Application Note AN-1050

DirectFET^{TM} Technology
Materials and Practices Application Note

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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)
4. Conformal coating

Factors causing thermal fatigue

In the DirectFET Board Mounting Application Note, AN-1035, International Rectifier 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)
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 board-attach 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, International Rectifier has used shifts in the drain-to-source resistance of the device when on, R_{DSon}, 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_{DSon} 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, International Rectifier's tests over 1000 thermal cycles give an approximation of the R_{DSon} 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.

Summarized test results

The table below brings together the results of International Rectifier'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.

Substrate composition	**Solder alloy**	**Temp cycle range (°C)**	**Mean R_{DSon} shift (μΩ)**	**Normalized R_{DSon} shift 1000+ cycles**
FR4	Pb	-40 +125	130	1.0
FR4 with underfill	Pb	-40 +125	3	0.02
FR4	Pb-free	-40 +125	180	1.3
AlSiC/Cu	Pb	-40 +125	260	1.9
AlSiC/Cu	Pb-free	-40 +125	190	1.4
AlSiC/Cu	Pb	-55 +150	270	2.0
AlSiC/Cu	Pb-free	-55 +150	310	2.3
FR4 with coating	Pb	-40 +125	300*	2.3*

* Even these figures do not fully reflect the potential impact of conformal coatings on performance. When using coatings, great care must be taken to avoid air pockets that can cause unacceptable increases in solder-joint resistance and even total failure of devices. Refer to the 'Use of conformal coatings' section for details.

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 International Rectifier 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.

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.

Test conditions

International Rectifier'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.

Results

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

Conclusion

Although DirectFET devices do not need underfill, using this process makes them almost impervious to solder fatigue from thermal cycling.

International Rectifier would like to thank Ablestik for supplying underfill samples and information.

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, International Rectifier 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.

Test conditions

International Rectifier'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 glass-woven substrate (FR4).

Results

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

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_{DSon} shift seen in International Rectifier'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. To list qualified devices, visit www.irf.com/ehs/leadfreepackage.html and scroll down to DirectFET. Alternatively, contact your local International Rectifier representative.

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), that have lower rates of thermal expansion.

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

Note: Although FR4 substrates typically have lower rates of thermal expansion than metal substrates (10–15ppm), 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.

Test conditions

International Rectifier has 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.

Results

With a lead-based solder, mean R_{DSon} shift rose from 130μΩ for to 260μΩ, a 100% increase. However, with a lead-free solder, the change from 180μΩ to 190μΩ was only about 6%. This confirms the potential of lead-free solder to perform well.

Even at the wider temperature range, mean R_{DSon} shift remained within acceptable limits: 270μΩ for lead-based solder, 310μΩ for lead-free solder.

Conclusion

Using metal substrates increases mean R_{DSon} shift but not to a level likely to cause problems in using DirectFET devices.

International Rectifier would like to thank The Bergquist Company for supplying insulated metal substrate samples and information.

Use of conformal coatings

Conformal coatings are used for protection in harsh environments. Various substances are used in coatings; International Rectifier has tested one silicon-based material at the request of a customer.

Test conditions

International Rectifier's tests initially complied with the manufacturer's instructions, which advised against allowing the coating to flow under devices because the thermal expansion of the material might lead to fatigue in the solder joints. This led to a major problem: material flowing up to but not under devices trapped air in the space beneath them. In high temperature testing, the pressure applied by the expanding air caused numerous device failures. The most failures were observed in devices with the greatest difference between can and die size, that is to say those trapping the most air beneath them.

The tests were repeated, this time disregarding the instructions and allowing the material to flow under the devices. Although this solved the problem of device failures, signs of increased fatigue in the solder joints were observed — as predicted by the manufacturer.

Results

As the summary table shows, mean R_{DSon} shift increased from 130μΩ for an uncoated FR4 board to 300μΩ for a coated board. Even this substantial rise does not fully reflect the potential problems of using conformal coatings with DirectFET devices.

There are two potential solutions to the problems identified in testing:

- Use of underfill before coating, preventing air from becoming trapped under devices
- Use of a coating material with a lower modulus of elasticity, allowing trapped air to expand without causing damage to devices

In any event, care is needed to avoid the failures observed in International Rectifier's tests.

Conclusion

The risk of air pockets forming underneath the device leads International Rectifier to recommend using underfill before applying a conformal coating. The type and properties of the coating must also be evaluated carefully.

Caution: Careful testing is advised when using conformal coatings with DirectFET devices.

International Rectifier would like to thank Techsil Ltd for supplying conformal coating samples and information.