Chapter 4

Results and Discussion

4.1 Life time of thin-film subjected to thermal aging

When we didn't age thin-film UBM bump, its life time is 192hrs. When we aged it for 100hrs, 200hrs, 300hrs, and 500hrs, its life time is 157hrs, 148hrs, 33hrs, and 3hrs as shown in Fig. 4.1. We could easily find the aging effect weakened the thin-film bump. This was due to the form of voids when we age it between UBM and solder. So when we performed electromigration test, sample aged can't be used more time than its aged life time.

We found voids between UBM and solder as shown in Fig.4.2 (c). When we aging thin-film bump after 1000hrs under 150℃. We could easily find interface unstable as shown in Fig. 4.2. As shown by electromigration result , aging100hrs, 200hrs and no aging life time is almost in the same range. But after we aging 300hr, its life time become very short. We think Cu is not enough to reaction with Sn so that Kirkendall voids form before electromigration test. The life time of bump was short as we expected because voids reduced the path of electron flow and induced electromigration effect more easily.

Bumps always fail at current from chip side to board side as shown in Fig. 4.3 and Fig. 4.4. Because our samples have thin Al line in the chip side, Al line would have high temperature during high current density electromigration test. Fig. 4.3 shows bump which aged at 150℃ for 300hr and fail under the electromigration stress at 0.28A for 33hrs and the bump shown in Fig. 4.4 fails after 3hr. Its always like melt before bump open because tin-rich phases i.e. gray region in SEM image, and lead-rich phases, i.e. white region in SEM image, not congregate after aging .We can compare Fig.4.2(b) and Fig.4.3 easily to find this different.

4.2 Thick-film UBM solder composition and structure made by aging

Before we age it, IMC thickness in chip side is 0.82 μm and in board side is 0.52 μm. In the beginning we used 150℃ to aging our sample. We find IMC would form about 3um in chip side need 1000hrs to aging it as shown in Fig 4.5(b), its mean that we need 42 day to use. It is not benefit. So we change our aging temperature to 170℃. When we age it at 25hrs, IMC thickness in chip side is 3.11 μm and in board side is 2.02 μm. When we aged it for 50hr, IMC thickness in chip side is 5.33 μm and in board side is 2.52 μm as shown in Fig 4.6. It was because Ni in chip side and board side reaction with Sn in solder, and they form Ni_3Sn_4 IMC layer, as shown by Figs. 4.10 and 4.11 . In chip side IMC is very close to the stoichiometric` Ni_3Sn_4 atomic percent. Ideal atomic percent Ni:Sn=42.9:57.1, and our EDX result is Ni:Sn=41.96:58.04. But in board side UBM that Ni has P on it, so its IMC composition atomic percent is Ni:Sn:P=44.76:49.84:5.40. If all Sn form Ni_3Sn_4, Ni seed (49.84/4)*3=37.305. It still have 49.84-37.305=12.535 Ni. We think its maybe have Ni_xP compound.

In thick-film solder ball，from the beginning don't aging Sn79.74%wt Pb20.26% to thermal aging 25hrSn75.78%wt Pb24.22%wt,at last aging 50hr, structure become Sn71.74%wt Pb28.26%wt. We can find our sample toward to eutectic point. Figs. 4.7, 4.8, and 4.9 illustrates these EDX result. According to 2000 Electromigration in Sn-Pb solder strips as a function of alloy composition Liu, C.Y., Chen, C., Tu, K.N. Journal of Applied Physics 88 (10), pp. 5703-5709 29, solder composition toward to eutectic point, it easily to have electromigration effect as shown in Figs. 4.21 and 4.22. Therefore after aging our sample for 50hrs at 170℃, its composition is not good to resist electromigration. However its had 5.3 μm Ni_3Sn_4 IMC in the chip side, so it possible that IMC can help bump to have more life time when we stressed sample under our test condition. Electrical resistivity of Ni_3Sn_4 has 28.5μΩ·cm higher than Pb 21.9μΩ·cm and Sn 11.5μΩ·cm. The electromigration test result would be shown in next section.

4.3 Thick-film UBM life time with thermal aging

If we don't age thick-film UBM bump, its average life time is 430hrs. When we aged it at 150℃ for 200hrs, its average life time is 484hrs. And when we aged it at 150℃ for 1000hrs, its average life time was 663hrs. We found aging improve the life time of bump under electromigration test. But aging for 1000hrs means that we need 42 day to use it. It isn't economical. So we change our aging temperature to 170℃ and performed electromigration test under 0.75A and 150℃ for 25 and 50hrs. In the beginning we used 0.8A to test. But sample always failed below 100hr. By IR results and the results of previous studies, too short electromigration test life time usually indicates the failure at Al line instead of solder bump as shown in Fig. 4.12. Choice suitable test condition is very important for our steady.

When we aged it at 170℃ for 25hrs, its average life time is 858hrs. But when we aged it at 170℃ 50hrs, its average life time is 701hrs as shown Fig 4.13. Although aging 50hr's life time less than aging 25hrs, but it is higher than sample free of aging. We speculcated although aging 50hrs would have most thickness of IMC, but it may change another character of sample like solder composition as described in the above section. So IMC can reduce current crowding effect and increase the bump life time. We aged sample just more than 1 day a little, its life time under 0.75A and 150℃ increased about two times. By Black's equation when we use bump which has thicker IMC bump in the true useful condition. We believed that bump would have more than two times of electromigration life time compared with bump without aging in practical as age in the reality used condition.

When sample failed, usually we can't get any information of solder which electron current from chip side to board side as shown in Figs.4.15(c) , 4.16(a), 4.17(e)and 4.18(a). Those bumps melt when they are open under electromigration test.

But in another bump which current from board side to chip side, we found Pb-rich phase form at the chip side by electron as shown Figs. 4.16(b) and. 4.18(b). And we also find solder like melt in the left region. We found this phenomenon at aging for 50hr and 701hr fail sample clearly. We think bump before open, maybe bump 2 temperature would very high let bump 3 be a little melt.

Because bump 1 is close to bump 2 than bump 4, as shown in Fig. 4.15(a). Cu is melt serious in bump 1 as shown in Figs. 4.19 and 4.20. Both of them have void on it.

We also used computer to detect our all line resistance instead of bump resistance during electromigration test as shown in Fig. 4.14. This figure show aging 0hr under current stress at fail at final 60hrs when it failure time is 385hrs. Resistance grown very slow in the 0hr to 380hr. Before bump fail, its resistance would jump quickly.

4.4 Thick-film UBM solder bump resistance with aging time

Because our sample have specific structure as shown in Fig. 3.8 , we can measure bump resistance. We used 0.2A to test it for 2min and used computer to collect bump resistance data, and used last 1min data to equalize it. Why we use smaller current to test it? Because we just wanted to evaluate IMC and structure effect for bump subjected to aging. If we used 0.75A for electromigration test, it may have another effect like joule heating effect. We found bump resistance aged at 0hr, 25hrs and 50hrs are 0.356m-ohm,0.370m-ohm and 0.403m-ohm. When IMC become thicker, its bump resistance would be higher. Although $P=I^2R$, increasing of R may increased the bump temperature under electromigration test. But we think bump major failure mechanism is current crowding effect. So reduce current crowding effect by IMC(Ni_3Sn_4) is more useful for bump life time under electromigration test. .

4.5 Thick-film UBM solder before open

We also used this special structure to find the middle state before bump opened to measure the bump resistance change as a function of electromigration test time. We put sample which aging free bump before electromigration test when we give 0.75A to bump and as time to grow up, its bump resistance arised as shown in Fig.4.23. It is interesting that bump resistance would decrease in half of day. We think after sample manufactured, there are contact resistance in high at the interface. When high current density and high temperature were applied to the bump , its reduced contact resistance. Hence, aging effect also can reduce contact resistance as shown Figs.4.30 and 4.32. There bump resistance would not down to much like sample which don't aging it.

We found it requires 96hrs for aging free sample grow to 3 times of its original bump resistance, it need 96hr. And if we aged sample for 25hrs at 170℃ before electromigration test, it would need 360hrs to increase bump resistance to 3 times of original. Aged 50hr needed 290hrs to reach 3 times of its original value. We believe arise of bump resistance because of void found by electromigration. When bump is more easily failed by electromigration test, it is more easily to have void. And its bump resistance would arise more quickly. According to four-point measure result , that time reach 3 times of original bump resistance accord our life time data.

We found if we didn't age our samples it void was continuous and horizontal form in the bump when electron current flowed from chip side to the board side as shown in Figs.4.24(b) and 4.25. If we aged the sample before electromigration test, we can find void would be more deep but it can have IMC piled up from chip side to board side as shown in Figs. 4.26 , Fig. 4.31 and Fig 4.33.

IMC looked very big and not clear before 1μm Al_2O_3 polish. After polish we can find true IMC distribution and void usually could be found after polish. So after no.4000 sandpaper grind, we must polish carefully. Usually void could be found after 1μm Al_2O_3 polish.

After 500hrs electromigration test for 50hr aged sample didn't fail. We polish it to get middle state of it. Figs.4.33 to 4.37 show OM image contract and SEI and EDX result of it. By these results, we can easily decide what composition of it by OM image.

Table 4.1 thick-film bump IMC thickness and aging time

170 ℃ aging time	Chip side IMC thickness	Board side IMC thickness
0hr	0.82 μm	0.52 μm
25hr	3.11 μm	2.02 μm
50hr	5.33 μm	2.52 μm