Aluminum: A Sustainable Substrate Alternative to FR4 in PCB Assemblies

Principles of Sustainable Production

Products are safe and ecologically sound throughout life cycle

- designed to be durable, repairable, readily recycled, compostable, or easily biodegradable;
- produced and packaged using the minimal amount of material and energy possible.

Processes are designed and operated such that:

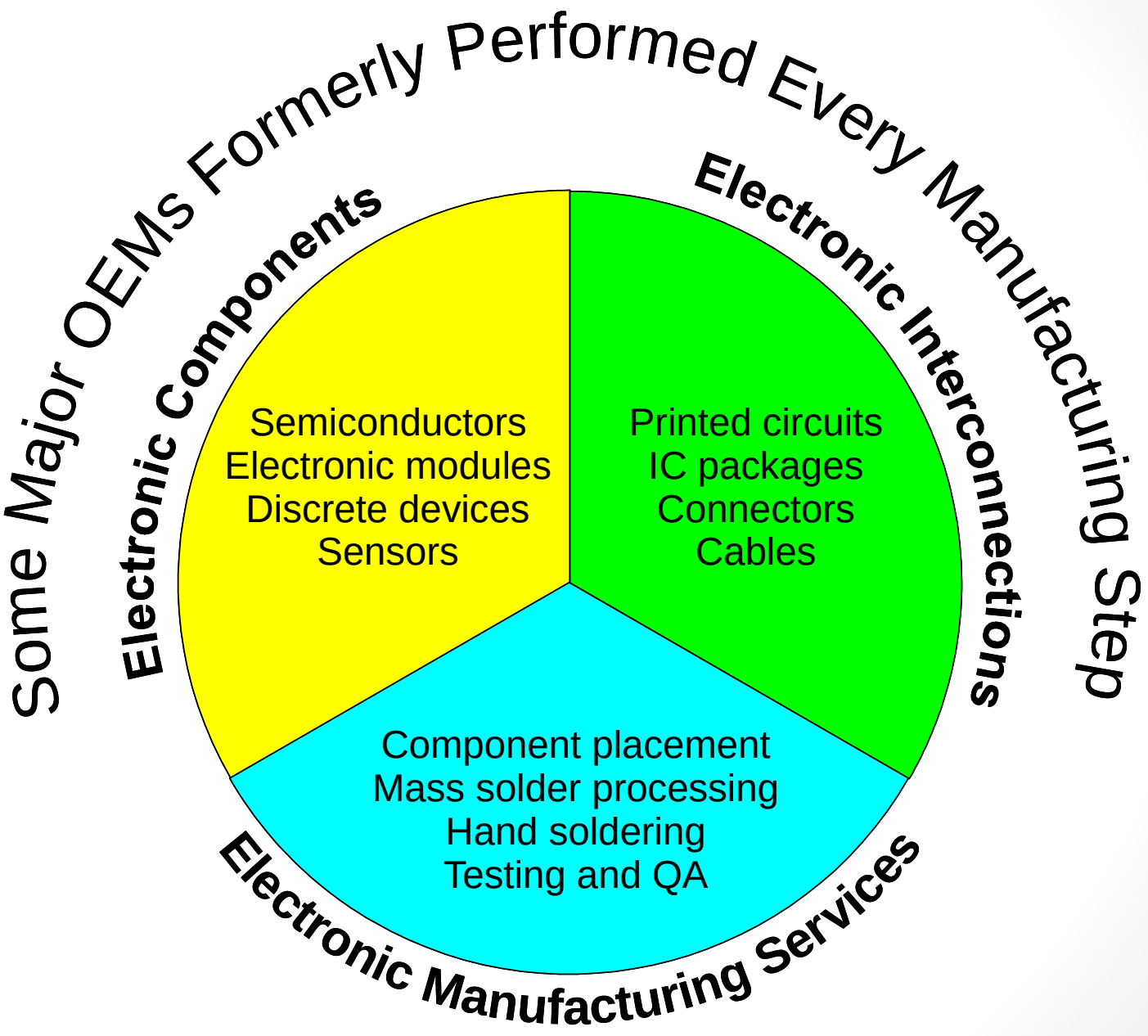
- wastes and ecologically incompatible byproducts are reduced, eliminated or recycled on-site;
- substances or physical agents and conditions that present hazards to human health or the environment are eliminated;
- energy and materials are conserved, and the forms of energy and materials used are most appropriate for the desired ends;
- work spaces are designed to minimize or eliminate chemical, ergonomic and physical hazard.

Source: Lowell Center for Sustainable Production

The Printed Circuit – Foundation of Electronics

- Electronics assemblies require substrates to support both the circuitry and the components which are interconnected thereon.
- Most substrates are composites of tailored organic resins and a reinforcing material and the most common of all is FR4 which is comprised of epoxy and glass cloth.
- The resins require petroleum products for formulation and at end of life, the accepted practice is to incinerate the assembly to recapture metals.
- While there may never be an end of oil, the price will continue to rise increasing the cost of all products which require its use.

Electronics Manufacturing Industry



Aluminum – An Attractive Alternative

- Aluminum has many attractive attributes which make it an appealing substrate alternative… It is:
  - Abundant (At 8.3 % its Earth's 3rd in abundance)
  - Low cost (~$2.00 per kilogram)
  - Good thermal conductor (~200 W/mK)
  - Relatively light weight (2.8g/cc vs 1.85 for FR4)
  - CTE approximates copper (22 vs 18 ppm/C)
  - Nontoxic/Environmentally friendly
  - It can be anodized form an alumina (Al_2O_3) skin

So what's the problem?

- Aluminum has be used in only a relatively few applications for a few compelling reasons, most notably is its high thermal conductivity which makes soldering challenging to difficult in the best of cases and nearly impossible in others.
- Good thermal conductivity increases the risk of the assembler forming cold joints on the one extreme and thermally damaging components at the other if dwells are excessive.
- Thus most designers have determined it is easier to use traditional laminates and then solve the thermal management issues associated with the assembly upon completion.
- There is however a way to employ aluminum if one is willing to think differently about the process of assembly, specifically by reversing the process and instead of placing components on circuit boards, building circuits on component boards…

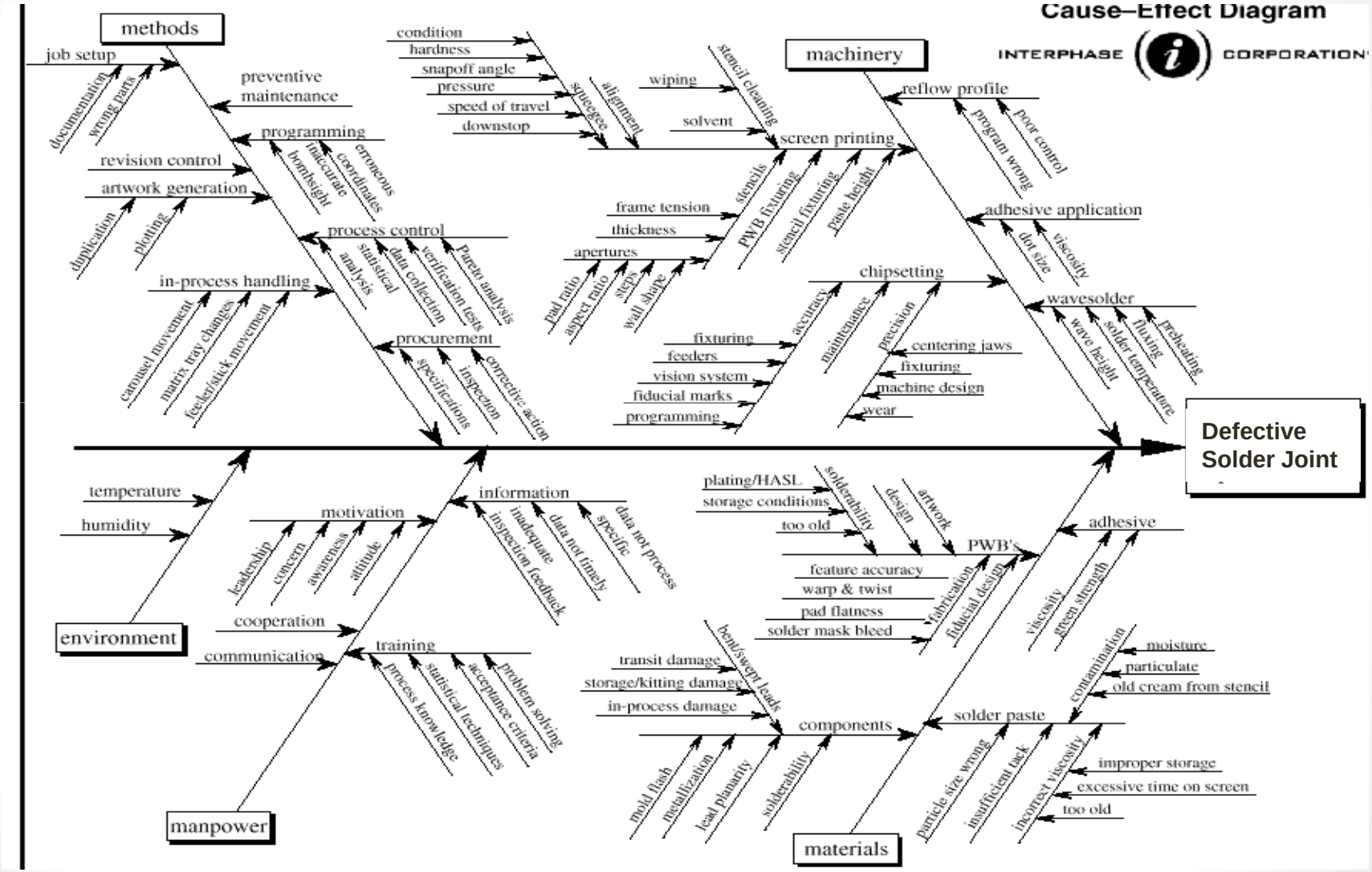
Soldering is a Lynchpin Technology

- Soldered interconnections in general have been undervalued, they are nevertheless gatekeepers of cost and performance and are key in system Integration
- Soldered interconnections are also commonly the limiting factor in product reliability and improved approaches to interconnection are required to meet future requirements in a sustainable manner
- While solder made possible reliable electronic interconnections in the past with tin-lead, lead-free solder is a wildcard with a thus far checkered reputation.
- Can lead-free solder provide the kind of reliability that true sustainability needs.

Solder - Past and Present Issues

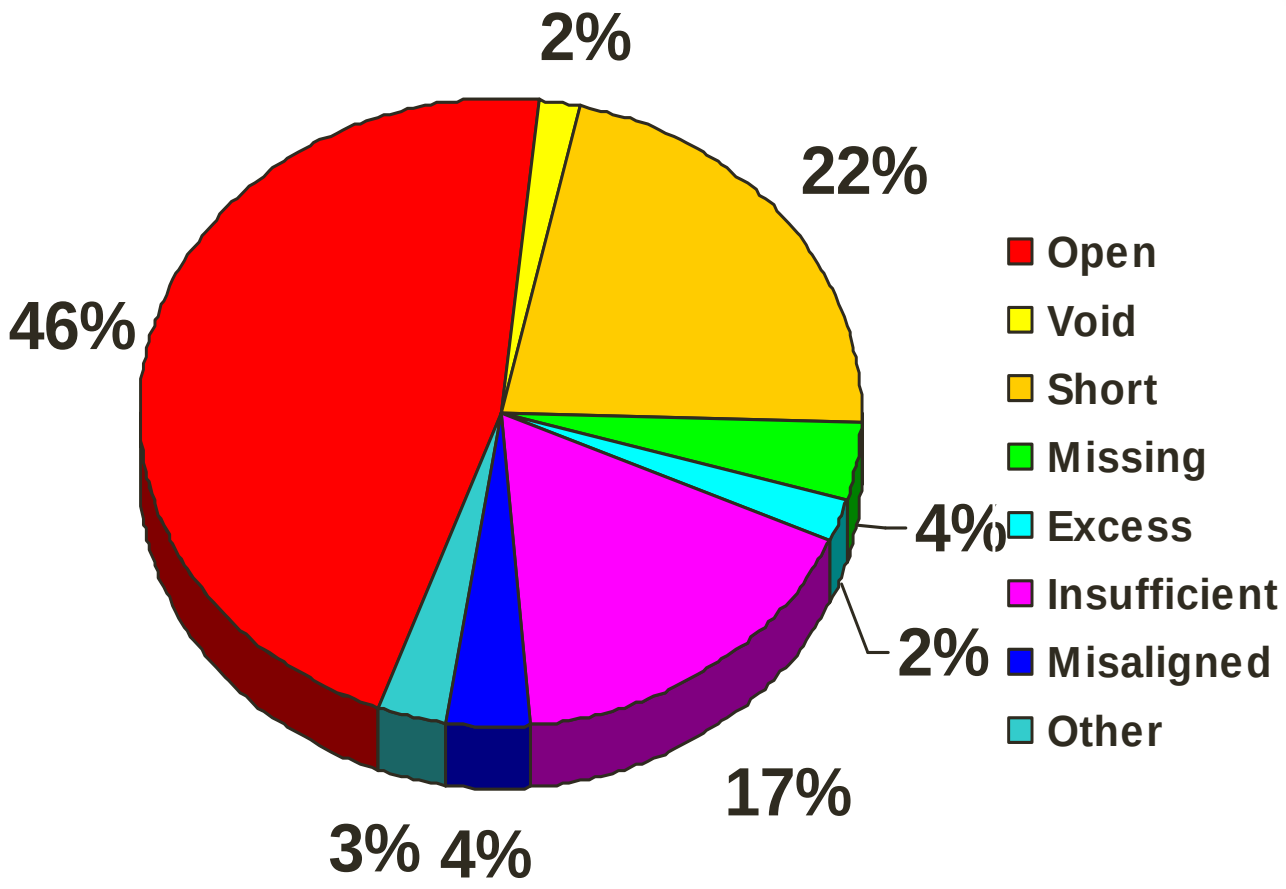
- Solder has long been an important technology for making electromechanical interconnections and it will likely remain so for many products into the future…
- However, there are intrinsic problems with solder, especially lead-free and as device contact pitch drops the problems with solder are becoming increasing apparent.
- Industry journals are replete with articles on the problems of solder and prospective solutions:
  - Opens, shorts, non wetting, voids insufficient solder, excess solder whiskers, popcorning, head in pillow, pad cratering, black pad, poor cleaning beneath low standoff components, etc…
- The list things to manage and control in the soldering process is long and involved…

Soldering Fishbone Diagram



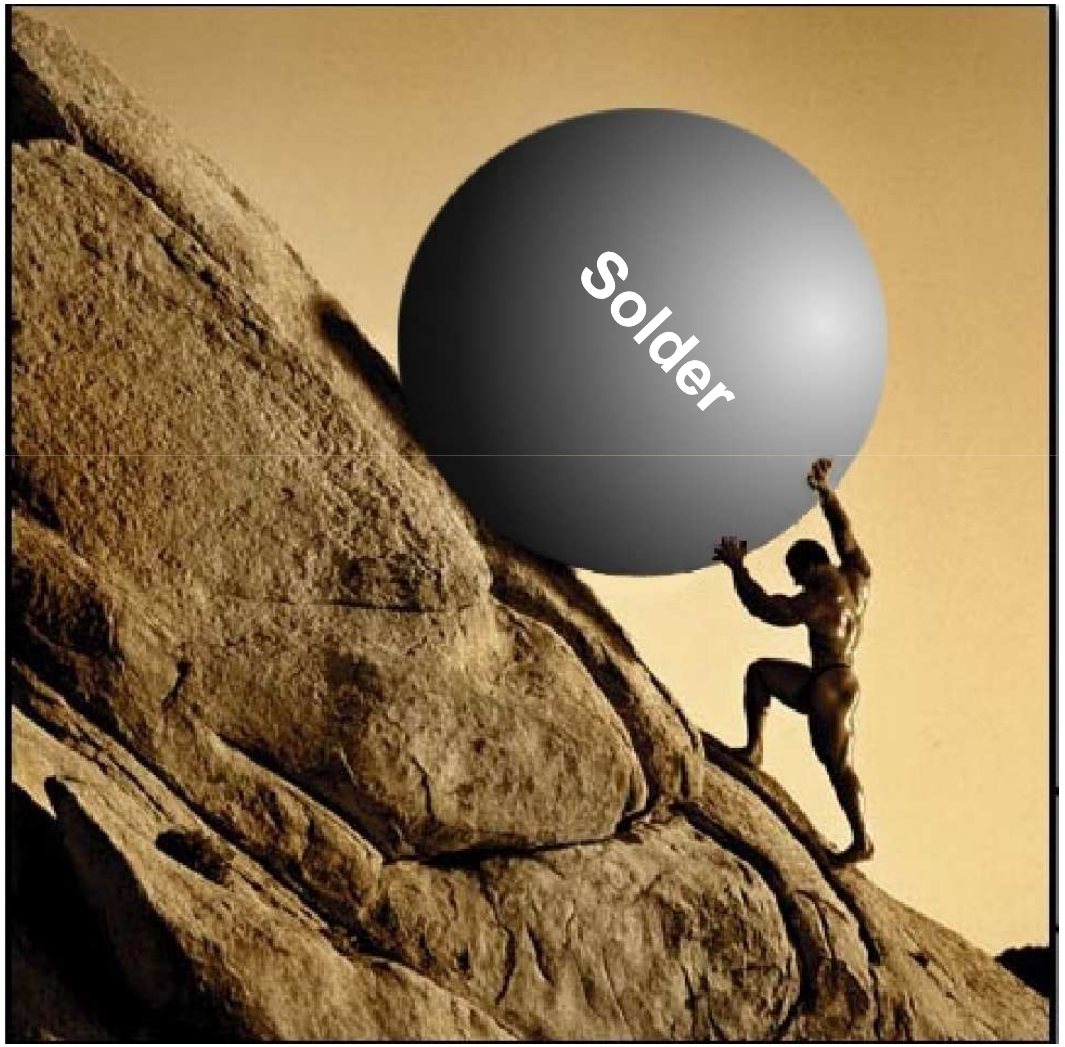
Source: Interphase Corporation

What are the Solder Process Problems?



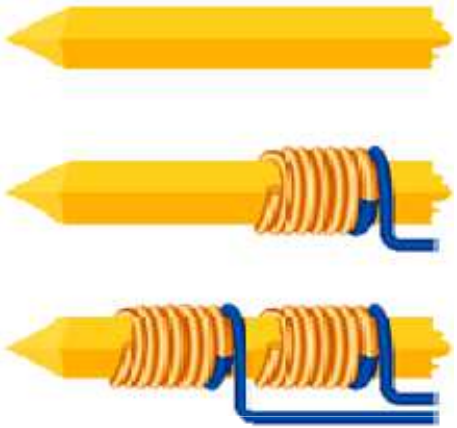
Source: Stig Oresjo "Blending Test Strategies for Limited-Access Boards" *Circuits Assembly* Aug 2002

The Punishment of Sisyphus

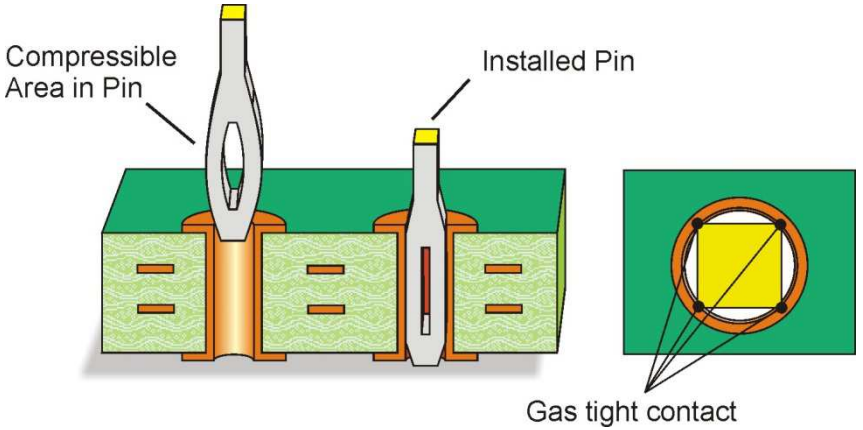


Can solder be reliably eliminated?

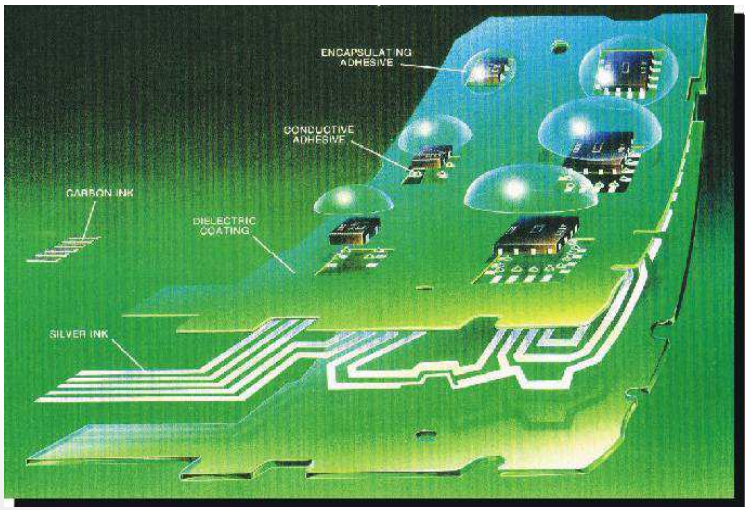
Actually It Already Has Been…



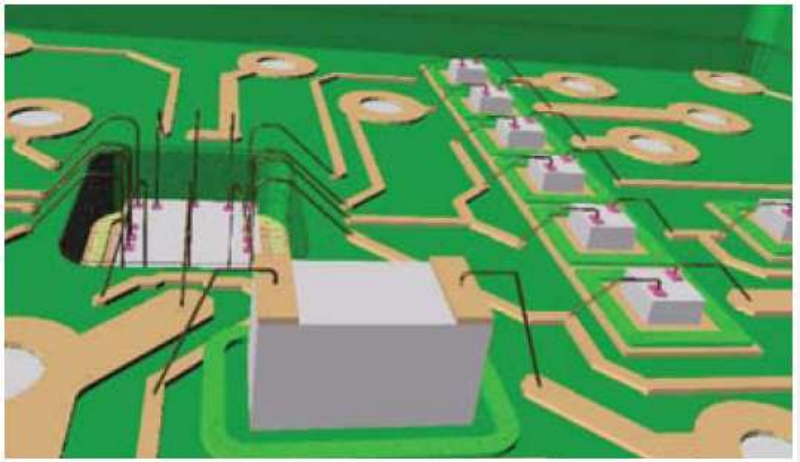
Wire wrap



Press fit



Conductive composites



Wire bond / Stitch wire

A Look at Processing…

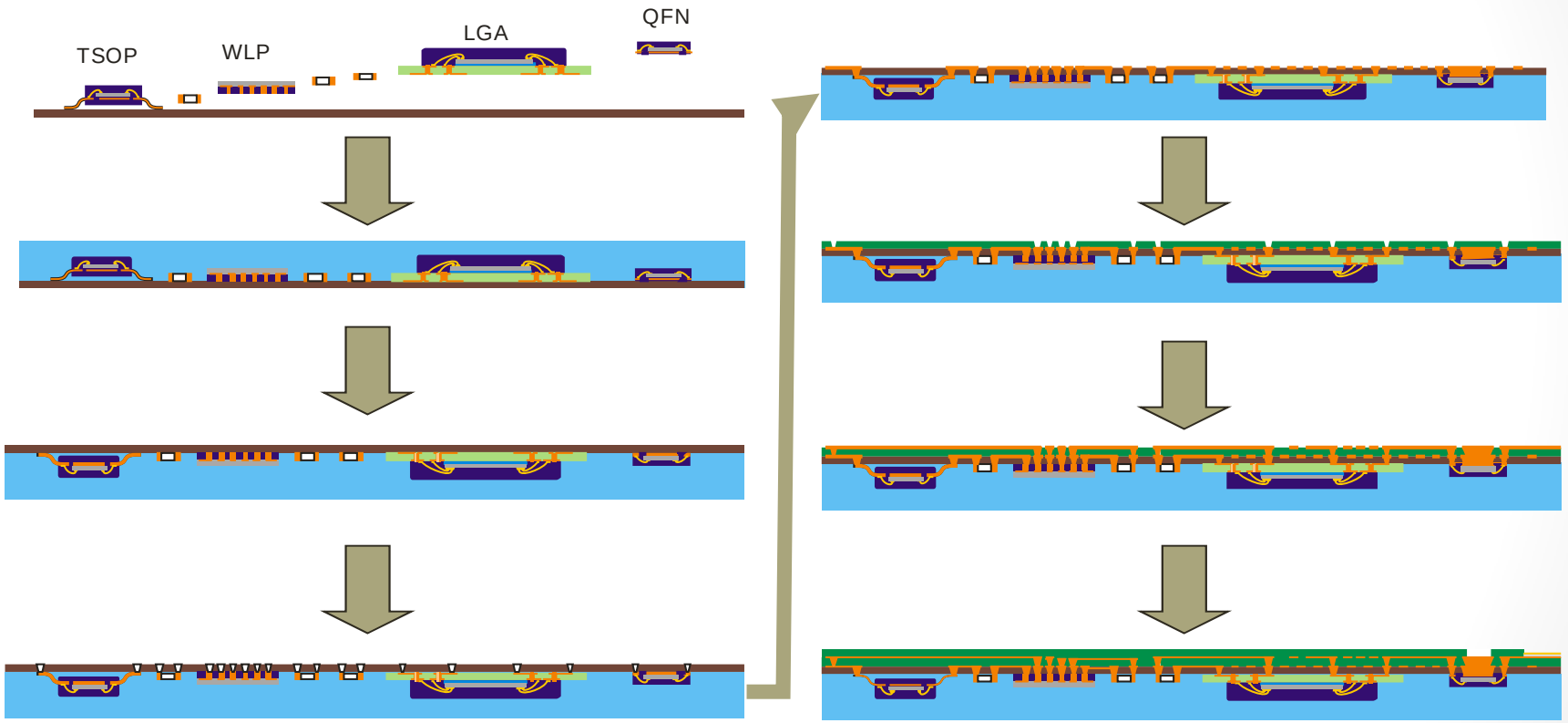
Electronics Manufacturing Steps

Design PCB Assembly	Fabricate PCB (multilayer)	Assemble PCB
1. Create schematic 2. Indentify components 3. Layout circuits 4. Validate signal integrity 5. Validate design DfM 6. Validate design DfR 7. Validate design DfE	12. Drill (stack height varies) 13. Desmear or etchback 14. Sensitize holes 15. Plate electroless copper 16. Clean and coat with resist 17. Image an develop resist 18. Pattern plate copper 19. Pattern plate metal resist 20. Strip plating resist 21. Etch base copper 22. Clean and coat with soldermask 23. Image and develop 24. Treat exposed metal (options) 27. Route to shape 28. Package 29. Ship	1 Procure components 5 Kit components 19 Place components 20 Inspect for missing parts 24 Perform hand assembly as required 32 Electrically test 33 Rework and repair as needed 34. Package 35. Ship

Reversing the Assembly Process can Eliminate Soldering

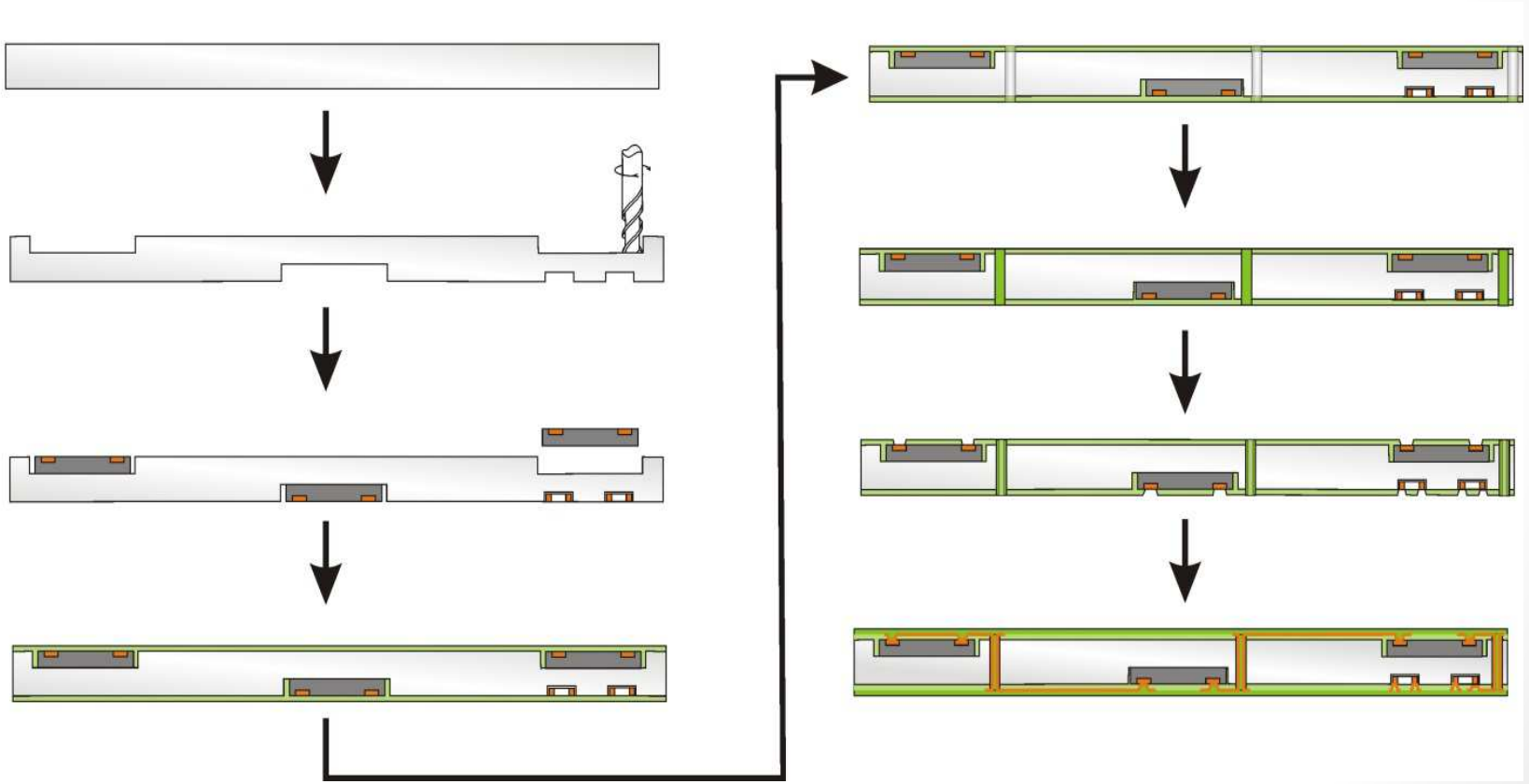
1. Position & bond various tested components on a temporary substrate or permanent metal or organic carrier in up or down position depending on base
2. Encapsulate/coat the tested components in place
3. Expose terminations (multiple options)
4. Interconnect terminations by additive or semi-additive board fab methods, combinations or alternative direct interconnection methods. Layers required will normally be less than for standard approaches do to the lack of need for solder connection lands

Sample Process Sequence



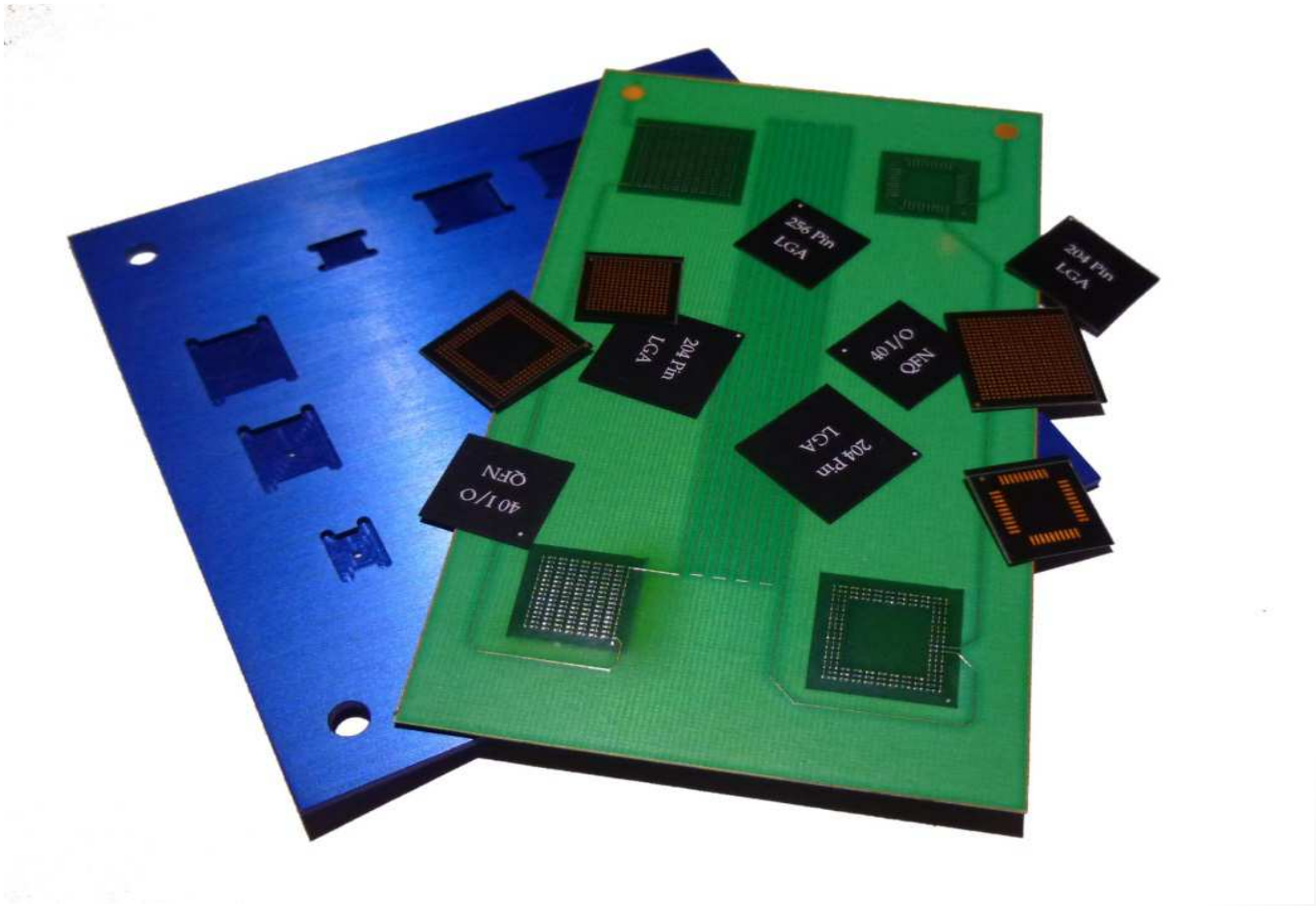
Patented

Aluminum Process Example

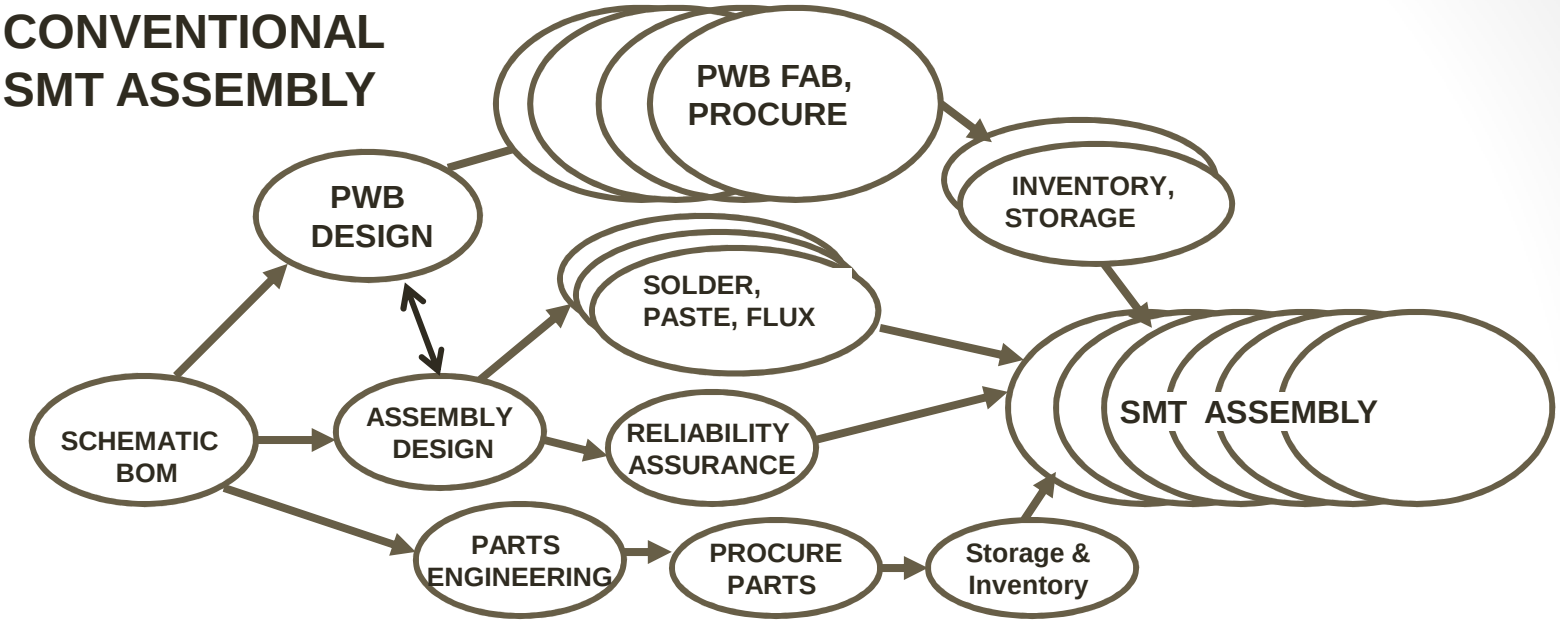


Patented

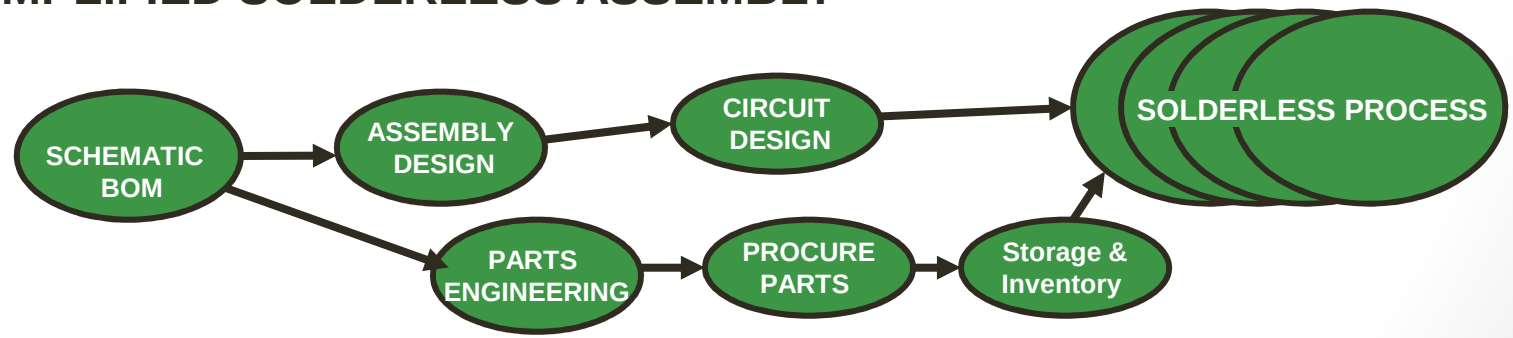
Aluminum Circuit Example



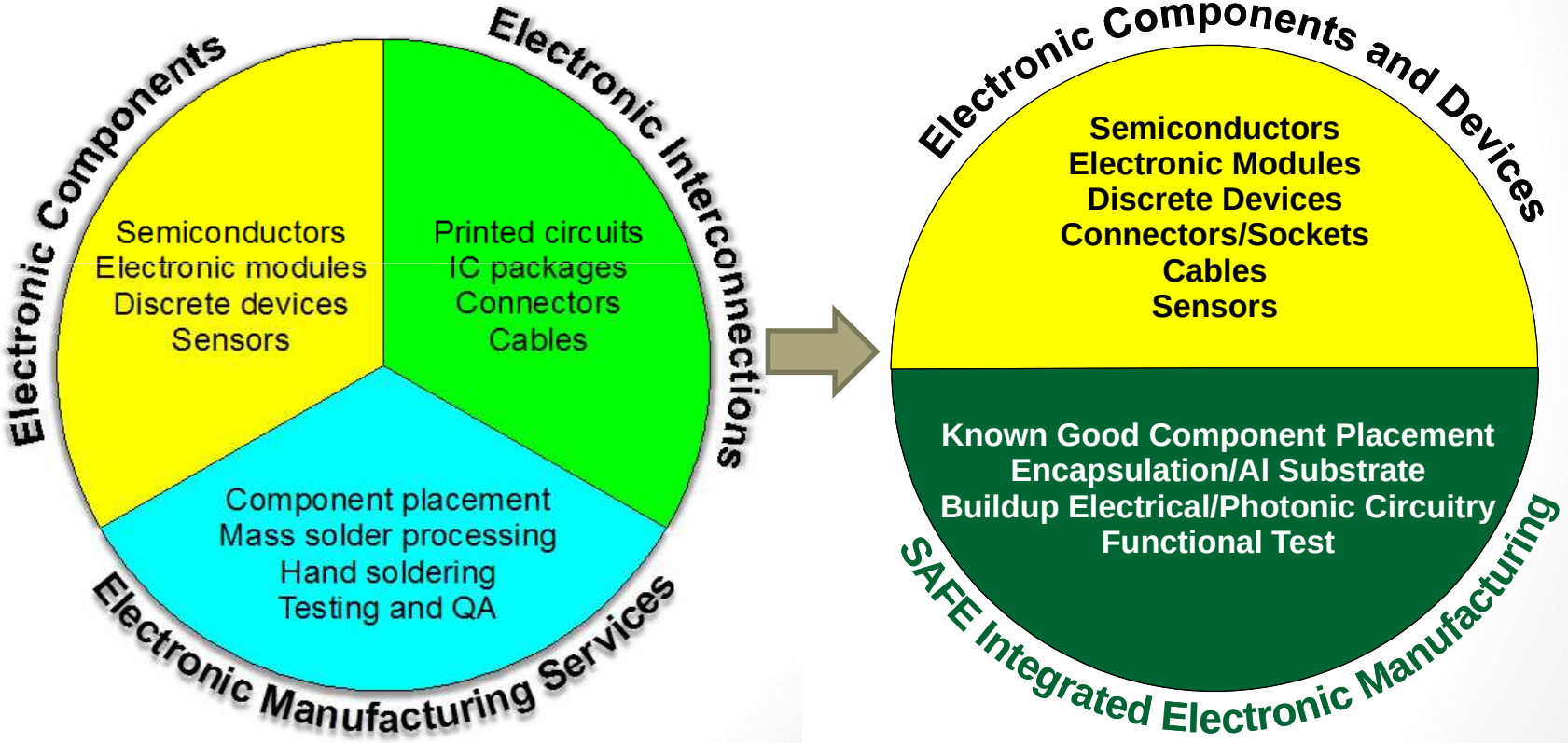
CONVENTIONAL SMT ASSEMBLY



SIMPLIFIED SOLDERLESS ASSEMBLY



Simplified Supply Chain



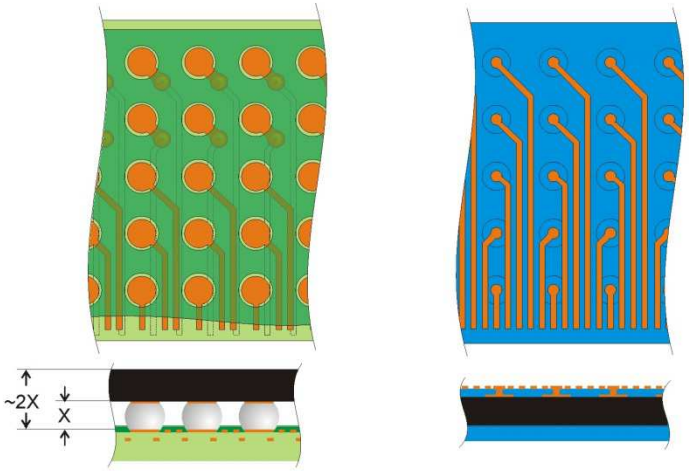
Solder Alloy Free Electronics (SAFE) Infrastructure is in Place

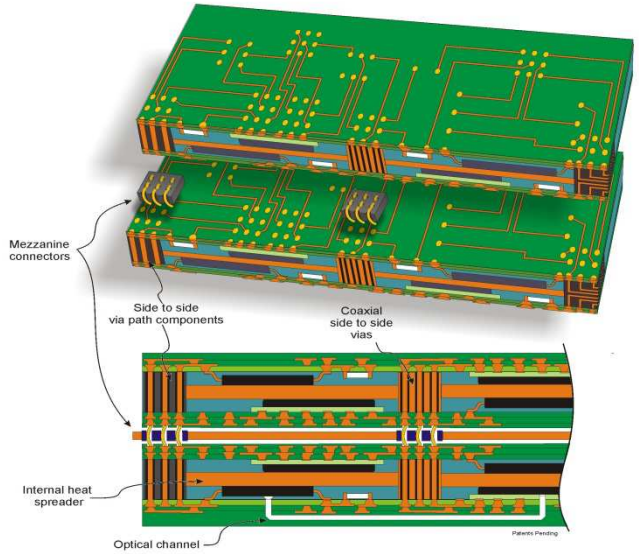
- Components can be placed conventionally
- Many suitable encapsulating materials available
  - Suitable CTE, low shrinkage, high thermal conductivity
  - Need not withstand soldering temperatures
- Low pressure molding techniques are available
- Aluminum substrates easily adapted
- Many possible options for via creation
- Semi-additive fabrication process well established
- All copper system both possible and advantageous
- Appropriate for all classes of products including flex
- Testing and rework... Philosophical concerns?

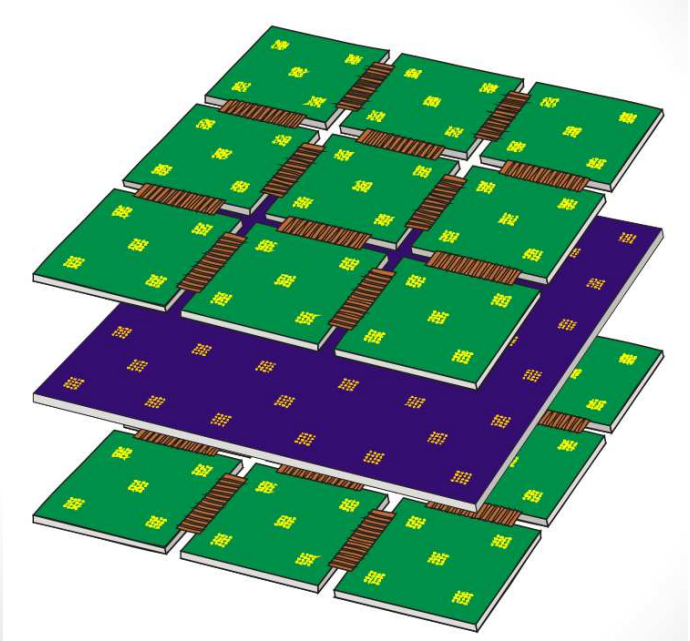
Solderless Assembly Benefits

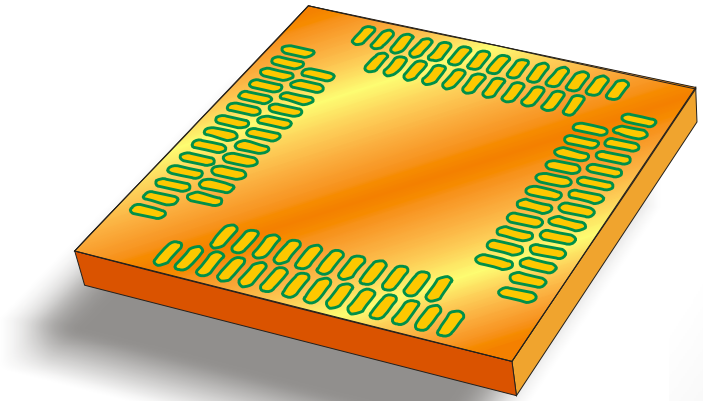
- **No PCB required**
  - No procurement, shelf life, testing, environmental related issues
- **No soldering required**
  - Multiple steps eliminated, weak link eliminated, no high temp
- **Reduced component concerns**
  - Leadless devices, MSL 1, all copper, no high temp damage, low profile
- **Circuit design layout easier**
  - Closer spacing, large lands not required, non functional leads ignored
- **Increased design security**
  - Component detail hidden
- **Integral thermal management**
  - Aluminum substrates – high conductivity and close CTE match to Cu
- **Enhanced reliability**
  - No solder joints, ESD and EMI, low temperature processing, simpler
- **Multiple novel structure options possible**
  - Stacked assemblies, rigid flex assemblies, optical pathways

Novel Possibilities and Benefits









What about testing...?

Testing is believed to be critical… Why?

- Most testing is predicated on the anticipation of manufacturing related defects and faults
  - Shorts and opens are accepted as facts of life
  - Lead-free assembly damage to assembly components
  - Thermal excursions reduce product life
- Current assembly technology has limits
- Simpler processes should yield higher
- The ultimate test is assembly turn on

Question…

Can time and money used for test be better allocated?

Changing Views on Reliability

- Reliability expectations vary for different types of products depending on application.
- However the importance of reliability has been fading, especially for consumer products due to faster products cycles
- The concept of application specific reliability should be a concern to manufacturer and consumer alike
- Electronic products are rapidly becoming much like seasonal fashion statements which is not sustainable
- Are we headed down the right road and in the right direction?

Planned Obsolescence

- Concept dated to 1932 with the publication of Bernard London's pamphlet titled *“Ending the Depression through Planned Obsolescence”.*
- The fundamental idea was to create products that became obsolete or ceased to function after a certain period of time or amount of use in a way that is planned or designed for by the manufacturer
- The concept holds sway still today but there have been subtle changes…
- Advertising influences emotions and confuses wants and needs

Planning for Failure

- For planned obsolescence to work, some self-destructive mechanisms must be integrated (implicitly if not explicitly) into the manufacturing systems. One is a reduced concern about reliability.
- "Brave New World" by Aldus Huxley - Here and Now
- There is a negative aspect to accelerating the rate of change in product cycles…

It is simply not sustainable if all of the world's peoples are to be served and benefit from electronic products…

Economics of Early Failure

- Early failures result in higher warranty costs to the manufacturer and the potential for product recalls, the cost of which can run into tens of millions of dollars
- Those millions in losses could potentially be multiplied many times over as every manufacturer faces the same risk when products do not perform to promised levels.
- In short, poor reliability is very costly both to individual companies and the world's peoples

Sustainability and Reliability

- To hold to the ideals of sustainable manufacturing, the electronics industry must make products that are be robust enough that they can be passed along to future users with no concern about longer term reliability.
- The earth has limited resources and there is general recognition that conservation is necessary
- In Japan and elsewhere, the manufacturing community has rallied around the idea that there is need to build products tied to the goals the "**Three Rs**"… Reduce, Reuse and Recycle.
- The missing 4th **R** is the one that stands for **Reliability**.
- Reliability is an important partner of Sustainability

Summary

- **Solderless assembly has actually been part of the electronics manufacturing process since the earliest days of the industry.**
- **Solder based assembly will likely persist for decades to come because of the established infrastructure.**
- **In the end, simplicity is key, ironically, to achieve simplicity requires discipline.**
- **Finally, there is both an obligation and a large opportunity to serve those billions of people who just happened to be born at the bottom of the global economic pyramid.**

“A mind, once stretched by a new idea, never returns to its original dimensions.”

~ Oliver Wendell Holmes ~

American Philosopher and Jurist