

## **Method for the Manufacture of an Aluminum Substrate PCB and its Advantages**

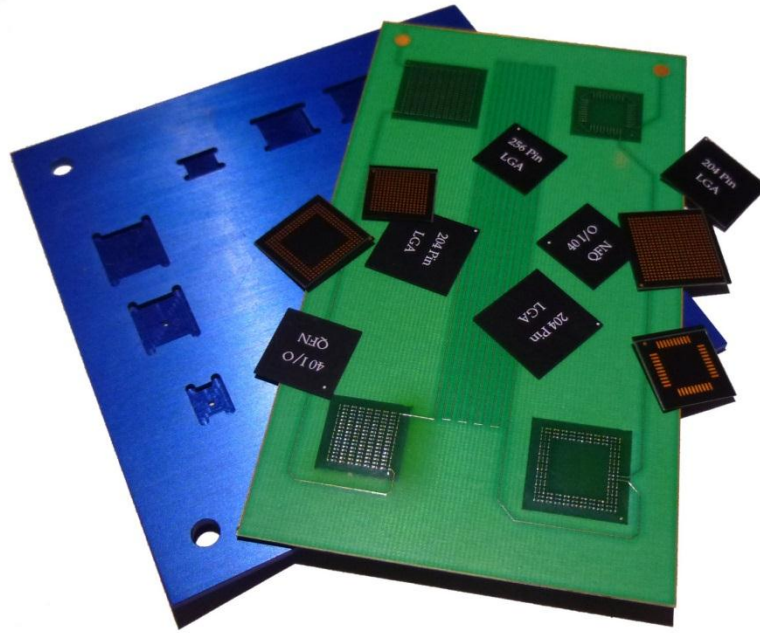
**Joseph Fjelstad**  
Verdant Electronics

### **Introduction and Background**

RoHS legislated restrictions on the materials used in electronics manufacture have imparted significant challenges on the electronics industry since their introduction in 2006. The greatest impacts have been felt by the mandated elimination of lead from electronic solder followed by the demand for the elimination of haloids from flame retardants used in traditional PCB laminates. In the years which have followed the electronics industry has been beset with a host of new challenges in its effort to comply. Failure mechanisms, both new and old, have surfaced which demand solution and the industry suppliers and manufacturing technologists have worked diligently to remedy those vexing faults through the development of a wide range of new materials and equipment for both board manufacture and assembly, along with modifications to the processes used in the manufacture and assembly of printed circuit boards.

Most of the problems which have confronted the electronics manufacturing industry have related to the solder assembly process. Lead-free solders were advertised early on as a drop-in replacement for traditional tin lead solders however field experience proved is not to be the case. The tin rich alloys along with the higher temperatures which were required for assembly cause the industry to scramble for solutions to such problems as champagne voids, poorer wetting, brittle solder joints, copper dissolution, tin whiskers, head in pillow, greater vulnerability to damage caused by explosive outgassing of absorb moisture in packages among others including cleaning of baked on fluxes following the high temperature assembly process. Lead-free solder also had spillover effects on the PCB laminate material itself as manufacturers experienced delamination and degradation of the resins used in circuit construction. One more recently encountered problem is a phenomenon referred to as pad cratering wherein resin beneath the copper land to which a component is attached is actually torn loose from the surrounding resin breaking through the copper and causing an open.

In this environment, an alternative approach to manufacturing electronic assemblies has been conceived and is presently being developed. The new method in simplest form is one which eschews the use of solder and is predicated on the use of aluminum substrates which house fully tested and burned in components to create what can be best described as a component board wherein the terminations of the components are proximately planar with the surface of the aluminum. In subsequent processing the aluminum component board is first coated with an insulating material and then circuits which interconnect the components are applied using buildup technologies. An example of a test vehicle is shown in Figure 1.



**Figure 1 Aluminum is a viable alternative to customarily used laminates when solder is not used to make interconnections between components and circuits. Aluminum is unique in that its surface can be anodized creating an insulation layer of alumina which can be colored and sealed. All components shown have a purposely selected 0.5mm contact pitch for reasons discussed in the text.**

The balance of this article will describe in more detail the processes used in the manufacture of such product and enumerate the numerous benefits that can be derived by simply reversing the manufacturing process. That is placing circuits on component boards rather than components on circuit boards.

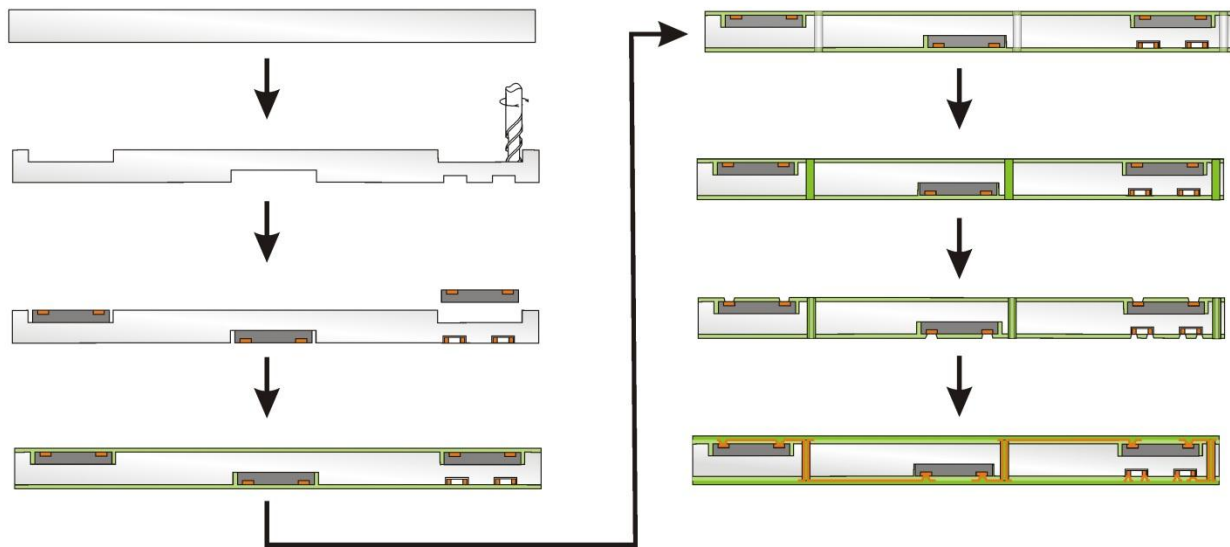
#### **Manufacturing Process for an Aluminum Circuit Assembly without the use of Solder**

What follows is a description of a new process for manufacturing a PCB which is comprised primarily of aluminum bypassing completely the soldering process in accordance with the precepts consistent the process outlined in various papers<sup>i,ii</sup>. This process is a subset of technologies which fall under the general umbrella term of SAFE an acronym which stands for either “solderless assembly for electronics” or “solder alloy free electronics”. SAFE manufacturing is relatively simple compared to traditional circuits and the cost should prove significantly lower.

In brief, the process is carried out by place electrically tested and burned in components onto an aluminum carrier plate/housing and established methods used for the manufacture of HDI buildup boards are carried out on the surface of the component bearing aluminum assembly with interconnection being made between components by copper plated circuits and vias.

Aluminum is an attractive choice as a substrate owing to a combination of different properties which include a coefficient of thermal expansion which is reasonably proximate to that of copper, dimensional stability which exceeds that of FR4, relative lightweight, good thermal spreading capability and low cost (aluminum is roughly \$2 per kilogram while FR4 in quantities of 2000 kilograms coming out of China runs around \$6 per kilogram<sup>iii</sup>). It is also worth noting that aluminum comprises 8.3% of the earth’s crust and is highly recycleable positioning it among the most sustainable of all circuit substrate choices.

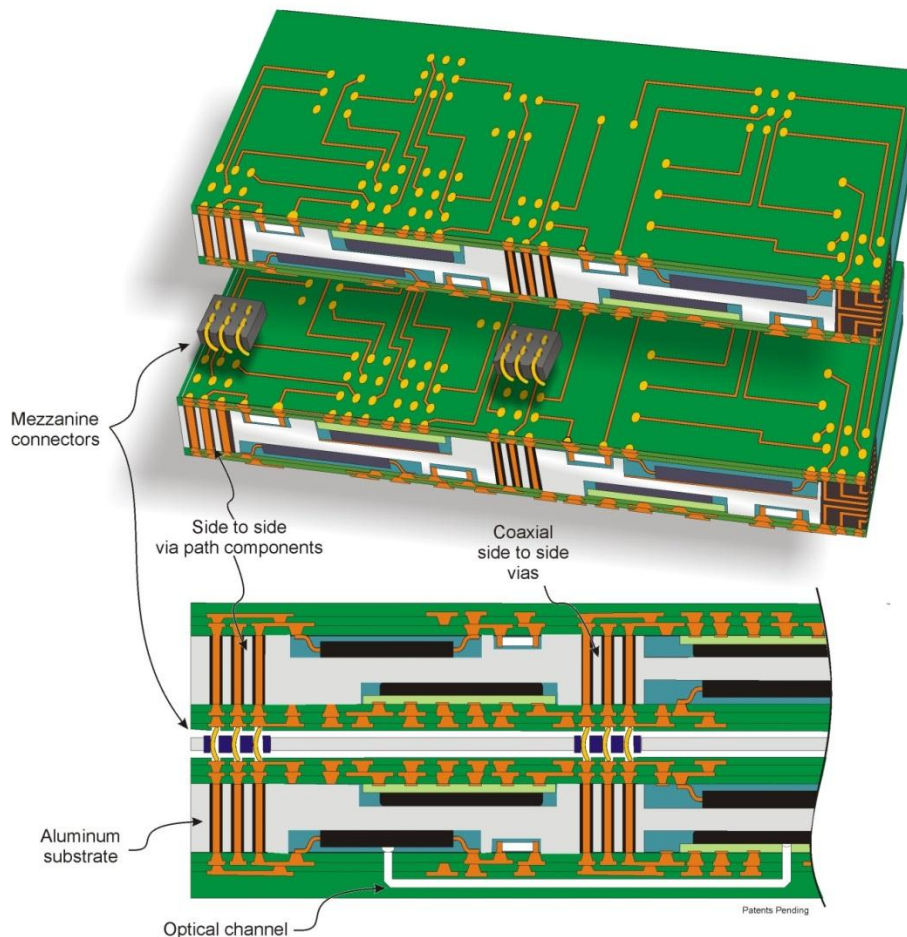
Turning to the steps in the process, a sheet of is prepared with cavities wherein components will be placed. The aluminum can be desirably anodized or coated with an insulating material which makes the surfaces nonconductive. Because the substrate is solid metal the cavities can be created by any of a number of steps including chemical machining, mechanical machining, laser cutting and punching. The substrate could also be embossed or cast with the cavities if desired. The cavities which receive the components are ideally formed such that the depths will match the components’ height so that when components are placed into their assigned cavities with leads facing up, the lead terminations will be flush with the surface. While the use of bare die is possible, the IC components to be used are ideally packaged (CSPs are very well suited), Packaged devices are preferred because packaged IC devices are much more easily tested and burned in and because they have standardized lead patterns and physical outlines making the design process simpler, especially if a single lead pitch is used for all components (e.g., 0.5mm). Additionally, nearly all packaged components use copper as the base metal for interconnections which is advantageous for more than just that one reason alone, as will be shown.



**Figure 2. The basic process steps for double sided aluminum circuit assembled and interconnected without solder are illustrated. From the top left, aluminum material is provisioned with cavities by milling (as illustrated), etching or embossing, wherein components are placed and then coated with an insulating material. Holes are drilled and then filled with insulating material, the redrilled. At the same time vias are formed to access component terminations. The circuit pattern is then plated and circuits sealed after last layer is complete leaving open feature required for interconnection and power (open features not illustrated). The metal core can serve both as heat spreader and power or ground layer.**

After the components are placed and affixed permanently on one or both sides of the aluminum carrier plate, layers of insulation are applied to one or both surfaces of the metal sheet covering the components. At this point, the assembly can be processed as if it were a standard rigid printed circuit with high density build-up layers on one or both sides, using lasers to drill holes down to access component terminations and commonly practiced plating and imaging processes to create the circuits. A difference is that a fill step with an insulating material may be required if through holes have exposed metal. However, if coated with epoxy, this may not be necessary. One caveat for those circuit manufacturers considering exploring processing circuits of this type is that if the aluminum is untreated, the edges need to be sealed to prevent contamination of subsequent processing chemistries that will be used in manufacture. While additional processing steps can be performed if desired and or required this assembly could be in some applications considered complete. The overall number of processing steps is obviously significantly reduced from those required for traditional processing of printed circuit assemblies. A simple example of a test vehicle is shown in Figure 1.

The longer range potential of aluminum structures is impressive and limited more by my imagination than technology. One such example is illustrated in Figure 3.



**Figure 3 Solderless aluminum substrates can potentially be stacked and interconnected and even “bolted” together using mezzanine connectors to create “aluminum brick” which might simultaneously solve a range of problems related to both performance by creating shortest path routing and the thermal challenges which often accompanies higher performance. Note that optical interconnection opportunities also exist as optical ports are commonly provided on the edges and/or the bottom of optical devices making provision of stable optical channels.**

### Advantages of Aluminum Circuit Assemblies

Beyond the structures just described, there are a striking number of advantages to the design and manufacture of electronic assemblies that do not use solder to make interconnections, especially those made with aluminum. However, the advantages of products manufactured using SAFE techniques also circumscribe the full range of benefits normally considered desirable for any electrical or electronic product. Following are brief discussions of those benefits:

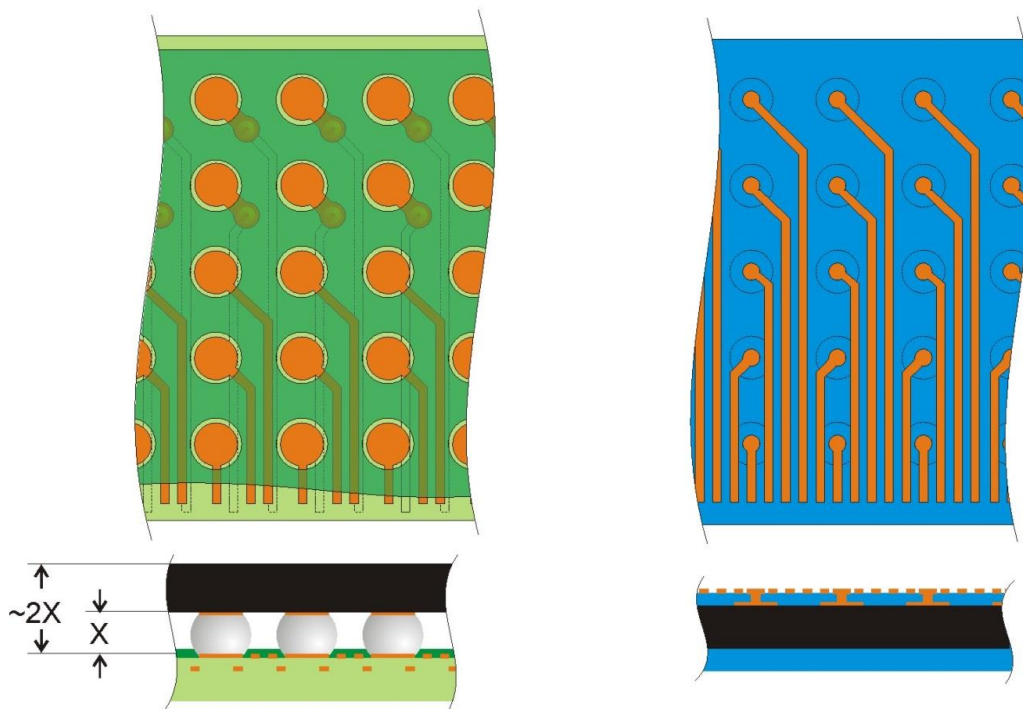
*Economic Benefits* – In a highly cost competitive global economy, the cost of manufacturing is always a high order concern. Looking first at material, the reader is asked to note again that the primary material of interest in this discussion has been aluminum. Aluminum is the 3<sup>rd</sup> most abundant material on our planet (oxygen and silicon are 1<sup>st</sup> and 2<sup>nd</sup> respectively), and as was mentioned earlier, it comprises 8.3% of the earth’s crust. Because of its commodity status, aluminum is sold by weight regardless of thickness and it is less expensive per unit volume than composite materials. Though aluminum is admittedly denser than FR-4 laminate, (2.8 g/cm<sup>3</sup> aluminum versus 1.8 g/cm<sup>3</sup> for FR-4) the amount of aluminum required can be very cost competitive in the long run. In contrast, the price of polymers varies due to the volatility of the price of oil, there are advantages to being able to use a material such as aluminum the price of which is reasonably predictable because of its global abundance.

Next the number of manufacturing steps is reduced significantly reducing manufacturing cost. What should be highly evident is that the entire soldering process with its many steps and requirements is omitted. No stenciling of solder, no paste inspection, no reflow, no post-assembly cleaning, etc. There is also no need to be concerned with moisture sensitivity of components. Thus the energy and time wasting baking steps that are commonly called for in conventional processing are

obviated. Depending on the complexity of the design, as it has been estimated independently by a number of manufacturing experts, the final cost of such assemblies could be 25-35% lower than traditional methods (exclusive of the component cost). The actual savings will depend on the specifics of the design and savings may be less, however any savings in today's highly competitive global markets is both welcome and highly prized especially if the final product is not subject to intense environmental scrutiny in search of metals and materials which are proscribed by EU regulations.

Another economic benefit is that the components used do not require special finishes to maintain solderability, nor do they need special treatment to keep out moisture because they will not experience the high temperatures required for lead-free solders. The lack of a need for a finish can and should reduce the cost of the components at some point in time, however it is possible that electronic component suppliers may in the near term charge a premium to the user for *not* adding solder balls or nickel-gold finishes processes. Finally, reliability also has an economic impact as warranty payouts for failed products can quickly cut into profits while simultaneously undercutting the manufacture's reputation.

*Electrical/Electronic Benefits* – Such constructions as have been described offer several electrical/electronic benefits. For example, where connections are made to terminations on component lands, the point of interconnection can be made without benefit of a large pad, which can reduce parasitic capacitance. This also frees routing space, allowing for a potential reduction in total layer count (further reducing cost). (see Figure 4) If proper planning is used in choosing components of a common grid pitch (e.g., 0.5mm) the integrated power mesh system (IMPS) design layout approach may be employed, thus reducing layer counts while improving signal integrity. With proper preparation, the aluminum core can serve as power or ground as mentioned earlier. This makes it possible to provide both power and/or ground immediately adjacent to every component. Finally, the completed assembly can also be relatively easily provided with a metal plating after the assembly is complete making the entire assembly metal jacketed and thus EMI and ESD immune, as well as nearly hermetic, exclusive of those areas left open for external I/O connections.



**Figure 4** at any given lead pitch, solderless assembly methods can significantly reduce both layer count by freeing up routing space and assembly height as solder often makes up half of the overall height of a mount package.

*Thermal Benefits* – When aluminum is used as carrier it becomes by default a heat spreader which is integral part of the assembly. This allows the designer to address thermal concerns early. Given the inverse relationship between long-term reliability and the number, temperature extremes and durations of the thermal exposures a component experiences, having a built-in thermal management solution is an intrinsic value-added feature.

*Mechanical Performance Improvements* – Since the components are encapsulated in the aluminum assembly and thus part of an integrated whole, they are fundamentally immune to the effects of shock and vibration.

The CTE (coefficient of thermal expansion) of aluminum and copper are relatively close (22ppm/C vs. 18ppm/C), which reduces the potential stress on interconnections; moreover, the materials expand predictably in all directions, whereas reinforced laminates have CTEs that may vary in X, Y and Z dimensions, sometimes quite appreciably (e.g., X ~20ppm/C, Y ~23ppm/C and Z ~80ppm/C).

The microvias which are used to make connections to components and to any additional build-up layers have been proven superior to solder joints, and (though there was recent report of microvias also being damaged by the lead free soldering process). Moreover, there is possibility in some cases to use relatively thin aluminum base material, which could allow the developer to bypass the final etching process and permanently form the final assembly into the desired shape, opening up new possibilities to the clever product designer.

*Design Security* – The methods suggested offer a design security benefit that may not be immediately obvious to many product developers. The methods employed obscure the components used in fabrication, making tear-down and reverse engineering of a product much more daunting and difficult for those wishing to understand what might differentiate the product in hand with previous competitive products. This benefit extends to all kinds of products, from consumer to military. Furthermore, the assembly makes it much more difficult for unscrupulous individuals to extract and reuse components, injecting them into the supply chain as counterfeit devices<sup>iv</sup>.

*Reliability Improvement* – Improvement in reliability is largely a byproduct of various elements of the electrical, thermal and mechanical performance benefits just discussed, combined with the benefits that can be obtained by simple bypassing of a high-temperature lead-free soldering process. To this point, it is worth repeating what was mentioned earlier and that is that the soldering process is typically the largest cause of defects in assembly and that solder joints are the most common sites for failure of electronic interconnection systems.<sup>v</sup> <sup>vi</sup>Moreover, in a solderless assembly, concern over tin whiskers, a topic that has returned to prominence in recent years, is relieved. Finally, conductive anodic filaments (CAF)<sup>vii</sup>, which is the growth of conductive fibers between adjacent vias in reinforced materials and tin whiskers<sup>viii</sup> are obviated by the ability to use homogeneous, unreinforced materials and elimination of solder respectively.

*Regulatory Compliance* – The EU's RoHS legislative mandate to eliminate lead from electronics solder has proven very costly<sup>ix</sup>, however, this stricture is automatically accommodated if one eliminates solder completely. The finished structure described is basically an all-copper interconnection system. On the finished product, only the surface sites required for making electrical connection to the other system elements, such as switches, connectors and the like, need to have a contact finish. The key point is that since neither copper nor aluminum is considered a problem, both the RoHS and REACH concerns should be obviated provided the other materials selected and used in the assembly are compliant. Additionally, the material declaration process is greatly simplified. These same benefits hold true relative to the use of conflict materials which is of growing concern among increasing numbers of both governmental and non-governmental organizations (NGOs) as the structures completed as described are completely devoid of any proscribed or sanctioned materials. In short, the assemblies described allow a product to much more easily pass regulatory scrutiny.

*Environmental Friendliness* – During the last few decades, concern over the environment has moved steadily into the consciousness of government officials, business leaders and the consuming public around the world. The term *social responsibility* is also often used to describe the concern; however, the fact that the industry makes products that impact the environment at the lowest possible level has become increasingly important. With that in mind, consider an electronic structure constructed principally of a material which is desirably and easily recycled, such as aluminum. Moreover, there is the significant amount of energy that is used in traditional manufacturing in component and assembly preparation and in the soldering process, which can be saved when solder is not used. Moreover as suggested earlier additional energy savings can be found by obviating need for all of the process steps leading up to and following the soldering process.

## **Discussion**

As has been shown there are many advantages to making aluminum circuit assemblies in a manner described. That said a recurring question is often raised: “*How does one test and rework such assemblies?*” The question is perhaps best addressed with a separate question: “*If the process is executed properly and the components are not subjected to thermal extremes, why is there a need to test and rework?*” The simple fact is that most electronic assembly problems are related to the inherent weakness of the soldering process and solder joints failure remains a leading cause especially when there is shock or vibration<sup>x</sup>. Moreover, below 0.5mm lead pitch, which is where the component roadmap trends are headed, assembly yields drop off appreciably, even with multiple preassembly inspection steps implemented and/or applied. The EMS industry has come to accept the weakness of its assembly and cleaning processes even as it strives to constantly improve them, making marginal improvements through new materials and equipment and as a result has come to also expect that rework and repair are a natural part of the manufacturing process.

This acceptance carries with it what can be best described as a self-defeating ingrained attitude and results in the manufacturing having to continually carry out a process that might otherwise be made unnecessary. In short, if the components are fully tested and burned-in and the processes used are properly controlled, the final product should be high-yielding, provided the design is inherently valid and robust. The limits of reliability of future electronic products could well be better defined by IC reliability than the reliability of the circuits and plated vias that are used to interconnect them.

## Summary

Such aluminum circuit structures as have been described in this paper are simple to design and eminently possible to manufacture. They can be easily produced using well-established manufacturing infrastructure tools, equipment and processing techniques which are simply reordered to make highly useful electronic products suitable for use in everything from consumer to high-reliability automotive, military and aerospace products. The limits are likely to be defined more by the imagination of the designer than the limits of the fundamental technology which has been described.

## References

- 
- <sup>i</sup> Fjelstad, J. "Reversing the Electronic Assembly Process", *Semiconductor International*, Vol 32 No. 13 pp 24-28 December 2009
- <sup>ii</sup> Fjelstad, J "Environmentally friendly assembly of robust electronics without solder", *Circuit World*, Vol. 34 Iss: 2, pp.27 – 33 2008
- <sup>iii</sup> W. Callister and D. Rethwisch, Appendix C, *Fundamentals of Materials Science and Engineering* An integrated Approach 3<sup>rd</sup> Edition. Wiley (2007)
- <sup>iv</sup> Lowry, R., "Counterfeit Electronic Components – An Overview" *Oneida Research Services White Paper*  
(<http://www.ors-labs.com/pdf/MASH07CounterfeitDevice.pdf> )
- <sup>v</sup> Lee, D., "What Can No Longer Be Ignored In Today's Electronic Designs" SMTA Chapter Meeting Presentation, Jan 2008  
([http://www.laocsmta.org/archive/Jan\\_2008\\_Plexus\\_Presentation.pdf](http://www.laocsmta.org/archive/Jan_2008_Plexus_Presentation.pdf))
- <sup>vi</sup> Engelmaier, W., "Reliability Issues for Printed Circuit Boards in Lead-Free Soldering" SMTA Presentation Archive  
([http://www.smta.org/files/Engelmaier\\_Opening.pdf](http://www.smta.org/files/Engelmaier_Opening.pdf))
- <sup>vii</sup> Karavakis, K and Bertling, S, "Conductive Anodic Filament (CAF) - The Threat to Miniaturization of the Electronics Industry" *MEPTEC Journal*, Number 4, pp 24-27, 2004
- <sup>viii</sup> NASA Metal Whiskers Web site <http://nepp.nasa.gov/whisker/>
- <sup>ix</sup> Buonpastore, P., "Survey: RoHS Costs at Over \$32 Billion" *PC Design and Manufacturing Magazine*, April 2008  
(<http://pcdandf.com/cms/magazine/95/4572>)
- <sup>x</sup> de Maio, D. "High-frequency vibration tests of Sn-Pb & lead-free solder joints" Proceedings *IEMRC/TWI Technical Seminar: Developments in Interconnection, Assembly and Packaging*, December 2008