Press-Fit Technology, a Solderless Method for Mounting Power Modules

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Abstract: Press-Fit technology offers the possibility of leadfree solderless mounting of power modules. Advantages of this new technology for power modules in comparison to existent technologies are shown. Results regarding high current behaviour, vibration loads and mounting are presented. The measured low electrical and thermal contact resistance show the ability to use the contact technology for a wide range of currents and applications.

I. Introduction

According to the RoHS directive, in 2006 most lead containing solder alloys have to be replaced by leadfree solders [1]. This results in higher melting point solders and lead free tin metallization of the PCB, which has significant effects on the mounting process.

Press-Fit technology is one possibility for leadfree solderless mounting of power modules. For lower currents, pin geometries with different plating materials have been investigated and pure tin as a favourable metallization identified [2].

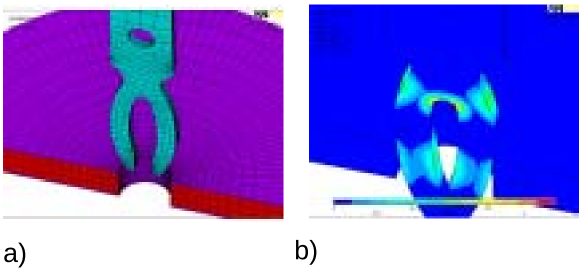
In this paper a specially designed Press-Fit contact for high currents will be investigated and qualified for the use in medium power modules. A module with compliant pins used for the Press-Fit mounting is shown without lid in figure 1.

Fig. 1: Power Module with compliant pins

II. Pin geometry

The large number of contacts in the power module makes it necessary to constrain the press-in forces whereas push-out forces, respectively holding forces, have to be high. Additionally, for the pin material copper has to be used to realize low electrical resistance.

A fork type pin geometry, that meets these requirements, is shown in figure 2 as a finite element simulation model.



a) b)

Fig. 2: a) simulation model (half structure) b) plastic strain in the pin during press-in process

During the press-in process, first the fork closure results in plastic deformation in the upper region of the pin. Afterwards the contact between the pin and the metallization of the PCB-hole is developing and elastic and plastic deformations generate a large contact area. Microsections of the contact are shown in figure 3.

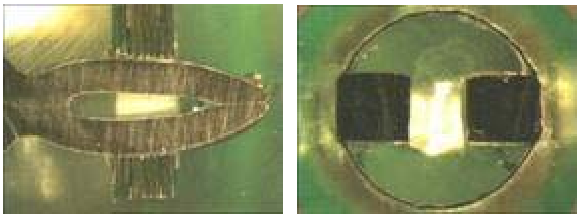


Fig. 3: a) longitudinal and b) vertical microsection of contact with 2.14 mm hole diameter

Contact forces of 54 N are simulated. With the knowledge of the contact force, the following simple formula can be used to estimate the resulting contact resistance [5],[6]:

$$R_{contact} \approx 140 \cdot \rho_{Sn} \cdot \sqrt{\frac{H_{Sn}}{P_{contact}}}; \begin{array}{l} H_{Sn} : hardness\ of\ tin \\ \rho_{Sn} : resistivity\ of\ tin \end{array}$$

$$= 140 * 1.1 \cdot 10^{-5}\,\Omega cm \cdot \sqrt{\frac{3 \cdot 10^4 \ \frac{N}{cm^2}}{54\,N}} = 0.036 m\Omega$$

The calculated low contact resistance was verified with experimental data during the qualification process. Values between 0.02mΩ and 0.04mΩ result from the measurements of 200 pins.

III. Press-in and Push-out forces

To meet tolerance requirements of common PCB manufacturing, a range of hole-diameters has to be investigated. For the minimum (2.14 mm) and maximum hole size (2.29 mm) press-in and push-out forces are measured. The plating of the pin is galvanic tin and for the PCB immersion tin is used.

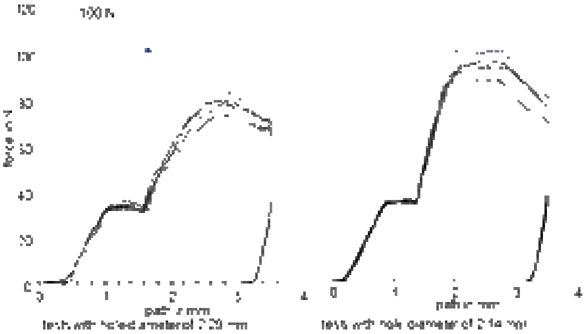


Fig. 4: Press-in forces for minimum and maximum hole size

Figure 4 shows forces occurring during the press-in process. The maximum press-in force of 102 N is measured for the minimum hole diameter, whereas the minimum force of 72 N results for the maximum diameter.

The first plateau of the curves shows the closure of the fork. Subsequently the forces are increasing, while the pin moves into the PCB.

Due to cold welding, holding forces are increasing over a short period after press-in. Therefore push-out forces are measured 72 hours after the press-in procedure. As shown in figure 5, the resulting forces are independent of the PCB-hole size and vary in the range between 45 N and 60 N.

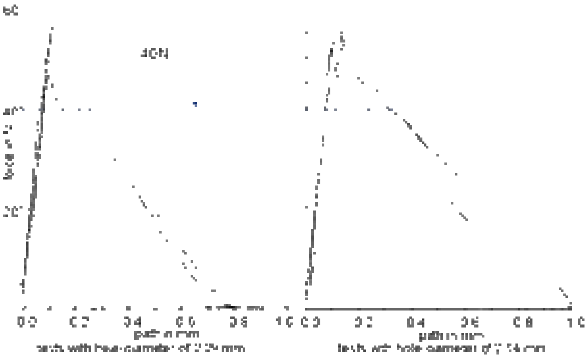


Fig. 5: Push-out forces for minimum and maximum hole size

Plastic deformations during the press-in process are responsible for the hole size independent push-out forces. Benefiting from this effect also repair cycles for the exchange of power modules are possible. After four repair cycles with new compliant pins in the same PCB no decrease of push-out forces could be detected. Also previous reflow processes of the PCB do not effect the push-out forces.

IV. Thermal-electrical behaviour

A test module with short circuit connections inside was built up to investigate the thermal-electrical behaviour of the Press-Fit contacts (see figure 6).

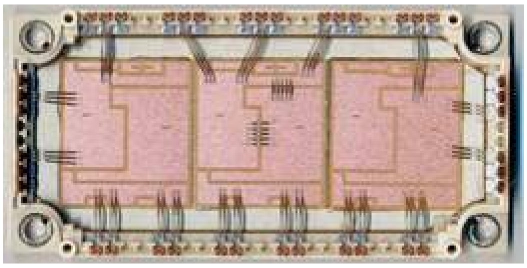
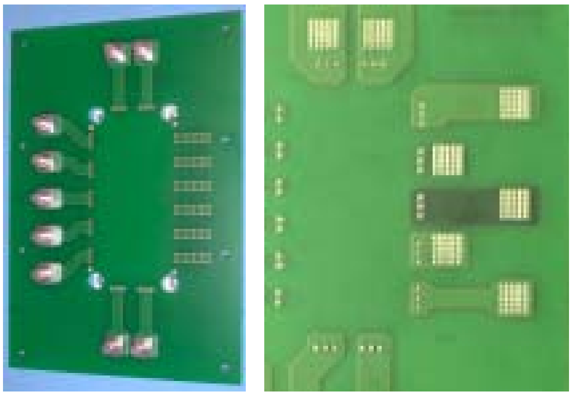


Fig. 6: test-module with short-circuit connections

Two different PCB-layouts shown in figure 7 were used to perform high current investigations. A copper thickness of 105 µm is used to realize the tracks. The PCB in figure 7a has got two copper layers, whereas figure 7b shows a four layer board.



a) b)

Fig. 7: test-PCBs for high current investigations

Heating the base plate to a constant temperature, the current in one pin has been varied and temperatures were measured with infrared thermography. As an example figure 8 shows the temperature distribution for a current of 80 A and a base plate temperature of 90 °C. No strong temperature gradient between PCB and compliant pin could be detected.

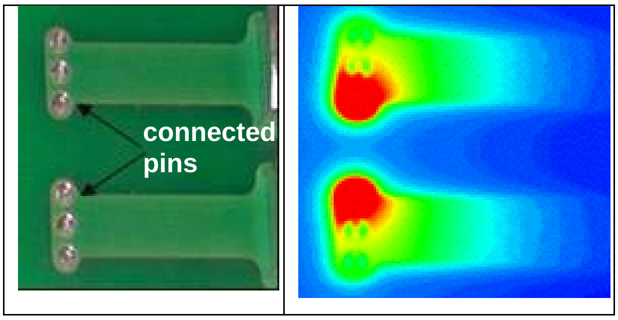


Fig. 8: infrared thermography for 80A per pin at 90 °C case temperature (conductor width 2x7.5 mm)

Figure 9 shows the maximum temperature in the pin after 25 s current conduction. With a base plate temperature of 90 °C a maximum temperature of 125 °C is reached at 75 A per pin. 125 °C is a typical continuous operation temperature of FR4. Therefore the maximum current in this work is defined for a pin temperature of 125°C. Using other PCB materials, the maximum temperature can be increased.

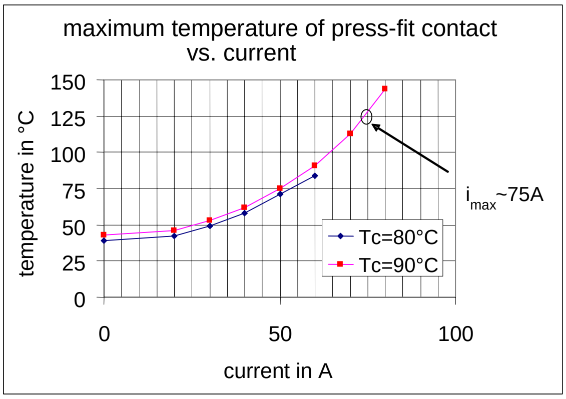


Fig. 9: maximum temperature for different base plate temperatures after 25 s

The base plate temperature has low influence on the maximum temperature, because heat transfer between pin and DCB-ceramic is mainly limited by the wire bonds.

Further investigations on different PCB-track geometries confirm the current carrying capability of the pins. The results in table 1 show that the use of three pins with the same track geometry allows to double the current.

conductor width in mm	4x 7,5	4x 15	2x 15	1x 15	2x 15
contacts	1	1	1	1	3
Layer (inner, outer)	i+o	i+o	i	o	i
max. current in A	71	73	73	66	139,5

Table 1: maximum current for different conductor geometries

Measuring the voltage drop during the high current tests, the distribution of the losses can be identified. The total resistance can be devided into parts shown in figure 10. Black circles in the picture show the measuring points for calculation of resistance.

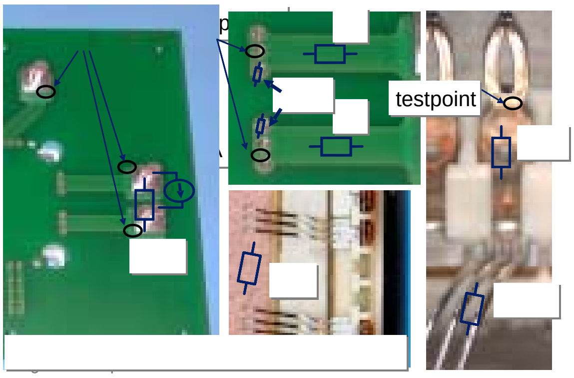


Fig. 10: electrical resistance of measurement setup

As listed in table 2 the total resistance is dominated by wire bonds and pin. The portion of contact resistance is lower than 5 %. Therefore the current carrying capability is not limited by the Press-Fit contact resistance but by the resistance of wire bond and pin.

The current can be increased by optimizing the PCB-layout, the use of thicker copper or PCB base material with higher T_g.

Resistance	mΩ	portion
$2*R_{kont}$	<2*0.09 *)	< 5 %
$2*R_l$	~2*0.36	~16 %
$2*(R_{bond}*R_{pin})+R_{cu}$	~3.6	~80 %
R_{ges}	~4.5	100 %
*) measurement according DIN standards results in values <0.04 mΩ		

Table 2: resistance portion of measurement setup

V. Environmental investigations

According to IEC 60 352-5 [3] climatic sequence tests including thermal shock, dry heat and flowing mixed gas corrosion tests have been conducted. The electrical resistance of 200 contacts has been measured before and after these tests. No increase of resistance could be observed after the tests. The Press-Fit technology realizes a gas-tight contact and no degradation due to corrosion or fatigue takes place.

Figure 11 shows the experimental setup, used to test vibration loads. Metal rods were used to simulate capacitor weight. The condition with a maximum of 5 g acceleration up to 200 Hz was selected to meet requirements of distributed drive technology.

Fig. 11: experimental setup of vibration qualification

Optical control and microsections after the test show no changes of the contact geometry.

The change of resistance after the vibration loadings is shown in figure 12.

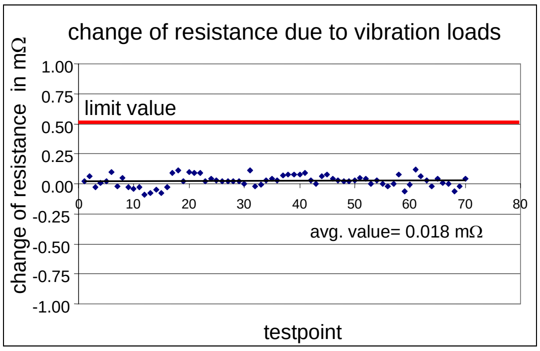


Fig. 12: change of resistance after vibration loadings

The observed differences are negligible and mainly caused by the inaccuracy of measuring the total resistance including wire bond and track resistance.

The high contact force of 54 N per Pin is responsible for the vibration-proof technology. No opening and closure of the contact is possible during the loadings.

VI. Comparison of contact technologies

Press-Fit technology is well accepted in automotive applications. For backplane connectors it is currently the dominant technology [8]. The main reason is the proven reliability of the interface. FIT (failure in time) rates can be used for reliability predictions on products which contain electrical connections [7]. In table 3 FIT rates of Press-Fit technology are listed in comparison to solder or plug connections. Conditions for the use of these values are 50 % of the rated current and an ambient temperature of 40 °C.

	Soldering manual/ machine	Press-Fit	Plug-In tin / gold
Failure rate λ in FIT *)	0.5 / 0.03	0.005	0.15 / 0.1
*) FIT = one failure in 10^9 hours			

Table 3: failure rates of contact technologies [7]

The absolute values are dependent of the environmental conditions. Failure mechanism like solder joint fatigue after thermal cycling or fretting corrosion of tin plated plugs doesn't occur with well designed Press-Fit contacts [4][6]. The resulting extremely low FIT value for Press-Fit contacts offers the possibility to increase system reliability under harsh conditions.

The high push-out forces of Press-Fit compliant pins holds the connection in place additionally to the electrical contact and avoids constructions, necessary for plugs.

In comparison to soldering, Press-Fit technology offers the possibility of mounting the power module on component and solder side of the PCB. This increases the design flexibility. Additionally the module mounting process can be separated from the soldering of PCB.

VII. Conclusions

Press-Fit technology offers the possibility of solderless mounting of Power Modules, meeting the demands of leadfree technology. No special surface plating or high accuracy PCB boards are needed. This work shows that low ohmic contact resistance can be realized using a fork type pin geometry with copper material.

The low electrical and thermal resistance enables the use of the contact for a wide range of currents and the current carrying capability is not limited by the contact resistance.

Environmental tests show that vibration loads and climate sequences have no negative influence on the contact resistance. This results from the gas-tight contact and high contact force.

The high holding forces of the contact are independent of the PCB hole tolerances. This reduces the effort for mechanical fixing similar to solder connections. The Press-Fit process can be separated from soldering and allows module mounting on soldering and component side of PCB.

The high reliability of Press-Fit contacts in general promise to increase the system reliability. This is especially of interest, if modules are operated in harsh environment.

Acknowledgement:

The authors would like to thank W. Kallee from Würth Elektronik for cooperation during design of pin geometry and PCB specification work,

T. Heinisch from Siemens, Center of Quality Engineering, for doing qualification work

and B. Böttcher from eupec for thermography investigations.

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