All Lead-free IGBT Modules and IPMs

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1. Introduction

It has been reported that acid rain caused by changes in the global environment is causing lead to be discharged from the solder in discarded electrical devices, and that this lead ends up polluting groundwater. As a result, lead-free solder is being used more and more (in compliance with the European Union's RoHS directive*1) instead of the conventional SnPb solder for mounting electronic components. Accordingly, it is desired that IGBT (insulated gate bipolar transistor) modules and IPMs (intelligent power modules) also are made "all lead-free."

In April 2005, Fuji Electric began supplying highly-reliable RoHS-compliant (all lead-free) IGBT modules. As a result, Fuji Electric's annual quantity of lead usage in IGBT modules decreased by approximately 1.5 tons in the 2005 fiscal year, and an additional decrease of 1 ton is anticipated for the 2006.

This paper introduces Fuji Electric's all lead-free compliant technology and product line of RoHS-compliant IGBT modules and IPMs.

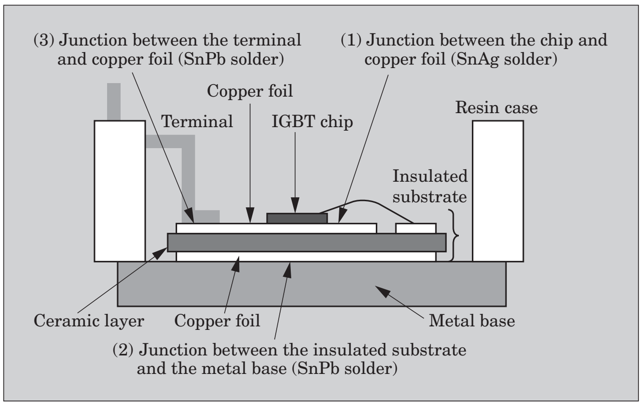
2. Locations that can be made Lead-free in IGBT Modules and IPMs

Lead used in IGBT modules and IPMs is mainly contained in the solder material. The use of lead-free solder involves the challenges of: (1) ensuring sufficient reliability as a result of the change in solder material, and (2) higher mounting temperatures when using lead-free solder. The challenge of higher mounting temperature can be overcome by changing the materials used to increase the thermal resistance and by changing the mounting devices.

The structure of Fuji Electric's IGBT modules and IPMs is shown in the schematic diagram of Fig. 1. Solder material is used in three locations: (1) the junction between the chip and copper foil, (2) the junction between the insulated substrate and the metal base, and (3) the junction between the terminal and copper foil. Lead-free solder has been used in location (1) since 1998, and the ability to withstand power cycles of this lead-free solder has been successfully improved. Therefore, our new development aimed to make locations (2) and (3) lead free.

*1: RoHS is restriction of the use of certain hazardous substances in electrical and electronic equipment.

Fig.1 Structure of conventional Fuji Electric IGBT module and IPM



3. Making the Junction between the Insulated Substrate and Metal Base Lead-free

We selected and considered typical SnAg solder and SnAgIn solder for use in a lead-free junction between the insulated substrate and metal base.

(1) Thermal cycling tests

Figure 2 shows the results of thermal cycling tests when various types of solder are used. When using typical SnAg solder, cracking occurred over approximately 30 % of the soldered area after 300 cycles in the thermal cycle test. When using the newly developed SnAgIn solder, however, almost no cracking occurred and the reliability was nearly the same as that of conventional lead solder.

The mechanism that improves the reliability of products using SnAgIn solder was compared to SnAg solder and verified by observing the microstructure of the fractured section and by performing a FEM (finite element method) analysis.

Figure 3 shows the results of an analysis of the stress-strain distribution generated by solder material

Fig.2 Results of ultrasonic monitoring of thermal cycling test

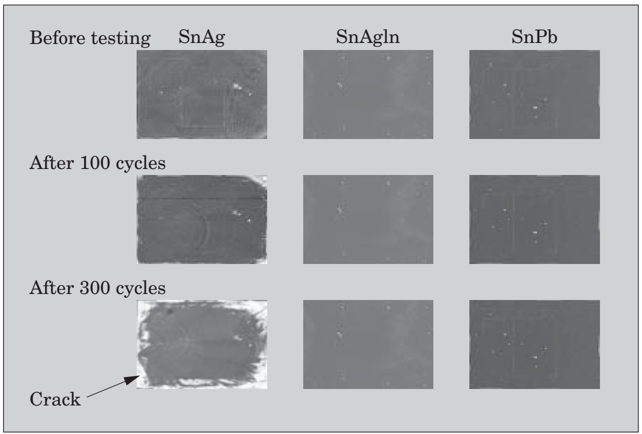


Fig.3 Results of simulated thermal stress of solder between insulated substrate and metal base (FEM analysis results)

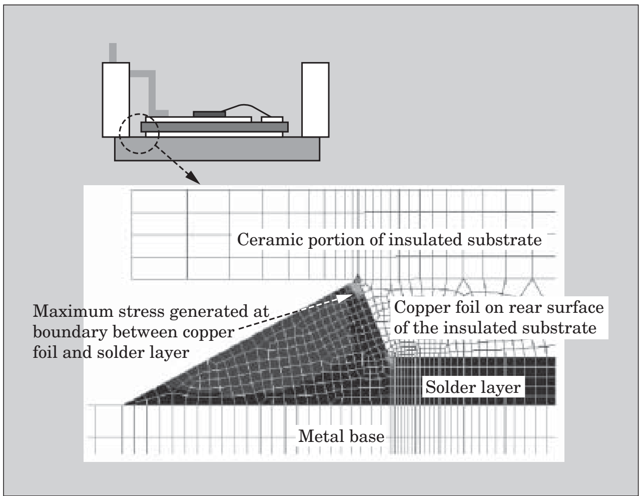


Fig.4 SEM view of fractured area of SnAg and SnAgIn solder after thermal cycling test

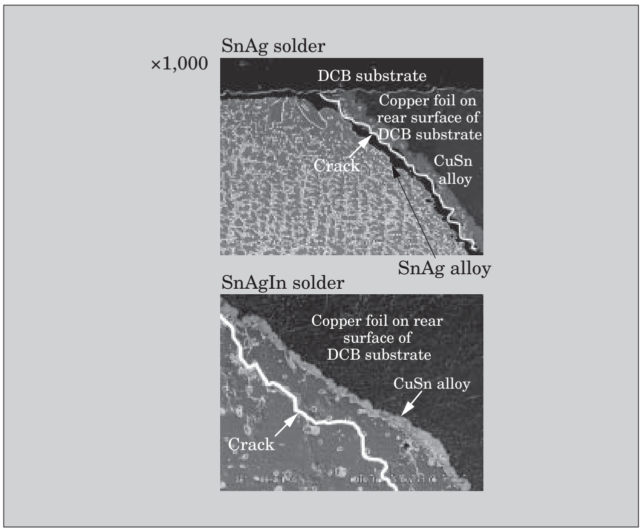
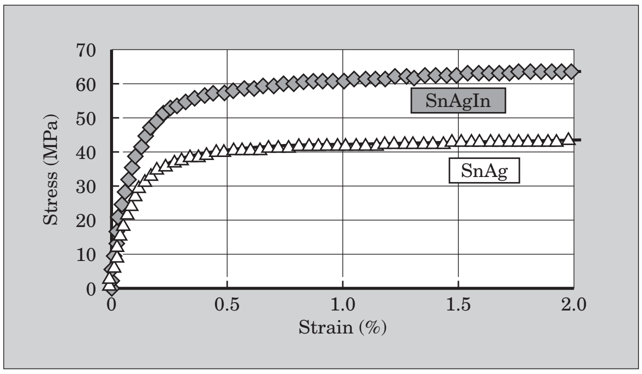


Fig.5 Results of tensile test for SnAg and SnAgIn solder at room temperature



underneath the IGBT module during a thermal cycle test. In this drawing, the maximum stress is generated near the boundary between copper foil on the rear surface of the insulated substrate and the solder layer.

Figure 4 shows the results of the fractured solder surface observed using a SEM (scanning electron microscope) after thermal cycle testing. The SnAg solder material was fractured at the boundary between SnAg and CuSn alloys in the vicinity of the copper foil on the rear surface of the insulated substrate. On the other hand, SnAgIn solder fractures not at the boundary between the CuSn alloy layer and the SnAgIn solder, but at the SnAgIn bulk solder layer, and the difference in fractured states can be seen clearly.

(2) Tensile strength test

Figure 5 shows the results of tensile strength tests of bulk SnAg and bulk SnAgIn solder material. Bulk SnAgIn solder material has a strength of approximately 1.5 times than that of SnAg solder. SnAg solder is observed to have coarser particles as the thermal cycling test progresses. Strength typically decreases as particles become coarser.

Based on the above results, the addition of In to the SnAgIn solder results in: ① suppression of the formation of a SnAg alloy layer, resulting in a change from fracturing at the alloy boundary to fracturing of the bulk solder material, ② an approximate 1.5 times improvement in bulk strength, and ③ particles that do not become coarser during thermal cycling tests. These factors are thought to improve the ability to withstand the thermal cycling tests.

4. Making the Junction between the Terminal and Insulated Substrate Lead-free

We compared and considered SnAg solder and conventional SnPb solder for use in a lead-free junction between the terminal and insulated substrate.

(1) Thermal cycling tests

The results of observation of the fractured section of solder material obtained after 300 cycles in a thermal cycling test showed no cracks in either SnAg solder or SnPb solder. From these results, we computed the stress and strain generated in the terminal area during the thermal cycling test, and speculated the reason that the thermal cycling test lifespan is longer for typical SnAg solder. Figure 6 shows the computed results. In contrast to the previously described junction between the insulated substrate and the metal base, it can be seen that the maximum strain is generated in a bulk solder area at the junction between the terminal and the insulated substrate. Because maximum strain is generated in the bulk solder material, the thermal fatigue lifespan of the terminal area solder can be estimated using the Coffin-Manson law for bulk solder material.

(2) Fatigue life testing

In order to assess the number of cycles to failure for bulk solder material, we implemented isothermal fatigue life testing of bulk solder material. The fatigue tests of the bulk materials were performed under the conditions of 25°C room temperature, 0.02 %/s strain rate. The life span was determined to be the number of cycles when the applied stress was reduced 25 %. Figure 7 shows the results of the fatigue life testing. The graph shows the number of cycles to failure (fatigue life) for each type of solder when stress is reduced by 25 % from the initial stress within the inelastic strain range. The amount of strain generated at the soldered portion of the terminal as estimated from the results of Fig. 6 is also shown. For withstanding generated strain, it can be seen that SnAg solder has the same or longer lifespan than SnPb solder.

Fig.6 Distribution of stress at junction between terminal and DCB substrate

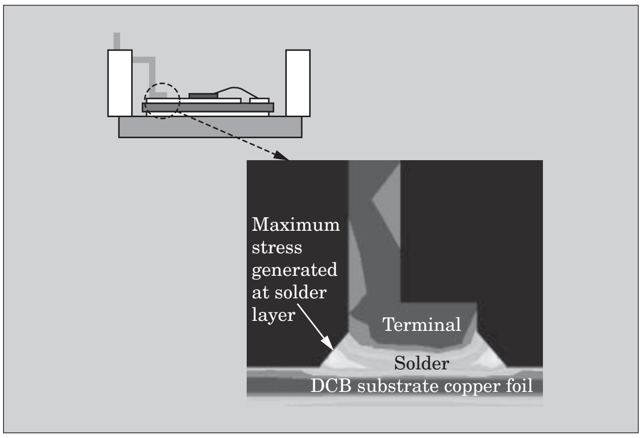
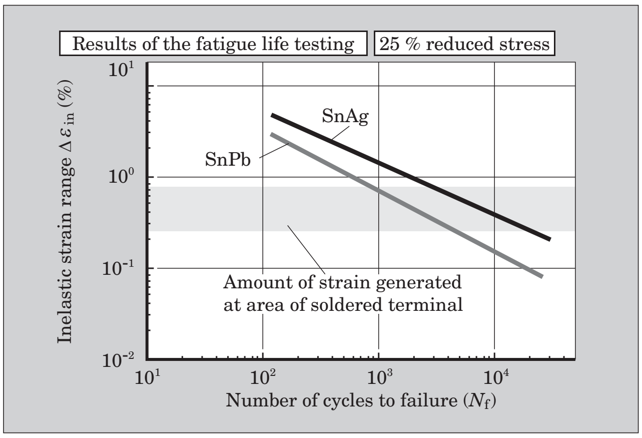


Fig.7 Coffin-Manson plots for SnAg alloy and SnPb alloy



Based on the Coffin-Manson plots of Fig. 7, it is thought that SnAg solder, used in the junction between the terminal and the insulated substrate in an IGBT module or IPM structure, will exhibit the same or longer lifespan as SnPb solder. This result is consistent with the results of thermal cycle testing of the terminal area of actual devices.

Based on the above results, we selected SnAg solder as a lead-free solder material for use in the junction between the terminal and the insulated substrate, and have realized the same or higher reliability as with conventional products.

5. RoHS-compliant IGBT Module and IPM Series

Fuji Electric's RoHS-compliant IGBT module and IPM series are listed in Table 1 and examples of the

Table 1 Fuji Electric's RoHS-compliant IGBT product line

(a) IGBT module

<table>
<tr><th></th><th>10 A</th><th>15 A</th><th>20 A</th><th>25 A</th><th>30 A</th><th>50 A</th><th>75 A</th><th>100 A</th><th>150 A</th><th>200 A</th><th>225 A</th><th>300 A</th><th>400 A</th><th>450 A</th></tr>
<tr><td rowspan="3">600 V</td><td colspan="6">M711 (EP2)</td><td colspan="2">M712 (EP3)</td><td colspan="6"></td></tr>
<tr><td colspan="6"></td><td>M636</td><td colspan="2">M633</td><td colspan="5"></td></tr>
<tr><td colspan="5">M717 (Small Pack)</td><td colspan="3"></td><td colspan="2">M232</td><td colspan="4">M233</td></tr>
<tr><td rowspan="5">1,200 V</td><td colspan="6">M711 (EP2)</td><td colspan="2">M712 (EP3)</td><td colspan="2"></td><td colspan="4">M254</td></tr>
<tr><td colspan="5"></td><td colspan="2">M636</td><td colspan="2">M633</td><td colspan="5"></td></tr>
<tr><td colspan="2">M717 (Small Pack)</td><td colspan="4"></td><td colspan="3">M232</td><td colspan="5"></td></tr>
<tr><td colspan="8"></td><td colspan="2">M233</td><td colspan="4"></td></tr>
<tr><td colspan="9"></td><td colspan="3">M235</td><td colspan="2"></td></tr>
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(b) IPM

<table>
<tr><th></th><th>10 A</th><th>15 A</th><th>20 A</th><th>25 A</th><th>30 A</th><th>50 A</th><th>75 A</th><th>100 A</th><th>150 A</th><th>200 A</th><th>225 A</th><th>300 A</th><th>400 A</th><th>450 A</th></tr>
<tr><td rowspan="2">600 V</td><td colspan="5">P617/P619</td><td colspan="4">P610/P611</td><td colspan="5"></td></tr>
<tr><td colspan="6"></td><td colspan="3">P622 (Econo-IPM)</td><td colspan="5"></td></tr>
<tr><td rowspan="2">1,200 V</td><td></td><td>P619</td><td></td><td colspan="4">P610, P611</td><td colspan="7"></td></tr>
<tr><td colspan="3"></td><td colspan="4">P622 (Econo-IPM)</td><td colspan="7"></td></tr>
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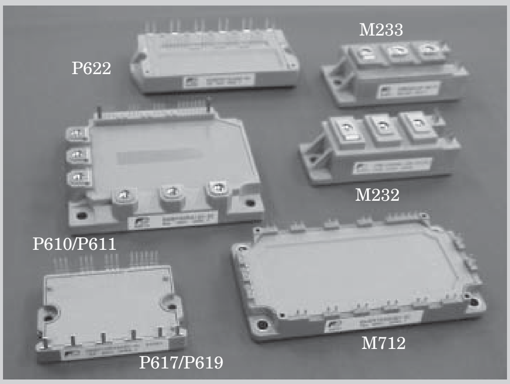
Fig.8 Example of Fuji Electric's RoHS-compliant IGBT modules and IPM packages



product packages are shown in Fig. 8. Fuji Electric is expanding its lineup of RoHS-compliant products sequentially, beginning with low-end devices used in consumer products which are easily discarded.

6. Conclusion

Fuji Electric's RoHS-compliant technology and product lineup of IGBT modules and IPMs have been introduced. These products are environmentally friendly and achieve the same or higher level of reliability as present-day lead solder products.

Through using this technology to develop all lead-free IGBT module and IPM products, Fuji Electric aims to help protecting the global environment.

References

(1) Morozumi, A. et al. Reliability of Power Cycling for IGBT Power Semiconductor Modules. IEEE Transactions On Industry Applications. Vol. 39, no. 3, 2003-05/06, p. 665-671.

(2) Nishimura, Y. et al. All lead free IGBT module with excellent reliability. Proceedings of the 17 International Symposium on Power Semiconductor Devices & ICs. May 23 – 26, 2005, Santa Barbara, CA.