A Study of Thermal Cycling and Radiation Effects on Indium and Solder Bump Bonding

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Abstract

The BTeV hybrid pixel detector is constructed of readout chips and sensor arrays which are developed separately. The detector is assembled by flip-chip mating of the two parts. This method requires the availability of highly reliable, reasonably low cost fine-pitch flip-chip attachment technology.

We have tested the quality of two bump-bonding technologies; indium bumps (by Advanced Interconnect Technology Ltd. (AIT) of Hong Kong) and fluxless solder bumps (by MCNC in North Carolina, USA). The results have been presented elsewhere[1]. In this paper we describe tests we performed to further evaluate these technologies. We subjected 15 indium bump-bonded and 15 fluxless solder bump-bonded dummy detectors through a thermal cycle and then a dose of radiation to observe the effects of cooling, heating and radiation on bump-bonds.

I. TESTED COMPONENTS

The dummy detectors were single flip-chip assembles of daisy-chained bumps. Measured channels were composed of 30 micron pitch indium bumps, a chain of 28 to 32; and 50 micron pitch solder bumps, a chain of 14 to 16. Figure 1 shows a schematic layout of a portion (8 channels) of an AIT dummy detector. Each chain was connected to pads on each end over which we measured the resistance to characterize the channel. AIT detectors had 200 channels each, MCNC detectors had 195 channels each.

II. THERMAL CYCLING AND RADIATION

Each detector was measured first for continuity before thermal cycling and radiation. These measurements were compared to the electrical resistance measurements done about 12 months ago[1] to yield an understanding of "time effect" on the bump-bonds. Then they were cooled to -10°C in a freezer in an air tight container for 144 hours. Subsequent measurements were compared to the measurements done before cooling to understand any "cooling effect" on the bump-bonds. This was followed by heating the detectors to 100°C in vacuum for 48 hours. The detectors were measured after heating and compared to the measurements done after cooling to yield an understanding of any "heating effect". Finally, the dummy detectors were shipped to the University of Iowa in three shipments to be radiated by a Cs-137 gamma source to 13 MRad and measured again to understand any "radiation effect". A randomly selected sample of detectors in each shipment was not radiated to give us an indication if the detectors were affected during shipment. This way we eliminated one of the shipments from consideration.

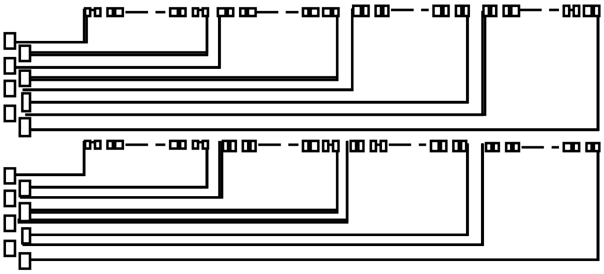

Figure 1: AIT Dummy Detector Bump Daisy Chain.

III. RESULTS

The effects we studied manifested themselves as large increases in resistance on the channels measured. These occurrences are described below.

A. Thermal Cycling

We categorize the problem occurrences after each step of the thermal cycling as follows:

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1. *Indium Bumps:*

   Occurrence A: A good channel (1-2 Ohms average resistance per bump) develops a high resistance (5-10 KOhms per bump) in 12 months.

   Occurrence B: A good channel develops a high resistance after cooling.

   Occurrence C: A good channel develops a high resistance after heating.

   In most cases the high resistance is accompanied by an average capacitance per bump of 2-10 picofarads.

2. *Solder Bumps:*

   Occurrence A: A good channel (1-2 Ohms average resistance per bump) is broken (a resistance of larger than 20 MOhms) in 12 months.

   Occurrence B: Cooling breaks a good channel.

   Occurrence C: Heating breaks a good channel.

Table 1 shows the distribution of the occurrences in indium bump detectors. No entry means no problem. The last column indicates the number of channels having an open or high resistance problem before the thermal cycling. There is a correlation between the occurrences of new problems and the original existence of problems. For instance, detectors E11 and E20 which originally had many problematic channels developed more new problematic channels over the thermal cycling.

Table 1: Indium Bump Problem Occurrence Distribution

Det-ID	Occur-A	Occur-B	Occur-C	Orig-Bad
E2				
E3			1	
E4				
E5				1
E8				
E11	14		1	37
E13	1		6	
E14	2			
E15			2	4
E16				
E20	20	2	8	74
E22				
E23			1	
E24				
E25				

Table 2 shows the distribution of the occurrences in solder bump detectors. No entry means no problem. The last column indicates the number of channels having a problem before the thermal cycling. Here we also see a correlation between the occurrences of new problems and the existence of problems before the thermal cycling. For instance, detectors MCNC-24 and MCNC-27 which originally had many problematic channels developed more new problematic channels over the thermal cycling.

Table 2: Solder Bump Problem Occurrence Distribution

Det-ID	Occur-A	Occur-B	Occur-C	Orig-Bad
MCNC-10	7	1	1	
MCNC-11				
MCNC-12				
MCNC-18				
MCNC-19				
MCNC-24	6	3	6	5
MCNC-27		1	7	12
MCNC-44				1
MCNC-50			1	1
MCNC-55			4	2
MCNC-59				1
MCNC-75				
MCNC-76			3	
MCNC-81				
MCNC-86	4	1	5	3

We calculated the occurrences per bump based on these observations and summarize the results in Table 3. The correlation mentioned above can be a reason to exclude detectors E11, E20, MCNC-24 and MCNC-27 from consideration for the effects of thermal cycling. If we do that, we then calculate the occurrence rates per bump as shown in Table 4.

Table 3: Rate of Occurrences (per bump)

Occurrence	**Indium Bumps**	**Solder Bumps**
A	2.1×10^{-4}	4.0×10^{-4}
B	2.2×10^{-5}	1.4×10^{-4}
C	2.1×10^{-4}	6.3×10^{-4}

Table 4: Rate of Occurrences (per bump) without Problematic Detectors

Occurrence	**Indium Bumps**	**Solder Bumps**
A	3.3×10^{-5}	2.6×10^{-4}
B	2.2×10^{-5}	4.6×10^{-5}
C	2.5×10^{-5}	3.3×10^{-4}

B. Radiation

On indium bump detectors, after the radiation we observed that almost every first channel in groups of four channels (see Figure 1) was at high resistance. The group of four channels is a geometrical pattern of the construction of these detectors. Having every first channel affected, rather than a random distribution, suggests the occurrence may be not a result of radiation but of some effect unknown at the moment. We will further investigate the effect by x-ray study of a sample detector.

On solder bump detectors, we observed that the aluminium layers both on the strips and the pads were extensively flaky and bubbly after the radiation. This may be a result of accelerated oxidation with radiation. We observed 6 out of 2280 channels (each with 14 or 16 bumps) were broken. This indicates a rate per bump of 1.8×10^{-4} for the radiation effect. We should point out that these 6 failures might be due to breakage in the aluminium strips due to radiation rather than the breakage on the bump-bonds. We can not distinguish this effect at the present time for geometrical and structural reasons, but will investigate in the future.

IV. CONCLUSIONS

The results of thermal cycling and radiation tests validate the feasibility of bump-bonding technologies for hybrid pixel detectors. They withstand extreme conditions. Heating to 100^{o}C, though, is more destructive than cooling to -10^{o}C, while the radiation effect is minimal. There is a correlation between the occurrences of problems due to these effects and existence of problems when the detectors were first assembled. The rates quoted are probably inflated due to the fact that some failures are caused by damage to the strips and pads due to repeated probing and radiation.

V. REFERENCES

[1] S. Cihangir and S. Kwan, talk presented at the 3rd International Conference on Radiation Effects on Semiconductor Materials, Detectors and Devices, Florence, Italy (June 28-30, 2000), to appear in Nuclear Instruments and Methods A.