

STRATEGIES TO MITIGATE THE TIN WHISKER PHENOMENON

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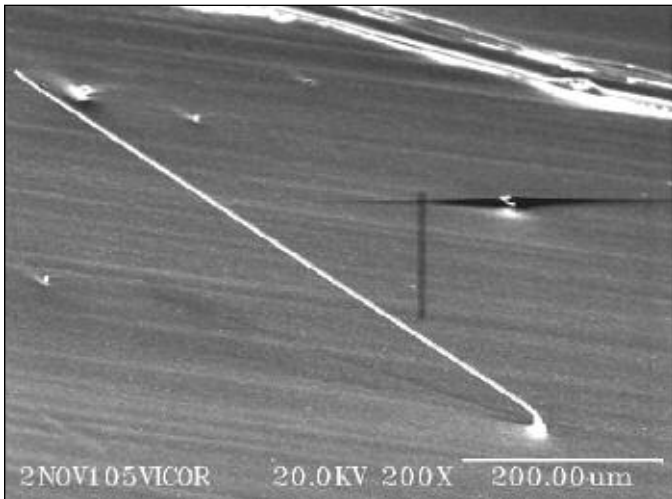
The tin whisker phenomenon is a failure mode associated with all electronic devices that use a number of low melting point elements (e.g., Sn, Cd, In) in operations such as soldering. Recognized many years ago, the problem was minimized by adding lead, now identified as a hazardous substance and banned.

This paper addresses significant questions concerning tin whiskers, and, in particular, Vicor's work to accommodate the no-lead requirement. Specifically, this work resulted in the adoption of seven strategies that mitigate the impact of the tin whisker phenomenon on Vicor power products, when tin finishes are used. The seven strategies are:

1. Use matte Sn finishes supported by testing
2. Use Ni barrier layer under non-bright Sn plating
3. Ban use of immersion Sn-type plating on PCB's
4. Subject Sn plated SMT components to lead-free reflow
5. Spin fill brick products
6. Comply with iNEMI & Jedec recommendations
7. Continue to monitor and comply with latest practices

Why are tin whiskers a concern?

Tin whiskers are a concern because they are conductive, can carry high current, and because Pb, the material that has been used for the last 50 years to limit whisker growth is being removed from use in most electronic devices. Extensive data is now available online. Examples of supporting references can be found at www.nemi.org or in On Semiconductor Application note TND311 found at www.onsemi.com



Exactly how and why a tin whisker grows is not completely understood. The whisker in the image, which grew to be 0.025" in length, was found on a connector sample provided to Vicor that was plated with 100% bright Sn. The whisker reached this length in only 4 months of storage in ambient conditions.

On what types of electronic materials can whisker growth be found?

Whiskers will grow from copper containing substrates finished with most low melting point elements including Sn, Cd, In, Zn and Sb. New research has shown that whiskers will even grow from Sn-Pb surfaces but the length of those whiskers is much shorter due to the presence of Pb.

Will whiskers grow from any copper substrate coated with other RoHS compliant solderable finishes?

No. Whiskers do not grow on solderable Au, Pd or Ag finishes.

Under what conditions will whisker growth occur on Sn finishes?

There are certain conditions that promote whisker growth and these include but are not limited to the following:

- Thin plating layers
- Residual stress within plating
- Intermetallic compound formation
- Diffusion (enhanced by temp)
- External stress (compressive)
- CTE mismatch
- Surface oxide
- Electrical bias

What role does Pb play in preventing tin whisker growth?

The best explanations from the literature are based on the fact that Pb slows the diffusion of Sn in the matrix and allows for rapid stress relaxation. Since diffusion is needed for whisker growth, slowing the rate of diffusion of Sn intragranularly or along grain boundaries is effective. Introducing Pb slows or prevents continuous whisker growth.

Besides using Pb, are there other elements that can be used as effectively as Pb?

No other elements have been shown to be as effective as Pb although some researchers have used Bi and Ag but with mixed results. The use of SnBi, SnAg or SnCu platings in Vicor products is being avoided. However, increasing the grain size of the plating or controlling the grain orientation has been shown to slow the rate of diffusion.

If the plater can't use a Pb substitute with confidence or with good economies, what can a plater do to limit whisker growth on Sn finishes?

The plater can use advanced Sn plating processes that produce platings with unique properties such as large grains or preferred grain orientation, the plater can use barrier layers, or the plater can use post plating treatments.

Why are thin platings most susceptible to whisker growth?

Thin platings develop greater compressive stresses than do thick platings.

Why do intermetallic compounds (IMC) make for whisker growth?

Non-uniform growth of Cu_xSn_y IMCs increases the local compressive stress in the rest of the tin plating. Conversely, Ni_xSn_y IMCs produce a tensile stress and reduce the compressive stress on the Sn plating.

Is it true that whisker growth will be highly accelerated by lead forming operations due to compressive stresses?

Recent studies by lead frame manufacturers and semi-conductor packagers have found no increase in Sn whisker growth as long as preferred Sn chemistries are used. Furthermore, since Sn recrystallizes at room temperature, mechanically worked grains will stress relieve and grow eliminating the risk of whiskering.

Why are large grains effective in reducing whiskering?

Whiskering is a diffusion-controlled process, and diffusion rates are very grain boundary (GB) sensitive; the greater the number of GB, the faster the diffusion rate and the faster the rate of whisker growth. IMCs also form preferentially along grain boundaries. Increasing the grain size of the plating will reduce the number of grain boundaries, slowing the diffusion rate. Additionally fewer GB mean fewer places for non-uniform IMC growth and reduced stress in the system.

What type of plating finishes is Vicor using in its RoHS, and non-RoHS devices?

Based on literature, iNEMI research, and VICOR testing, VICOR has developed the following Matrix:

Solderable Finishes	Vicor Position – Recommended use on Cu alloys based on iNEMI	Vicor Position – Recommended use on Non-Cu alloys based on iNEMI
Ni – Pd – Au	Accept	Accept
Ni – Pd	Accept	Accept
Ni – Au (ENIG)	Accept	Accept
Ni – hard Au – soft Au	Accept	Accept
Whisker resistant matte Sn 6 µm minimum thickness	Accept – when supported by vendor Chemical Supplier Testing	Accept
Whisker resistant matte Sn @ 6 µm minimum thickness with Ni @ 2 µm minimum underplate	Accept – when supported by vendor Chemical Supplier Testing	Accept
Semi-matte Sn	Reject	Accept
Bright Sn	Reject	Reject
Bright Sn with Ni underplate	Reject	Reject
Reflowed matte Sn	Accept	Accept
Hot dipped SnAgCu	Accept	Accept
Hot dipped AgCu(Ni)	Accept	Accept
Hot dipped SnAgSbCu	Accept	Accept
Ag or AgPd	Accept – only use where electromigration is not an issue	Accept
Immersion Sn	Reject	Reject
Sn-Bi (alloy plate)	Reject	Reject
Sn-Cu (alloy plate)	Reject	Reject

What experience does Vicor have in using components that are finished with 100% Sn plating or SnAg(Cu) solder dipping?

Vicor has been using ceramic components with 100% Sn finishes for more than three years without whisker related field returns. Vicor has been using semiconductor plastic molded packages with 100% Sn leads for more than two years from suppliers such as the following to name just a few.

- On-Semi, www.onsemi.com
- TI, www.ti.com
- ST-Micro, www.st.com
- Carsem, www.carsem.com

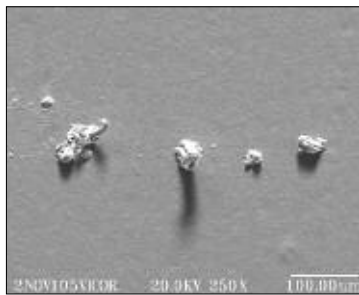
Leads on magnetic components finished with SnAg have been in production use for three years without field returns.

What whisker testing has Vicor performed on 100% Sn finishes?

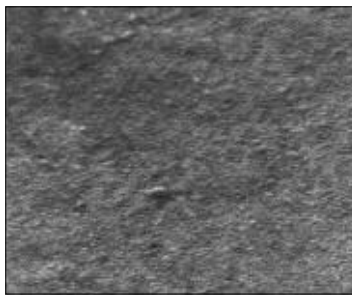
Vicor conducted initial trials on 100% matte Sn in 2003 before extensive data was available. In that testing, just as our vendors predicted, large grained 100% Matte Sn plating on Cu lead frames resists whiskering even when the plating is put in compression and at elevated and humid environments. Bright Sn was unacceptable with whisker growth, reaching 700 µm observed on samples stored at ambient. Compressed matte Sn whisker growth was 10 – 20 µm.

Vicor continues to inspect, on a lot-by-lot basis, the quality and type of 100% Sn plating. We also require our vendors to supply supporting documentation on plating chemistries used.

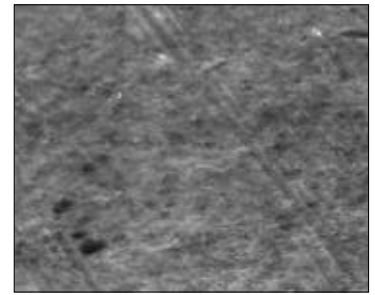
Using its scanning electron microscope, Vicor has the ability to examine grain size on incoming lots.



Bright Sn @ ambient
500 Cycled



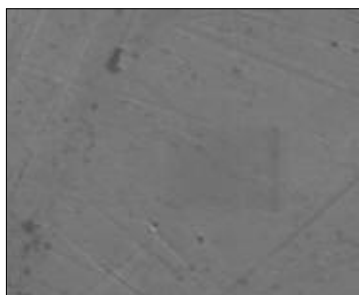
Compressed matte Sn in 85/85



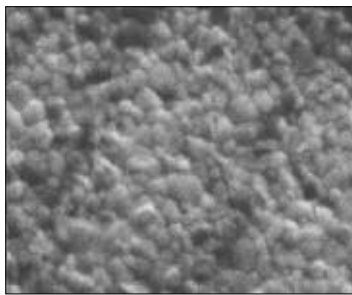
Compressed matte Sn

What has Vicor seen when performing grain size examination?

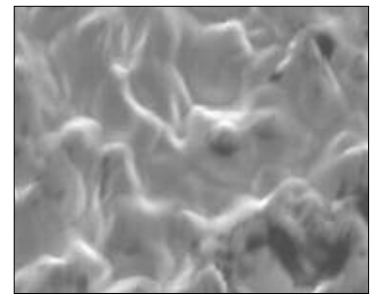
Simple SEM examination has shown that not all matte Sn plating is the same. It may look matte but may not be whisker resistant because of the presence of small grains or other properties. Original SEM images were at 4000X revealing grains of either 1 – 2 μm (less desirable) or $>6 \mu\text{m}$ (preferred).



SEM – Bright Sn virtually
featureless Sub-micron grains



SEM – matte Sn "A"
small grained 1 – 2 μm



SEM – matte Sn "B"
small grained, $>6 \mu\text{m}$

Are there recommended suppliers of 100% Matte Sn Plating?

Yes. In all cases component suppliers and plating subcontractors are requested to submit documentation consistent with Vicor CST-0001, RoHS Material Declaration.

- Technic Inc., www.technic.com - Technistan EP-LS is used on pins
- Vicor will be adding post-plate oxidation treatment Techni - E260
- MacDermid Inc., www.macdermid.com
- Atotech Inc., www.atotech.com
- Enthone Inc., www.enthone.com

Where would Vicor use Sn plating in their product?

Sn plating is used on IC packages, passives, pins (internal to the module) and in some cases external pins. In RoHS-compliant modules, Vicor provides our customers with the option of using Ni/Au plated pins or Sn plated pins.

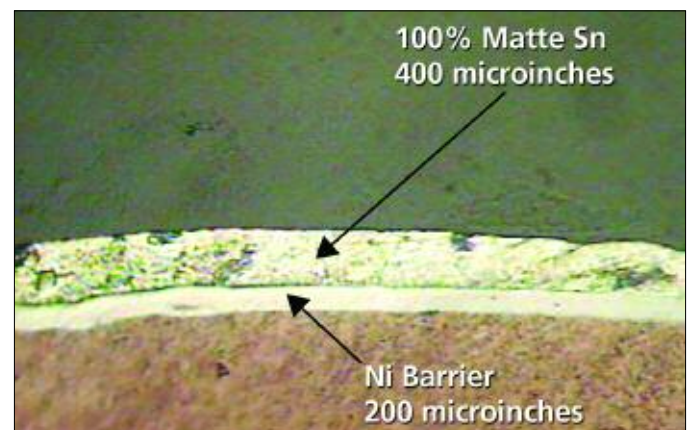
Will Vicor use Sn plating on PC Boards?

No. Vicor's PCB that are currently processed using ENIG will continue to be processed using ENIG. Product that was previously HASL (SnPb) will be finished with either ENIG or Immersion Ag or HASL (SAC Alloy) as the application demands. Vicor does not restrict the use of OSP if the application permits.

Other than using matte Sn chemistry or reflowed Sn or reflowing Sn plating in the fabrication process, does Vicor use any other techniques to mitigate or control whisker growth?

Yes. Where possible, Vicor uses Ni barrier layers under Sn plating. A minimum of 2 μm is requested based on iNEMI and plating chemical supplier recommendations. Where possible, Vicor requests that Sn plating be annealed after plating for 1 hour at 150°C to promote controlled IMC formation and reduced Sn whisker risks.

Vicor pins are subjected to Pb-free reflow during surface mount operations further reducing the risk of whiskering.



Sn plating on pins is typically 300 – 500 microinches over 100 microinches minimum Ni.

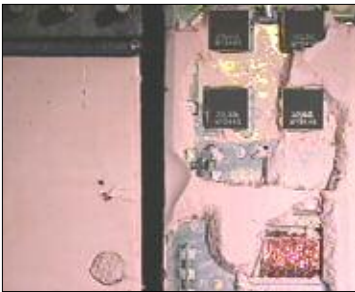
Other than using matte Sn chemistry, or Ni barrier underplate, or post plate treatments, or reflowed Sn or reflowing Sn plating in the fabrication process, does Vicor use any other techniques to mitigate or control whisker growth?

Yes, conformal coat. Conformal coatings or epoxies have been suggested by many as a way to reduce whisker risks, but for most suppliers this is at a cost. Vicor already uses a type of thick conformal coating spin fill in its brick products as part of its thermal management strategy. In addition, this silicone-based polymer is 90 – 92% filled ceramic particles adding additional resistance to whisker growth. This fill material encapsulates all components, wets leads, and fills the space between package leads, components, and traces. This is a well-developed technology for Vicor.

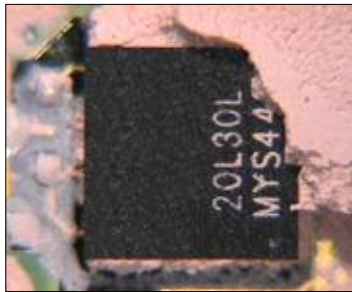
How will Vicor product resist Sn whiskers?

- Use matte Sn finishes and select chemistry supported by testing
- Use Ni barrier layer under non-bright Sn plating
- Ban use of immersion Sn-type plating on PCB's
- Provide other plating options to include ENIG (Ni/Au), Ag, PdNi, etc.
- Subject Sn plated SMT components to lead-free reflow
- Spin fill brick products
- Comply with iNEMI and Jedec recommendations staying current with the literature base
- Continue to monitor plating finishes and comply with latest practices

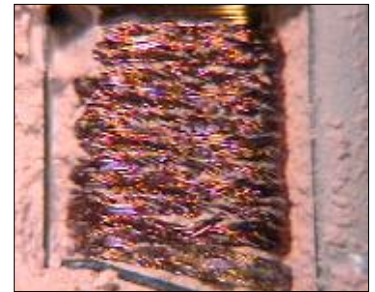
Examples of Vicor conformal coating (spin fill) in opened bricks



Spin fill with cover removed and spin fill conformal removed showing areas next to and between devices



Module with cover removed Conformal Coat – Minimum thickness of spin fill is 0.040" thick and minimum lead spacing is 0.015"



Expanded view of Spin fill



Patrick Lavery is a Principal Process Engineer, in Vicor's Brick Manufacturing Engineering Organization, in Andover, MA. He is a Materials Scientist with expertise in material systems, materials analysis, and material analysis equipment and has been involved in coating and plating applications for about 20 years. He holds patents in advanced coating technologies utilizing plating and chemical deposition methods. He received his A.B., B.E Metallurgy, and M.E. Materials Science degrees from Dartmouth College and Dartmouth College, Thayer School of Engineering.