DirectFET™ Technology

Materials and practices

About this document

Scope and purpose

The growing DirectFET™ range includes various can sizes and device outlines. There are now lead-free variants, identified by a PbF suffix after the part number (for example, IRF6618PbF). This application note provides information about the potential impact of four factors in assembly: underfill, lead-free solder, insulated metal substrates and conformal coatings.

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1 Factors causing thermal fatigue

In the DirectFET™ Board Mounting Application Note, AN-1035, Infineon offers guidelines for designing and assembling boards using this range of devices. Of course, in reality, customers have to balance numerous conflicting requirements when they select the materials and practices for their production facilities. In writing this document, the aim is to provide more background information on the potential impact of four factors:

1. Underfill
2. Lead-free solder
3. Insulated metal substrates (IMS)a
4. Conformal coatings

When surface mount devices are assembled onto boards, dissimilar rates of thermal expansion in the device and substrate can cause fatigue in the boardattach solder. This may lead to an increase in the thermal and electrical resistance of the solder joint. Consequently, when investigating materials and practices for use with DirectFET™ technology, Infineon has used shifts in the drain-tosource resistance of the device when on, $R_{DS(on)}$, to monitor the onset of thermal fatigue.

The control with which changes are compared is a medium can device mounted on an FR4 substrate using a lead-based solder alloy. The device was then subjected to a thermal cycle range of -40°C to +125°C. Results of this test are taken as 1.0, with the results of other tests quoted relative to this baseline. Normalized shifts in $R_{DS(on)}$ over 1000 cycles varied from 0.02 to 2.3, indicating that some processes improve resistance to fatigue while others degrade it.

Thermal cycling provides an accelerated simulation of the impact of repeated power cycles. Assuming that a power cycle takes the board junction from ambient temperature to 105°C, one thermal cycle has an effect equivalent to at least 15 power cycles. Therefore, Infineon's tests over 1000 thermal cycles give an approximation of the $R_{DS(on)}$ shift that would be seen after more than 15000 power cycles.

Where appropriate, for example with insulated metal substrates, the thermal cycle range was extended to -55°C and +150°C to verify that the device can withstand the environments in which such materials might be used.

2 Summarized test results

The table below brings together the results of Infineon's evaluations of the listed materials and practices. In summary, underfill was found to make a major contribution to fatigue-resistance, while all other changes had a detrimental impact.

Table 1 Fatigue testing results

Substrate composition	Solder alloy	Temp cycle range (°C)	Mean $R_{DS(on)}$ shift (µΩ)	Normalized $R_{DS(on)}$ shift 1000+ cycles
FR4	Pb	-40 to 125	130	1.0
FR4 with underfill	Pb	-40 to 125	3	0.02
FR4	Pb-free	-40 to 125	180	1.3
AlSiC/Cu	Pb	-40 to 125	260	1.9
AlSiC/Cu	Pb-free	-40 to 125	190	1.4
AlSiC/Cu	Pb	-55 to 150	270	2.0
AlSiC/Cu	Pb-free	-55 to 150	310	2.3
FR4 with conformal coating	Pb-free	-40 to 125	180	1.3

The remainder of this paper describes the conditions under which the tests were conducted, discusses the significance of the results and offers points to consider when using DirectFET™ with the listed materials and practices.

Note: Performance in specific manufacturing environments may differ from that observed.

The tests performed to date indicate the probable implications of the listed materials and practices. Although Infineon believes its results to be representative, customers should be aware that larger sample sizes and more rigorous control procedures would be required to ensure that no other factors had influenced the outcome of the tests.

3 Use of underfill beneath devices

Underfill provides increased physical protection, which can improve performance in harsh environments. It is used extensively with solder-balled components.

3.1 Test conditions

Infineon's tests used a multipurpose, cyanate ester underfill material designed for use with CSP, BGA and Flipchip components. The underfilling process complied with the manufacturer's instructions.

3.2 Results

Enhanced performance was expected but the results far exceeded predicted gains. Mean $R_{DS(on)}$ shift dropped from 130 µΩ to 3 µΩ, a fall of almost 98%.

3.3 Conclusion

Although DirectFET™ devices do not need underfill, using this process makes them almost impervious to solder fatigue from thermal cycling. Infineon would like to thank Ablestik for supplying underfill samples and information.

4 Use of lead-free solder alloys

With international legislation requiring gradual replacement of lead-based solders with lead-free alternatives, the effect of different solder alloys on device performance is increasingly important. The use of higher reflow temperatures for lead-free solder than for lead-based equivalents can present problems for normal plastic packages. However, Infineon is confident that DirectFET™ devices will not be adversely affected by the temperatures needed by lead-free alloys because all testing has been conducted with reflow profiles peaking at 260°C.

4.1 Test conditions

Infineon's tests used:

- Lead-based **Sn62 Pb36 Ag2** (near eutectic)
- Lead-free **Sn95.5 Ag3.8 Cu0.7**

These alloys have been compared using different substrates and production conditions. The results reported were achieved using a standard glasswoven substrate (FR4).

4.2 Results

When used on a glass-woven substrate, lead-free solders generally perform in a similar way to lead-based equivalents. However, Infineon's tests showed mean $R_{DS(on)}$ shift rising from 130 μΩ to 180 μΩ.

4.3 Conclusion

As there is no reason why lead-free solder should not match or even surpass lead-based solder in performance, it is possible that the increase in $R_{DS(on)}$ shift seen in Infineon's tests might have been influenced by other factors. In low-volume tests, there is the potential for significant differences in resistance between individual devices or batches of devices used in the lead-based and lead-free groups.

Some DirectFET™ devices are qualified for use with lead-free pastes. Others are undergoing qualification. Products that are evaluated with both lead-containing and lead-free solder pastes are identified by PbF suffix. Products without the PbF suffix are not recommended for use with lead-free pastes.

5 Use of insulated metal substrates

Insulated metal substrates are commonly used in high-power applications, where their increased thermal capacity is important. Aluminum-based (Al) substrates showed the high rates of thermal expansion typical of this material, making it difficult to achieve good reliability in solder joints and therefore make full use of the thermal properties of the metal substrate.

More recently, suppliers of insulated metal substrates have introduced new materials, including aluminum silicon carbide (AlSiC) and copper (Cu), which have lower rates of thermal expansion.

Table 2 Thermal expansion of materials

Material	Thermal expansion (ppm)
Al	24
AlSiC	15
Cu	17

Note: Although FR4 substrates typically have lower rates of thermal expansion than metal substrates (10–15 ppm), they become pliable at higher temperatures and this itself puts stress on components. Metal substrates are more stable at high temperatures and, because of their better heat-conduction properties, tend to run cooler than FR4.

5.1 Test conditions

Infineonhas done tests on both AlSiC and Cu substrates, using samples supplied by The Bergquist Company. Unsurprisingly, given their very similar rates of thermal expansion, results for the two materials were almost identical (and within the expected variation of the test method).

The insulated metal substrates were tested with both lead-based and lead-free solder alloys. Initial tests used the same temperature cycle as for the control but this was later extended to -55°C and +150°C; glass-woven substrates do not perform reliably at the upper end of this range.

5.2 Results

With a lead-based solder, mean $R_{DS(on)}$ shift rose from 130 μΩ for to 260 μΩ, a 100% increase. However, with a lead-free solder, the change from 180 μΩ to 190 μΩ was only about 6%. This confirms the potential of lead-free solder to perform well. Even at the wider temperature range, mean $R_{DS(on)}$ shift remained within acceptable limits: 270 μΩ for lead-based solder, 310 μΩ for lead-free solder.

5.3 Conclusion

Using metal substrates increases mean $R_{DS(on)}$ shift but not to a level likely to cause problems in using DirectFET™ devices. Infineon would like to thank The Bergquist Company for supplying insulated metal substrate samples and information.

6 Using conformal coatings

Conformal coatings of various materials are used for protection in harsh environments. At the request of some customers, Infineon tested a silicone based coating with DirectFET™ devices.

6.1 Test conditions

Infineon complied with the manufacturer's instructions regarding the application and curing of the conformal coat material, and then subjected the parts to the test.

6.2 Results

As the summary table shows, mean $R_{DS(on)}$ shift was identical to that shown for the same FR4 Pb-free substrate without a conformal coating. No device failures were seen.

6.3 Conclusion

Many customers are successfully using conformal coatings with the latest DirectFET™ devices. However, as many different coating materials are available, Infineon recommends careful evaluation of the properties of proposed coatings. Infineon would like to thank Henkel AG for supplying conformal coating materials and information

Revision history

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6.1	05-June-2020	Update to Infineon template

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