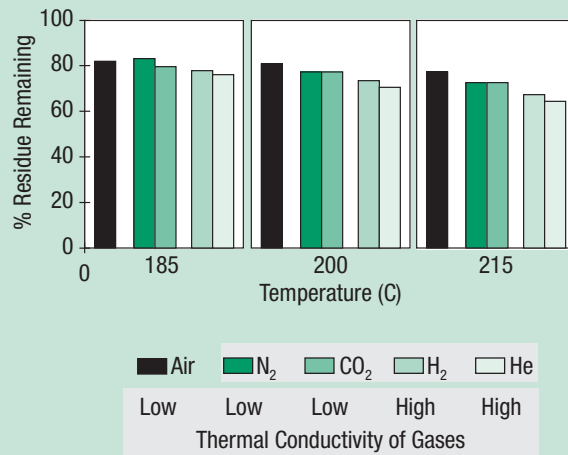


**Effects of Inert Gas Soldering on Solder Pastes and Paste Residues**

Apart from the improved wettability achieved with nitrogen and inert reflow atmospheres, there are additional benefits to be realized. The use of an inert atmosphere can effect a more efficient volatilization of solder paste vehicles. In addition, the paste residues that are left behind from the reflow process are not degraded by oxidation at soldering temperatures and prove to be easier to clean. Oxidation of the rosin during heating involves the conjugated double bonds of the abietic acid system. The reaction produces a combination of peroxides, hydroxy and keto compounds. The oxidized rosin acid is considerably less soluble in cleaning solvents than the original rosin, and appears as one cause of white residues on the surface of the circuit board.<sup>3</sup>

The behavior of commercially available formulations of both rosin based-mildly activated (RMA) solder paste and low-residue, no-clean solder paste was studied under air, nitrogen, and hydrogen, carbon dioxide, and helium reflow atmospheres. These solder pastes were not formulated for any specific reflow atmosphere. The analytical techniques used include thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC). TGA records the changes in weight percent of a sample as a function of temperature and time. This analytical technique is useful for determining the temperature at which solder paste vehicles are volatilized and the amount of paste residue remaining after reflow. (In this evaluation, the term vehicle will be used, in a generic sense, to describe nonmetallic components of solder paste.) In the TGA experi-

**Figure 9: Reflow Atmosphere Effects on RMA Solder Paste Volatiles**



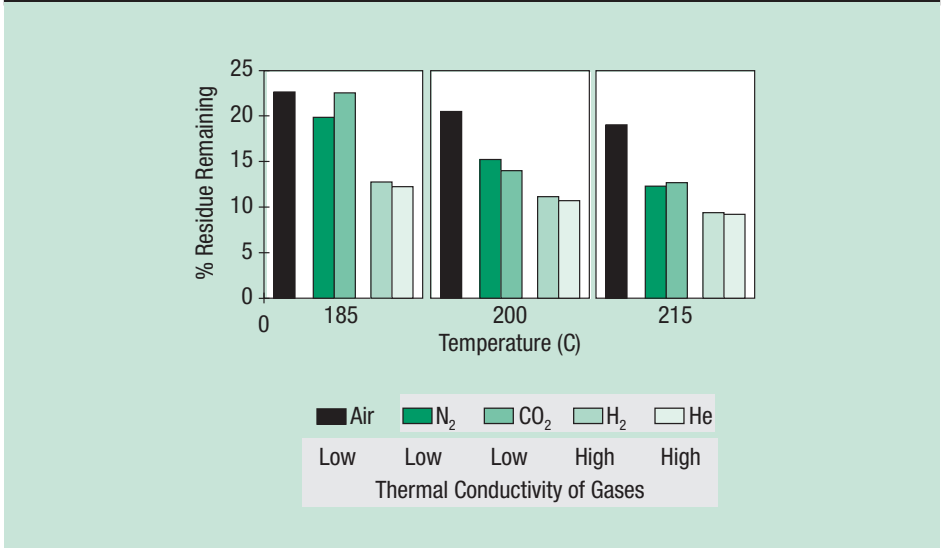
ments, the paste samples were heated from ambient to 600°C at a rate of 10 degrees C per minute.

The measure of atmosphere effects on solder paste vehicles is diminished when using solder paste in a TGA experiment since nearly 90% of the sample is nonvolatile metal alloy and not vehicle. Consequently, the percent metal content was factored from the original weight percent values to evaluate the effects of the various atmospheres on the paste vehicles only. The resulting thermograms quantify the percentage of solder paste vehicle that can be expected to remain as residue on the circuit board when processed under the various reflow atmospheres studied.

Figures 9 and 10 represent the data collected in the TGA analysis of RMA and low-residue solder pastes at 185°C—near the liquidus temperature, 200°C, and 215°C—near the peak solder reflow temperature. The data showed that 77.8% of the vehicle remained as a residue to be cleaned when using an RMA solder paste reflowed at 215°C in air. The use of nitrogen as an inert atmosphere afforded a 5.3% reduction in residue, and when the RMA paste was evaluated under a hydrogen atmosphere, 12.6% less residue was observed. The atmosphere effects were more pronounced when evaluating a low-residue solder paste formulation. In this study, 19.2% of the paste vehicle remained when reflowed under an air atmosphere at 215°C. This represented a fourfold decrease in residue versus the RMA solder paste/air trials. By eliminating oxygen from the reflow atmosphere, a 35% decrease in residue remaining was afforded with either the nitrogen and carbon dioxide atmospheres. TGA trials using hydrogen and helium atmospheres resulted in about 50% less residue. The comparison of the H<sub>2</sub> and He trials indicated that hydrogenation of the paste vehicle leading to an increase in volatility does not occur.

Two factors, heat transfer ability of the reflow atmosphere and solder paste residue oxidation, contribute to the mechanism that gives rise to these observations. The thermal conductivities of these atmospheres are listed in the following table<sup>10</sup> relative to air, and suggest that hydrogen and helium are more efficient heat transfer mediums. This efficient heat transfer results in an enhancement of the volatilization of solder paste nonmetals.

**Figure 10: Reflow Atmosphere Effects on Low-Residue Solder Paste Volatiles**



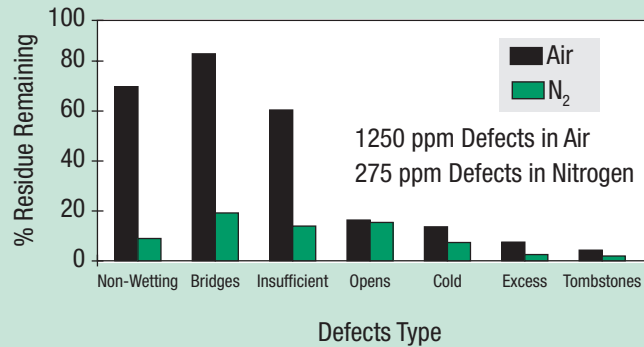
Soldering Atmosphere	Thermal Conductivity
Air	1.00
Nitrogen	0.99
Carbon Dioxide	0.62
Hydrogen	6.90
Helium	5.84

Hydrogen, or nitrogen/hydrogen forming gas blends have been employed as reducing atmospheres in high temperature soldering and brazing applications. However, thermodynamic calculations show that hydrogen is not reducing to the solder oxides in the temperature regime of the solder reflow process.<sup>11</sup> Experimental data supporting these thermodynamic calculations have been presented by Oates and Todd.<sup>12</sup> Their results indicate that the onset of reduction of metal oxides by molecular hydrogen begins at 138°C for Cu (II) oxides, 144°C for Cu (I) oxides, 319°C for Pb (II) oxides, and 400°C for Sn (IV) oxides. Therefore, hydrogen functions as an inert, high heat transfer fluid at typical circuit board reflow temperatures.

Solder paste and rosin samples were evaluated using differential scanning calorimetry (DSC) to study paste residues and the adverse effect of oxidation on vehicle volatilization. DSC records heat energy lost or gained as a consequence of endothermic or exothermic reactions occurring in the sample. Physical processes that are endothermic include solid to liquid and liquid to gas phase changes. Oxidation is an exothermic process for nearly all organic reactions. DSC thermograms of both RMA and low-residue solder pastes showed exotherms within the temperature regime of electronic soldering, indicating residue oxidation. At elevated temperatures, a significant exotherm was observed. Exotherms were not observed in thermograms acquired using nitrogen and hydrogen atmospheres. DSC data from Hwang<sup>13</sup> also clearly indicated the oxidation of rosin in air versus nitrogen. These studies show that oxidation of organic components of solder paste formulations can contribute to larger amounts of residue left on the substrate after reflow.

There are some obvious advantages to minimizing the amount of residue left on the circuit board after solder reflow. For manufacturers requiring that a cleaning step be performed, there is less residue to be cleaned. When using a no-clean solder paste formulation, the reduction of paste residues can result in a more cosmetically appealing product. Also, test probes remain free of tacky residue, resulting in more efficient in-circuit testing. In general, the paste residue remaining after the reflow process can be minimized by maintaining a minimum heat exposure and by conducting reflow in an inert atmosphere.<sup>13</sup> Solder pastes which are formulated with vehicle chemistries that complement the effects of the inert atmospheres can result in no-clean, no-residue soldering processes.

**Figure 11: Controlled Atmosphere Effect on Solder Defect Rates—Air Versus Nitrogen**



### Atmosphere Effects on Solder Defect Rates

Several test programs have been conducted at customer sites to demonstrate the advantages of using nitrogen for IR solder reflow. Customers found that the most significant benefit of nitrogen atmospheres is the reduction of soldering defects. Long-term evaluations of nitrogen reflow atmospheres at Xetel Corporation (Austin, Texas) showed a reduction of greater than 75% in overall soldering defects resulting in a savings of over \$20,000 per month in rework labor costs.<sup>1</sup>

Xetel was most concerned with decreasing defects due to solder nonwetting. This type of defect was of particular importance to their process engineers because each of their inspectors had to subjectively determine what qualified as a nonwetting defect. Test-detectable defects such as solder bridges and opens were also recorded. The consistent identification and correction of these defects were major criteria in the atmosphere evaluation.

Figure 11 shows the defect data acquired over a two-month period. Air and nitrogen reflow atmospheres were alternated for two-week intervals in the IR furnace during normal production schedules. The circuit boards were Type I and Type II boards of medium complexity, with each board averaging approximately 200 solder joints. Boards from many different production lots were processed in each atmosphere. More than 6,700 boards were run in air (nearly 1.5 MM solder joints) and more than 12,700 were run in nitrogen (over 2.5 MM solder joints).

The overall solder defect level for the IR operation fell from 1,250 ppm in air to 275 ppm in nitrogen, with nonwetting defects being reduced by greater than 85%. This result is directly attributable to reflow soldering in nitrogen and the subsequent minimization of solder oxidation. The data indicate that other solder defects were also decreased significantly when assemblies were processed in nitrogen. Solder bridging was reduced by nearly 78%, and solder defects due to insufficient solder decreased 77%. The decrease of these two defect types can also be attributed to decreased solder oxidation resulting in an increase in the wettability of reflowed solder paste to component leads and circuit lands.

## Conclusions

The presence of low oxygen concentrations in soldering atmospheres causes oxidation of tin-lead alloy systems used in electronic soldering. These surface oxides are predominantly SnO and SnO<sub>2</sub>. The exclusion of oxygen by use of an inert atmosphere has a positive effect on the solder reflow process. Inert atmospheres have been demonstrated to decrease wetting angle and increase wetting force. Overall solder defect levels were reduced by more than 75% in production trials using inert soldering atmospheres. Inert atmospheres have also been demonstrated to be effective at reducing the amount of solder paste residue remaining after solder reflow by reducing flux oxidation. When a nitrogen atmosphere is used in conjunction with a low-residue solder paste, the amount of vehicle remaining as residue is reduced by 35%. Hydrogen and helium reflow atmospheres afford similar TGA thermograms, indicating that solder paste volatiles are more efficiently evolved when a high heat transfer atmosphere is employed. New flux and vehicle chemistries, ideally low in nonvolatile rosin, should complement the benefits that can be realized when reflow soldering is performed in an inert atmosphere.

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