Reliability of PressFIT connections

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Abstract

Customers of power electronics require ever more modern, easy connection technologies, which also provide a higher reliability to meet the trends to higher temperatures and new applications. PressFIT is a force fitting technology for power semiconductor modules, which offers these possibilities. Such technology is well known as a highly reliable connection for several years in the industry, in telecommunications and in automotive designs. But for high current frequency controlled inverters, this technology is new. To take into account the application specific requirements, we modify common reliability test procedures for power modules and PressFIT connections. The data are analysed with special focus on the electrical resistance after climatic, vibration and temperature loads.

The conclusion of all tests is that the reliability of the PressFIT technology is superior and also well suited for power semiconductor modules.

1 Force fitting connections

1.1 Basics

If two contact faces of a connection are fitted together, there are only a few spots which are really connected (metal to metal) and which carry the current – also for polished surfaces. The minimum radius of such a microscopic metal-metal contact is typically 10µm.

In force fitting technologies like PressFIT, there is always a necessary plastic deformation on these really effective contact points within the contact zone, due to the high contact pressure that occurs since the macroscopic contact force concentrates on a small microscopic contact area. That means the two faces will be merged (Fig.1). Thus, the effective contact zone will be increased and - that is the most important thing – a gas tight contact zone is generated, which is very robust against corrosive environments.

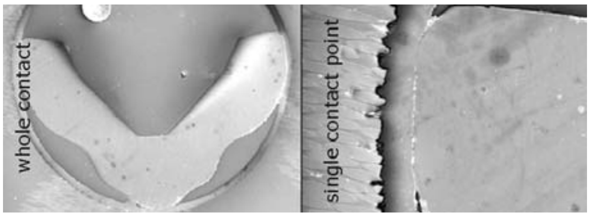


Fig. 1: SEM micrograph from a cross section of well merged surfaces in a force fitting connection (here EasyPIM™ PressFIT)

A schematic drawing of this is shown in Figure 2.

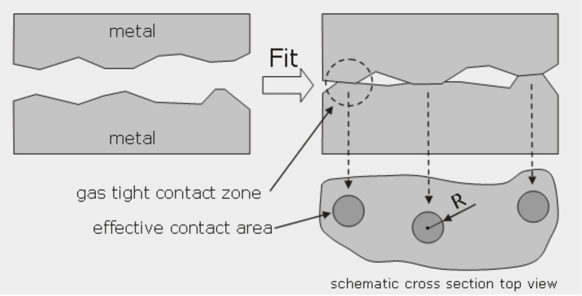


Fig. 2: Principle of PressFIT connection [2]

The connection principle is the well known cold welding effect. Therein, free electrons are generated out of the plastic deformation of both contact faces. The metal-bond electron cloud links the free electrons and connects them again with the same mechanism as in the basic metal. The bonding force is indeed lower than in the prior grid, but is increasing within the first hours of the connection due to recrystallization effects.

Cold welding is not suitable for detachable contacts (e.g. bonding of relay contacts) but well dedicated for permanent contacts, where the requirements regarding reliability are often much higher [2].

1.2 Common subjects for connections

1.2.1 Overlays

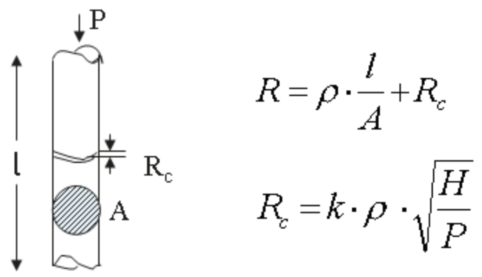
On every surface there are existing overlays out off corrosions, organic waste (e.g. fat) and other contamination, which can lead to contact problems. Here, the oxide layers from corrosion effects are generating the most problems.

One way to prevent such problems is to provide a surface out of noble metals. These surfaces are only leading to corrosion layers with a thickness of 2nm, which is such thin that quantum-mechanical tunnelling provides a sufficient current transport mechanism.

On all base metals, there can appear corrosions overlays in a thickness from 5nm up to more than 100nm. To build a good contact and to keep this alive, there are two mechanisms working:

The first is the so called “fritting”. This is the effect, where by electrical breakdown at voltages above typical 20mV (depending on overlay thickness) most corrosion will be burned away. This works well up to layers of about 100nm thickness. The disadvantage is that, for voltages below the 20mV limit (like for signals or measurement voltages), fritting does not occur and therefore large contact resistances may lead to big problems in the application.

A second way is to make sure that such disturbing overlays are destroyed during the contact formation process. The corrosion layers can be destroyed by a sufficient contact force like those in PressFIT connections. This second option seems to be the better one, because it does not need noble metal surfaces and is universally applicable, no matter what kind of electrical function the contact has to carry. The minimum force for destroying surface corrosion layers was determined out of earlier investigations about force fitting technologies to amount to 2N for every contact point. To calculate the evaluated resistance e.g. for new connector designs, the following approximation formulas are established [2] [5]:



$$R = \rho \cdot \frac{l}{A} + R_c$$

$$R_c = k \cdot \rho \cdot \sqrt{\frac{H}{P}}$$

Rc:= constriction resistance (because only spots are conducting)
A := Area; H := Hardness; P := Contact force ; k:=Constant
ρ :=Specific resistance

Fig. 3: Resistance of a connector

In the two formulas mentioned (Fig 3), the constriction resistance R_c is the main value and is synonymous with the common wording of the “contact resistance”. For PressFIT, the value of the contact resistance is calculated to approximately 0.05 mOhm.

This resulting, very low resistance, leads to a pretty stable high reliable connection in combination with the gas tight contact zone of the PressFIT technology. And it is also the reason, why a PressFIT connection can carry very high currents compared to other connectors, what makes it suitable for power semiconductor modules.

1.2.2 Fretting corrosion

In every design, there are ongoing movements during lifetime, due to vibrations or displacements from thermal cycles. Those are also leading to micro-movements between both partners of a contact system.

Because of the relative high holding forces of a PressFIT connection, the actual movements are expected to be negligible in most cases.

However, microscopic motions of the contact system have to be considered nevertheless.

If the surface of the connectors is plated with a noble metal, there will be no contact problem over lifetime. But, due to the friction, the lifetime of the plating (for noble metals mostly a flash of <0.1µm gold) is limited so that sometimes the problem is only shifted to a later date.

The movements within a contact system are generally under 10µm. In this range, the effective contact areas of a PressFIT contact zone are kept. The result is, that there is no relevant change of the contact resistance measurable over system lifetime, consequently the PressFIT contact is never expected to be the limiting factor (Fig. 4).

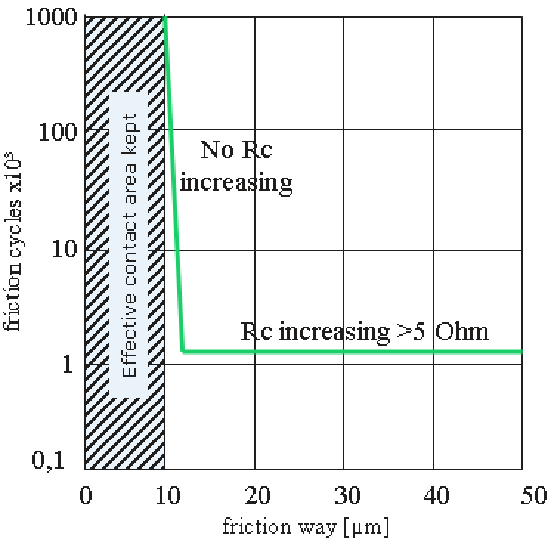


Fig. 4: Relation of friction and resistance

If there are movements above the 10µm, the connector resistance increases to a few ohms quickly, in most cases (Fig. 4) [2].
While a periodic displacement > 10 µm, resulting from periodically overcome of the holding force, will lead to contact degeneration for PressFIT contacts in the way described above, a limited number of long-range displacements are tolerated by the PressFIT contact system.
The effect is that the high contact force is able to generate new, gas tight contact zones after a movement. That means also, the contact can compensate some displacements resulting from mounting displacements due to tolerances.
In the same way, a PCB may be re-used with a PressFIT connector more than one time (e.g. for rework) so that a failed device can easily be replaced. Due to plastic deformation and tolerance issues, a PressFIT contact Pin must not be assembled to a second PCB after having been demounted from a first PCB, however.

2 PressFIT connections for power modules

2.1 EconoPIM™ & EasyPIM™ PressFIT

One of the crucial questions for PressFIT technologies is the one for the contact material and geometry providing large enough force to remove corrosion layers and guarantee sufficiently high holding forces, providing enough flexibility not to destroy the contacted PCB, tolerating manufacturing tolerances for conventional PCB holes (vias), and providing sufficiently large current capability.
Due to this, two PressFIT designs with flexible force fitting geometries have been developed (Fig. 5 and Fig.6). One for the EconoPIM™ and one for the EasyPIM™ modules, providing current carrying capabilities to max. 50A /pin and 25A/pin, respectively [1] [3].

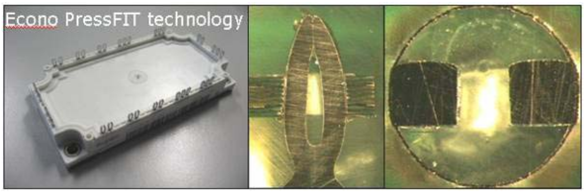


Fig. 5: EconoPIM™ PressFIT

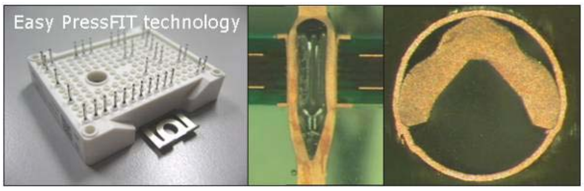


Fig. 6: EasyPIM™ PressFIT

2.1 Two designs – one basic technology

Both technologies - EconoPIM™ and EasyPIM™ PressFIT - are based upon the same principles for force-fitting connections.
Both are built with a copper alloy and have a surface plating of pure tin.

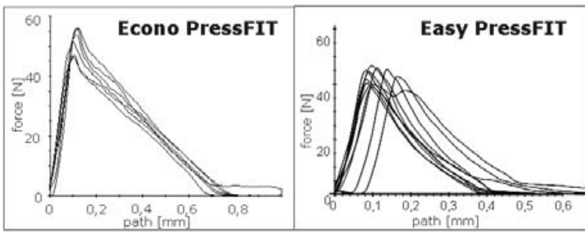


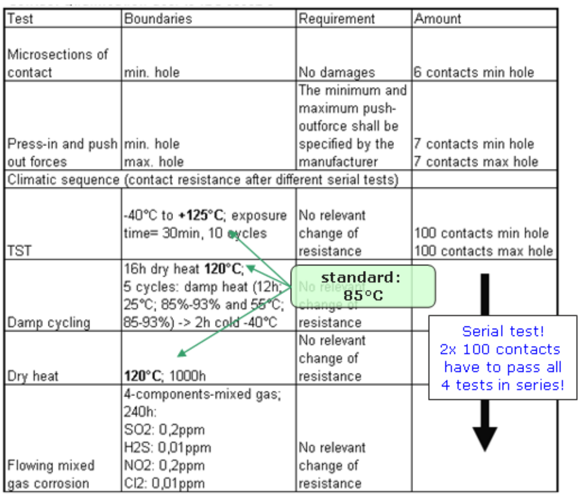
Fig. 7: Holding forces of two designs

As shown in figure 7, the holding forces, which are corresponding with the contact forces, are for both PressFIT designs in the same range.
The slightly increased value of the EconoPIM™ is designed due to that the geometry has one contact point more.

3 Reliability of PressFIT connections for power modules

3.1 Standard reliability tests to release a new PressFIT design – with enhanced conditions

To qualify and release a new force fitting design, there is a well established release program, which is described in the IEC standard 60352-5 (Fig. 8) [4]. Therein, all the tests have to be made with standardized PCB's (with minimum and maximum hole diameters) and especially the climatic sequence is a quite challenging test. Looking at the test conditions of this program yields an obvious mismatch between the requirements for power modules and this standard reflecting the needs of standard PCB-applications, especially with respect to the temperatures defined for the various test steps.
So, due to the required suitability for power modules, the temperatures in the single components of the climatic sequence have been increased. The green field in figure 7 denotes the temperature defined in the original standard [4].
The maximum temperature in the Temperature Shock Test (TST) has been shifted from 85°C to the common maximum temperature for power modules of 125°C. Also the temperatures in the damp cycling and the dry heat test have been increased from 85°C to 120°C. This value even lies significantly above the common maximum temperature for standard PCB's of 105°C.



Test	Boundaries	Requirement	Amount
Microsections of contact	min. hole	No damages	6 contacts min hole
Press-in and push out forces	min. hole max. hole	The minimum and maximum push-outforce shall be specified by the manufacturer	7 contacts min hole 7 contacts max hole
Climatic sequence (contact resistance after different serial tests)			
TST	-40°C to **+125°C**; exposure time= 30min, 10 cycles	No relevant change of resistance	100 contacts min hole 100 contacts max hole
Damp cycling	16h dry heat **120°C**; 5 cycles: damp heat (12h; 25°C; 85%-93% and 55°C; 85-93%) -> 2h cold -40°C	No relevant change of resistance	
Dry heat	**120°C**; 1000h	No relevant change of resistance	
Flowing mixed gas corrosion	4-components-mixed gas; 240h: SO2: 0,2ppm H2S: 0,01ppm NO2: 0,2ppm Cl2: 0,01ppm	No relevant change of resistance	

standard: 85°C

Serial test! 2x 100 contacts have to pass all 4 tests in series!

* Example of Easy PressFIT

Fig. 8: Contact qualification acc. to IEC 60532-5 adjusted to power module needs

All the qualifications have been passed, without any failure and without any noticeable contact degradations.

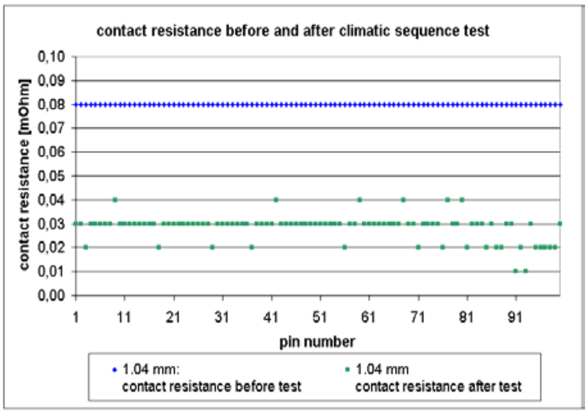


Fig. 9: Contact resistance after a climatic sequence

As shown in figure 9, the contact resistance of the PressFIT contact is even decreased after the climatic sequence test (here with the minimum hole diameter of 1.04mm). This is the well known effect described above, resulting from recrystallisation and the further merging of the contact partners.

3.2 Standard reliability tests to release a power module – with enhanced conditions

For power modules, there is also a well established standard accepted, according to the IEC 60749 [6] (Fig.11). In addition, some further tests became usual regarding the influence of the environment of the modules, according to the IEC 60068-2 Part 43 and 52 (Fig.11) [7] [8].
Again, to get a quite good conclusion about the reliability of a power module combined with the PressFIT technology, some enhancements of the common tests for modules have been done.

The first difference is that in most cases, all the reliability tests for modules are made without a PCB. Here, in all tests the modules are mounted, that means are pressed into a PCB.
In the H3TRB (high humidity, high temperature, reverse bias), the TST (thermal shock test) and the vibration test, there was installed an additional online resistance observation during the whole tests. Thereby, every slight change or interruption can be noticed. The voltage here was adjusted at ~1.3mV (1.2mV to 1.4mV, depending on temperature in test and corresponding electric conductivity) and the current was set to 1A. As described above, these low values are important to eliminate fritting effects, which could blur small changes of the contact resistance. Consequently, there is no possibility of any unseen effects left during the test. The observed resistance value (1.3mOhm at room temperature) belongs to the whole test setup and consists of two contact resistances and a small circuit path. This is due to the online measurement is built with a loop from a first pin and its contact resistance, over the test PCB to a second pin over his contact resistance (Fig. 10).

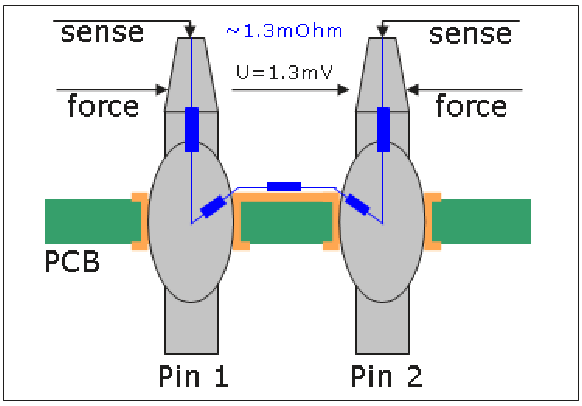
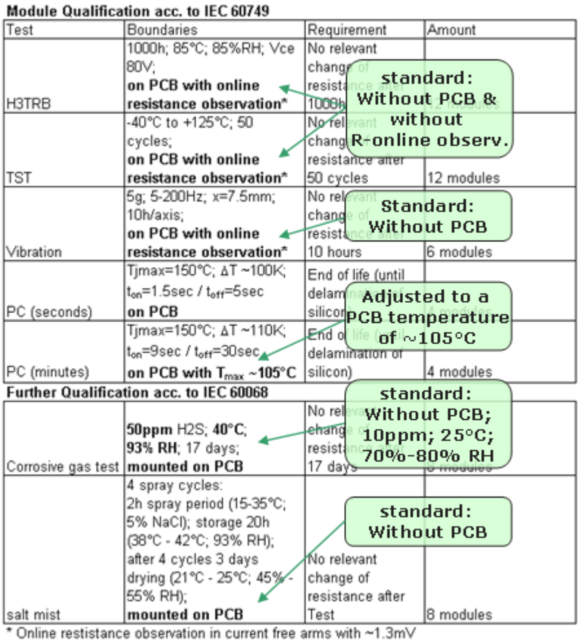


Fig. 10: schematic drawing of the online resistance observation setup.

Also some conditions of the single tests have been made stricter as mentioned before:
For the PC (power cycling) test with cycles in the range of a steady temperature state ("minutes"), the temperature was not only adjusted to the maximum chip temperature as usual, but also to a maximum PCB temperature of ~105°C.
Finally, also the parameters of corrosive gas test were made stricter. Instead of 10ppm H2S, the concentration was set to 50ppm. The temperature in the chamber was shifted up to 40°C, compared to 25°C in the standard, and the humidity was set to 93% instead of the maximum of 80%. These values are out of the limits of the available test equipment.



Module Qualification acc. to IEC 60749

Test	Boundaries	Requirement	Amount
H3TRB	1000h; 85°C; 85%RH; Vce 80V; **on PCB with online resistance observation***	No relevant change of resistance after 1000h	12 modules
TST	-40°C to +125°C; 50 cycles; **on PCB with online resistance observation***	No relevant change of resistance after 50 cycles	12 modules
Vibration	5g; 5-200Hz; x=7.5mm; 10h/axis; **on PCB with online resistance observation***	No relevant change of resistance after 10 hours	6 modules
PC (seconds)	Tjmax=150°C; ΔT ~100K; t_{on}=1.5sec / t_{off}=5sec **on PCB**	End of life (until delamination of silicon)	4 modules
PC (minutes)	Tjmax=150°C; ΔT ~110K; t_{on}=9sec / t_{off}=30sec **on PCB with T_{max} ~105°C**	End of life (until delamination of silicon)	4 modules

Further Qualification acc. to IEC 60068

Corrosive gas test	**50ppm** H2S; **40°C;** **93% RH**; 17 days; **mounted on PCB**	No relevant change of resistance after 17 days	8 modules
salt mist	4 spray cycles: 2h spray period (15-35°C; 5% NaCl); storage 20h (38°C - 42°C; 93% RH); after 4 cycles 3 days drying (21°C - 25°C; 45% - 55% RH); **mounted on PCB**	No relevant change of resistance after Test	8 modules

* Online restistance observation in current free arms with ~1.3mV

Fig. 11: module qualification acc. to IEC 60749 and 60068

The green fields denote the boundaries defined in the original standards [6] [7] [8].

All modules related tests have been passed without any measurable contact degeneration.

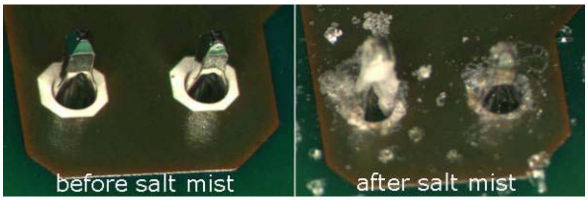


Fig. 12: Contacts before and after salt mist

Also in the online resistance observation, no interruption or conspicuous change has been detected (example see figure 13).

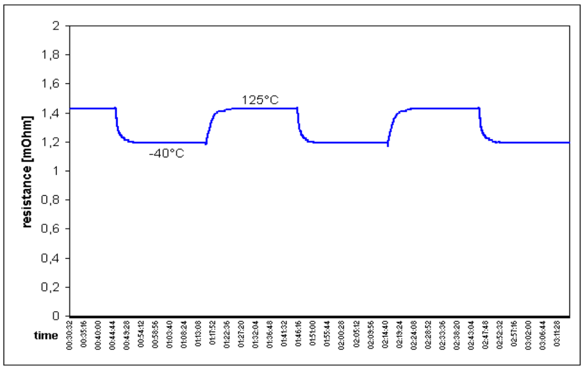


Fig. 13: Value pattern (mOhm) of online resistance observation – here of TST

The in figure 13 shown cut out of a chart from the sensitive online resistance observation in the TST test gives a fine image about the changing electric conductivity due to the two temperatures of -40°C and +125°C. No deviation could be noticed over operating time of all the tests.

Because the robustness against vibration loads is an important issue, there was made an additional small vibration test with the same boundary conditions as in the “standard” test (see Fig. 11) but with an acceleration of 20g. In such a test (standard or special), it is always difficult to find a representative setup because the geometric design and the masses in real applications are never of a similar type. So it was decided, to vibrate the module with a small single PCB without additional masses but due to this, also without a fixation at the module or the machine. These boundaries have also been used for the “standard” vibration test (Fig. 11). An online resistance observation was not possible because the equipment was too sensitive for this test. But the measurement setup was once again the same.

The result shows that also a really strong vibration (with 20g) could not damage or degrade the PressFIT contact (Fig. 14).

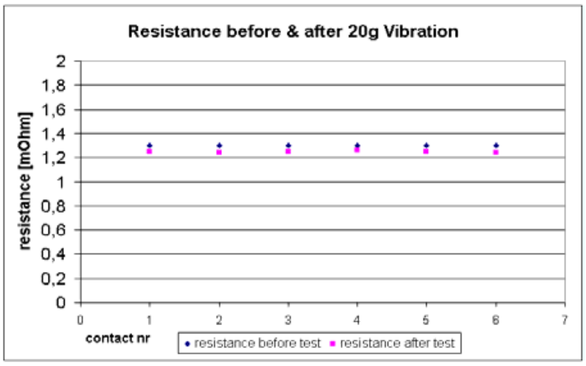


Fig. 14: Resistance before and after 20g vibration load

3.3 Reliability & Rework

Today, in most production lines rework is rare and not planned in standard calculations for yield or quality targets in the power range of modules with solder or PressFIT connections.

However, for modern production sites it is mostly mandatory to get a design which is suitable for service and repair. That means for power modules that they have to provide the possibility of demounting. As shown in previous publications modules with PressFIT connections can be demounted and the PCB can be used two more times with a new module [1] [3].

But what’s about the reliability of the PressFIT? To assure that in case of such a rework situation the module reliability is not deteriorated, an additional TST test series with EconoPIM™ PressFIT modules has been made.

First, a standard TST (from -40°C to 125°C; with readouts at 50cycles and 100 cycles) was done up to 150cycles, to get a comparability to a run with an identical but reworked setup (Fig 15).

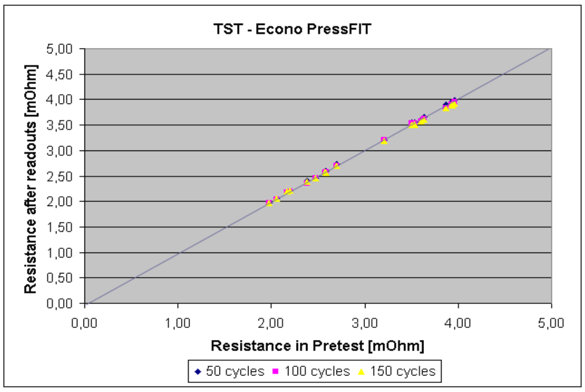


Fig. 15: Comparison of resistances after TST from 50 to 150 cycles without rework

For the rework test, the procedure was as following with the same test setup as before:

A first module was taken and pressed into the PCB board as usual. After a pre-measurement of the resistance, 50 cycles of TST (-40°C to 125°C) have been made, with following measurement of resistance again. Then, the module was pressed out and a new, second module was pressed in as usual. Again, pre-measurement, TST and measurement of resistance after TST has been done. This procedure was done again for an additional time so that three modules have been ran trough 50 cycles of TST each – all in one and the same PCB.

The PCB has a few connections to measure the resistance of the pins, which have different connection lengths. Due to these different lengths in the setup, there is a wide spread of the single resistance values in the results because they are dominated by the lead resistances between contact and measurement points.

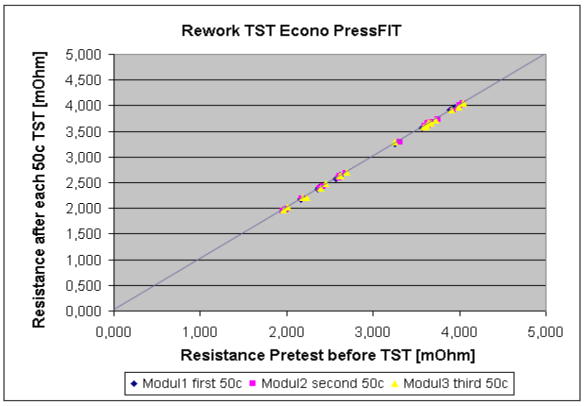


Fig. 16: Three modules in three times TST in series with one PCB board. Details see text.

However, as shown in figure 16, there was no relevant change of the resistance detected for the three modules and three TST tests.

4. Conclusion

A lot of tests regarding the application of the PressFIT technology and its reliability in power modules have been performed.

The result of the whole program can be concluded as follows: Not one of the tests cause a measurable contact degradation. The resistance of the connection, which is the leading value for the quality of the connection, is very stable during and after several loadings. This means not only that high current can be handled safely over the lifetime, but also the advanced integrated functions with low voltage and current (e.g. current sensing) will be kept absolute stable beyond the lifetime of the system.

Due to this, the PressFIT technology is well suited for the application of power semiconductor modules – especially for future requirements of higher reliability.

Literature

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