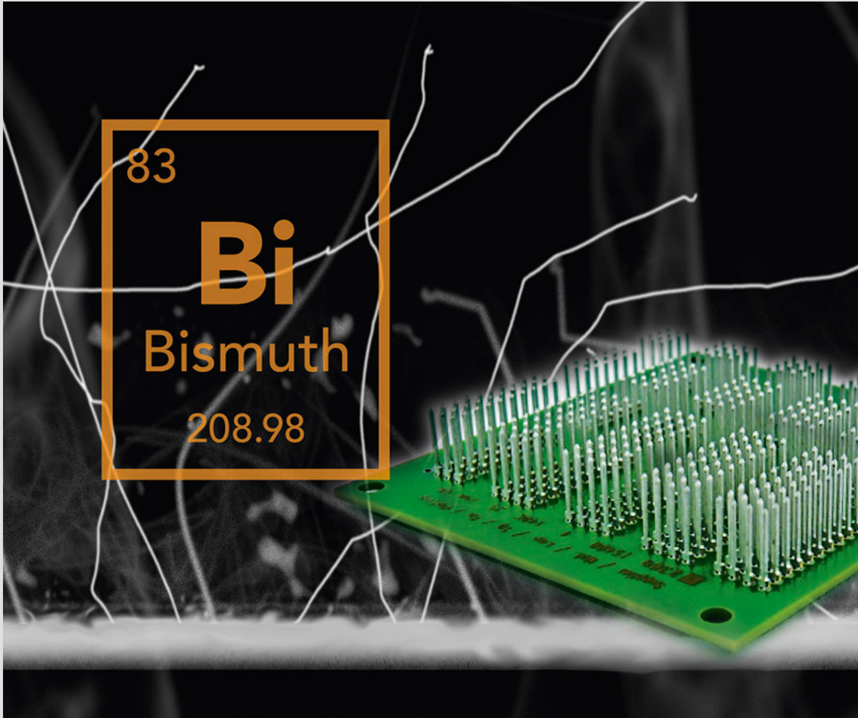
TE connectivity

LITESURF – TIN-FREE ELECTROPLATING FOR PRESS-FIT TECHNOLOGY

Environmentally safe solution for tin whisker growth prevention

Author:

Frank Schabert
Senior Manager Research & Development,
TE Connectivity Product Development Engineering



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1 | EXECUTIVE SUMMARY

Automotive electronics and interconnection technologies are challenging application fields. Harsh environmental conditions require interconnection technology offering high levels of performance combined with extreme robustness and durability.

For this reason, Press-Fit is becoming the most widely adopted printed circuit board (PCB) electrical interconnection technology. This is due to its high level of reliability combined with the economic and environmental advantages compared to traditional lead (Pb)-based solder processes. In addition, the accuracy of Press-Fit compared to soldering - with the ability to automatically log each PCB pin insertion as well as the ability to make repairs to the PCB connection, makes it a highly attractive technology.

Press-Fit, however carries one potential challenge with the long known risk of metallic whisker growth associated with tin (Sn)-based plating technologies that have been designed to provide a protective surface and lubrication. In extreme cases, such whisker growth has the potential to reach other pins and to cause short-circuiting. With the increasing number and complexity of electronic control functions in the vehicle, as well as the middle-term prospect of electric vehicles – with battery controls active around the clock, not only during driving – requiring even greater levels of operational durability, automotive manufacturers are challenged to ensure ever greater reliability and robustness. For electrical PCB connectivity, that requires solutions that minimize whisker risk but also are based on non-hazardous and environmentally safe substances, meaning no lead.

TE Connectivity's LITESURF is a lean plating finish for Press-Fit pins. Instead of tin (Sn) this plating consists of bismuth (Bi), a non-hazardous heavy metal, which reduces the risk associated with metallic growth by a factor of over 1,600.

LITESURF confirms that TE's Press-Fit technology offers fast, economical and highly reliable manufacturing with true automotive grade robustness and virtually no risk from metallic whiskers.

2 | INTRODUCTION: PRESS-FIT TECHNOLOGY – ADVANTAGES AND RISKS

Press-Fit is becoming the most widely adopted printed circuit board (PCB) electrical interconnection technology for the following reasons:

2.1. | RELIABILITY

The specially designed Press-Fit pins (Fig. 1) are inserted into matching holes (metal sleeves) in the printed circuit board (PCB) where a tin (Sn) pin surface and a tin hole surface establish a gas-tight intermetallic bond between the tin layers on both sides through cold welding. This combination of excellent electrical connection and mechanical fixing makes Press-Fit interconnections very durable and robust, for example against vibration. Press-Fit has been proven to offer up to ten times more reliability over IDC connections (according to IEC norm) and between ten and one hundred times lower failure rate when compared to soldering.

2.2. | SOLDER-FREE

Press-Fit involves no use of lead-base solder. In addition to the environmental advantages it eliminates many of the challenges associated with high temperature soldering processes such as the need for expensive high temperature plastics and thermal stress to the connector itself.

2.3. | CONTROLLABILITY

Press-Fit offers the advantage of a fully automated insertion process during which, the quality of the pin insertion, specifically the pin travel and insertion force can be logged and checked later if necessary.

In addition, the presence of the pins in the holes and/or protruding from the bottom side of the PCB can be checked by on-line camera inspection. Not only are there fewer risks of process faults (such as bridges, bad wetting and flux residuals), Press-Fit processes offer a greater ability to monitor quality than can be achieved by inspecting solder joints.

2.4. | REPAIRABLE

Unlike solder, Press-Fit connections also offer the advantage of being repairable with the ability to make re-insertions of the pins into the PCB, typically with a maximum of 2 repairs.

3 | FORMATION OF TIN WHISKERS

The inherent reliability of Press-Fit described above, ensuring the electrical connection and mechanical fixing, also carries the potential risk of metallic whisker growth.

Establishing the mechanical and electrical point of contact requires a relatively high contact and therefore insertion force. The compression of the elastic Press-Fit zone during the insertion into the PCB hole, which ensures both mechanical and electrical connections, causes permanent stress that can lead, over time, to the growth of metallic whiskers on the tin surface. In extreme cases whisker growth could reach other pins and cause short circuits.

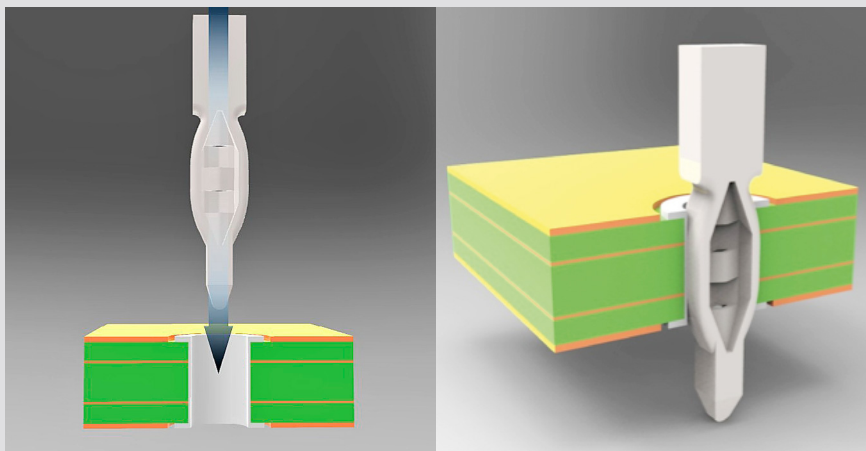

Fig. 1: TE Connectivity Multispring Press-Fit pin inserted in the matching PCB hole

Tin whiskers are tiny metal filaments which grow up from tin layers under certain boundary conditions. At a diameter of only 1-4 microns (i.e. magnitudes thinner than a human hair) and a length up to multiple millimeters originating within the Press-Fit hole, whiskers are hard to see with the naked eye. Tin whiskers not only grow over time but have good electrical conductivity and are well connected to the base material from which they develop. If they come into contact with a neighboring electric interconnection, they can cause a short circuit or arc, possibly causing a subsequent system malfunction.

The formation of whiskers on tin plating layers is a stress-relief mechanism: Tin atoms migrate from a stress zone to an area of lesser stress. In this zone, tin whiskers are likely to form. Stress build-up could

be the result of internal intrinsic film stress or externally applied stress on the film. Miniaturization with higher packaging density and reduced distance between pins will exasperate the risk caused by whisker incidence.

The areas most likely to produce whiskers are the regions directly adjacent to the middle section of the pin where the pressure gradient is high. The shape of the hole limits the risk of whiskers to grow out of the hole and bridge to other metal parts. Most recorded whiskers simply do not grow long enough to do that, however the residual risk cannot be ignored.

To mitigate the mechanical stress, which is the root cause of tin whisker formation in Press-Fit pin applications, caused by the relatively high insertion force required to press the pin into the hole, TE Connectivity has optimized the shape of its Multispring Press-Fit pins. Fig. 1 shows that the shape of the thicker middle section of the pin, where the fixing and connection zone is established, is leaf-shaped with a rounded contour. This design helps to avoid steep pressure increases on the PCB hole's inner surface, which could be the result of sharp corners on the pin.

4 | ELIMINATION OF LEAD AND ITS CONSEQUENCES

The metallic whisker phenomenon has been known for over 75 years, however, traditionally, the impact had been restricted by using lead (Pb), as part of the electric terminal (contact) plating and solder formulation, which prevented or mitigated tin whisker formation.

Meanwhile, international regulations like RoHS II (Restriction on Hazardous Substances) have limited the use of harmful/toxic substances such as lead in solder joints or plating to a small number of exceptional application areas – automotive being one due to the harsh environmental conditions.

In 2019 these exceptions will be reviewed and it is expected that the exception to use Pb as a mitigating agent in automotive applications will be removed. The use of lead is therefore being phased out from automotive electronic interconnection technology.

To date tin has been used as a replacement for lead-tin alloys. However, this transition has resulted in the re-emergence of the whisker phenomenon that had previously only been considered as an academic topic rather than a practical problem.

Put simply, Press-Fit technology offers many benefits driving its increasingly wider application. However, risk of whisker formation represents its one potential weak spot, which must be addressed given the huge increases in in-vehicle electronic control functions and the need to ensure the ultra-high levels of robustness and reliability as autonomous driving becomes a reality. This requires reliable environmentally safe tin-free Press-fit solutions that will eliminate the risks associated with tin whisker formation.

5 | TIN WHISKER PREVALENCE AND THEIR BEHAVIOR

Although whisker formation is also known from other materials such as molybdenum, tungsten, cadmium and zinc, tin is the material which is most widely used in electronic interconnection technology as a protective plating layer against oxidization and as an anti-friction coating. Therefore, this paper solely focuses on the mechanics of tin whisker formation.

Tin whiskers are metal growths of high conductivity that can change the direction of their growth spontaneously. This combination of unpredictable growth direction and high conductivity can contribute to whisker induced failures.

Once whiskers grow long enough to bridge over to other metal components, they have the potential to cause short circuits. They have been documented as the cause of problems in satellite systems, nuclear power plants, communication systems, computers, and the list goes on (Fig. 2).

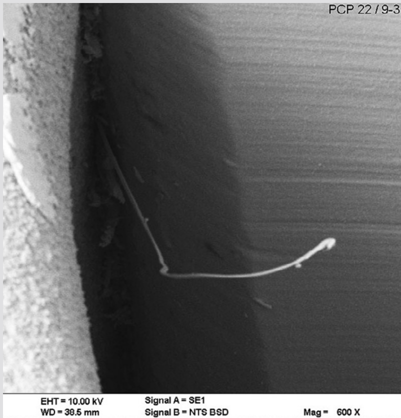

Fig. 2: Tin-whiskers growing from the crevice of a pin and plated PCB through-hole

However, some automotive applications are more sensitive to whisker induced failures than others. For example, digital control applications or power supplies are rarely affected since the higher current densities produced in the whisker due to the change in voltage are significant enough to melt the whiskers immediately away. The only real danger with higher voltage power supplies is arcing (if the change in voltage is high enough).

Conversely, applications requiring analog signals in the milliamp magnitude can be affected by whiskers. For example, a typical sensor signal of 4 to 20 milliamps matches the 10 milliamps and up to 0.45 V that a whisker can typically carry.

Various attempts to mitigate tin whisker risk have been made over several years. These include the use of other Pb-replacement alloying metals, such as SnAg, as well as the application of extra deposited film layers, yet no universal, easily implemented solution has been successfully developed that is not limited to restrictive tolerance levels.

6 | LITESURF ELECTROPLATING AND METALLURGY

LITESURF is a new Press-Fit plating technology that presents negligible whisker growth risk. It utilizes bismuth (Bi) plating which is applied in a standard electroplating bath, using a proprietary electrolyte solution, directly onto the copper (Cu) alloy base material of the Press-Fit pins.

The resulting Bi based LITESURF plating thickness is considerably thinner than that of Sn being around 0.4 microns

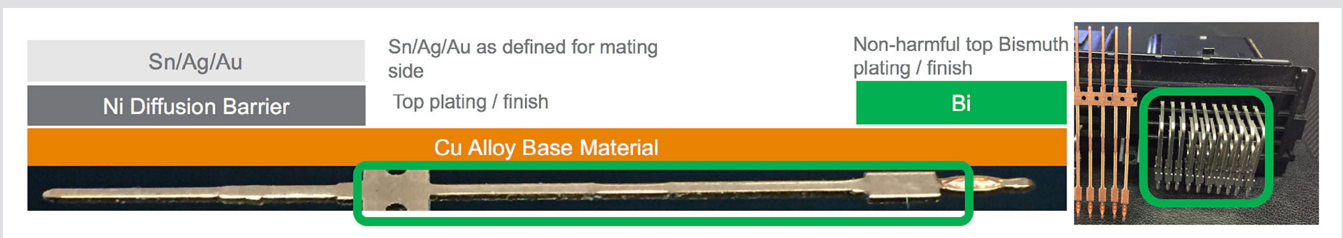

Fig. 3: Overview of Bi-based LITESURF plating composition

Bi shows an easier application behavior during electroplating with the ability to be applied more evenly. Furthermore, the Bi coating is not only the functional surface but also acts as a diffusion barrier towards the Cu alloy base material (Fig. 3).

Once applied, Bi forms a stable oxide layer on the top of the plating which prevents oxidization and reduces friction during the insertion process. In this respect, it behaves in a similar way to Sn. In comparison to Sn, Bi is slightly harder and its melting point is higher at 271° C (Sn = 231° C).

	Reference Plating (Sn Flash)	LITESURF
Occurrence **(> 100 µm)**	4 %	< 0.1 %
Max Length	376 µm	93 µm ***
Impact	100 %	10 %
Risk	1 = 100 %	< 1 : 1.617 = < 0.0 %

Fig. 4: Comparison between Sn plating and LITESURF plating whisker risk reduction (300 pins tested)

6.1 | BENEFITS OF LITESURF

During several years of research and development it was not possible to conclude that Bi based plating produced a zero whisker growth occurrence as some particles were detected. However, there are several factors which dramatically reduce the risk of whisker impact on an electronic system by utilizing Bi-based plating technology. This was demonstrated in tests comparing pins with a Bi-based plating to those with Sn-based plating (Fig.4)

6.1.1 | PARTICLE INCIDENCE OVER 100 µM

The occurrence/number of tin whiskers on a tin plated pin was measured at 4 % for whiskers with over 100 µm in length. In contrast, the occurrence/number of whiskers of this dimension on the Bi plated pin was less than 0.1%.

6.1.2 | PARTICLE SIZE

The maximum whisker size discovered in the case of Sn-based plating was 376 µm in length compared to 93 µm unconfirmed whisker length in the case of Bi-based plating.

6.1.3 | BISMUTH CONDUCTIVITY

In addition, Bi has a lower conductivity than Sn (Sn = 0.115 µOhm, Bi = 1.29 µOhm.) This means that in the unlikely event of a whisker-induced short circuit the amount of current that can be transported is considerably reduced thus reducing the potential impact of Bi whiskers by a factor of ten.

The reduced number and size of whiskers or particles combined together with the reduced potential impact due to the lower conductivity of Bi compared to Sn results in a whisker risk reduction by a factor of over 1,600 (or: <1:1,617 = <0.06 %)

6.2 | SUITABILITY FOR ALL MAJOR PCB TYPES

The Bi plating discussed here can be equally used with SnCu PCBs, with AgCu PCBs and with Organic Surface Protection (OSP) PCBs. As the fixing of the pins in the PCB holes does not rely on intermetallic reactions, LITESURF can be used in combination with different PCB technologies.

6.3 | ADDED BENEFITS

For manufacturing strategies like Sn-reflow on the connector side, a Bi plating offers the additional benefit of its higher melting point. 0.4 µm of Bi on the Press-Fit pin is enough to withstand a continuous furnace.

7 | BISMUTH – SAFETY AND AVAILABILITY

Bismuth has a long history of use in many areas including pharmaceutical and cosmetic applications. There is no known mechanism of absorption in the body and it has a low reactivity. It is therefore classified as non-hazardous [7, 8, 9, 10, 11, 12].

During the use of Bi as a surface material for Press-Fit pins, special care is taken to avoid any exposure of the workers to Bi powder as metal powders, in general, are considered a health risk. However, no specific risk from Bi in powder form, is known.

Bi is usually a by-product of the Cu, Pb or Sn refining process where the concentration of Bi can be between 100 and 10,000 ppm.

Separating Bi from Copper down to 5 ppm is state-of-the-art and is practiced in the mining refineries for ore and recycled shredder-fractions. For more background cf. [1, 2, 3, 4, 5, 6].

8 | SUMMARY AND OUTLOOK

After around four years of development and intense research, TE Connectivity’s Bi-based LITESURF now provides a reliable environmentally-friendly tin-free plating solution for use with Press-Fit interconnections with negligible risk from metallic whisker growth.

In comparison to Sn-based plating solutions, research has proven that LITESURF reduces the whisker risk by a factor greater than 1,600.

In addition, pins using LITESURF plating technology, require up to 30% lower insertion forces.

Other benefits of the LITESURF product process include carbon footprint reduction by up to 50% and the usage of nickel (Ni) is reduced by 80%.

LITESURF pins can be used with all major PCB technologies and is compliant with Sn-reflow treatment.

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PLEASE NOTE

More details on Multispring ST06 Press-Fit pins can be found under the TE-spec.: 108-90800

(http://www.te.com/content/dam/te-com/documents/automotive/global/Multispring%20Press-Fit%20Double%20Pin.pdf)

More details on NanoMultispring Press-Fit pins can be found under the TE-spec.: 108-90836

(http://www.te.com/content/dam/te-com/documents/automotive/global/1654334-1-nanomqs-interconnectors.pdf)

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TE Connectivity Germany GmbH
Ampèrestrasse 12-14
64625 Bensheim | Germany

www.TE.com

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