BGA Underfill for COTS Ruggedization

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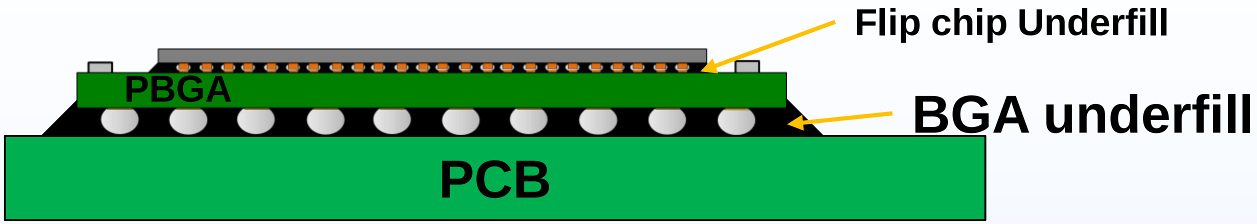
Underfill History

- Early ceramic flip chip did not have underfill.
  - Si : CTE ~3ppm/°C Ceramic substrate ~8ppm/°C
  - Had hermetic seal
  - Had die size limit
- 1987 : Hitachi used underfill and demonstrated improvement of temperature cycling life of flip chip. IBM also saw the same effect.
- 1991 : IBM introduced organic flip chip (17ppm/°C).
  - Underfill was implemented in this product.
- ‘2000s : Widespread of handheld device
  - CSP/BGA were underfilled for drop reliability.
- Temperature cycling life of BGA and CSP can be also enhanced by underfill, when done right.

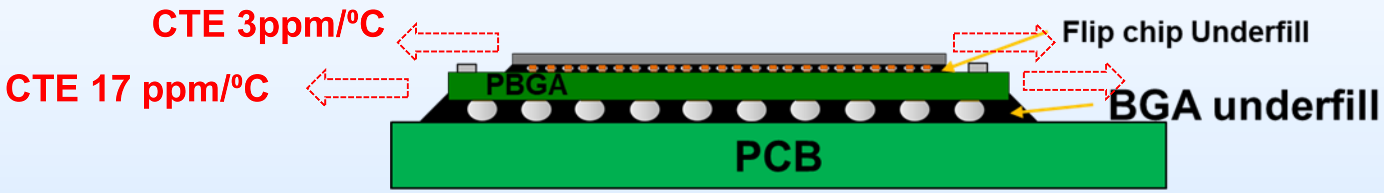
Current Status of NASA



- Underfill enables flip chip solder bump to survive temp cycling. ex) Class-Y parts.
- Plastic BGA parts are becoming reality for flight missions.
  - Organic class-Y parts 38535 spec development activity
  - COTS parts and assemblies for small missions
  - Custom SiP for flagship missions
- Underfill can be used for enhancing BGA reliability:
  - shock, vibe, and thermal cycling reliability.
- Underfill can be also used for ruggedizing parts other than BGAs.
  - Ex) TSOP, CSP, etc

Package Ruggedization Using Underfill

- How underfill works:
  - Redistribute stress on the solder joints to underfill.



- Requirement for flip chip due to large CTE mismatch and small standoff height.
- Package size and standoff height dependent for BGA.

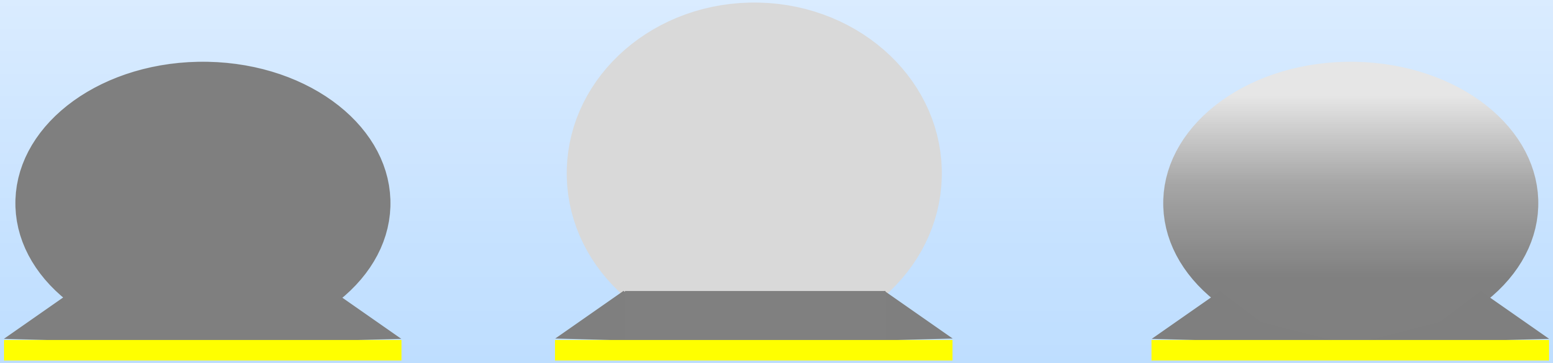
Data from Literature

	Temp cycle condition	Without underfill	With underfill	Data source
TSOP	0 to 100ºC	1st failure at 150 cyc	No failure until 3000 cyc	Alan Emerick et al, 1993
CSP	-40 to 125ºC	N_{63} ~ 3300	1 or no failure up to 5200 cyc, out of 180 samples.	Jing Liu et al, 2003
uBGA	-65 to 125ºC	4 of 10 failed by 800 cyc	No failure up to 4500 cyc	Jong-Min Kim et al, 2003
BGA	-40 to 125ºC	N_{63}~4690	N_{63}~5780	Haiyu Qi et al, 2009

- **Conventional BGA and CSP have good temp cycle performance which can be improved by underfill – Application Specific**
- **uBGA and TSOP temp cycle life can be significantly improved by underfill – Technology Enabler**

COTS Part Challenges

- **Commercial BGAs use lead-free solder**
  - **Require higher temperature to assemble, spheres may not melt during reflow when assembled onto a flight board.**
  - **Several factors may affect final solder joint composition.**
    - **Paste volume, peak reflow temperature, time above liquidus, etc.**
  - **Mixed SnPb-PbFree solder joint reliability is not fully understood.**
  - **Cracking from mechanical shock.**



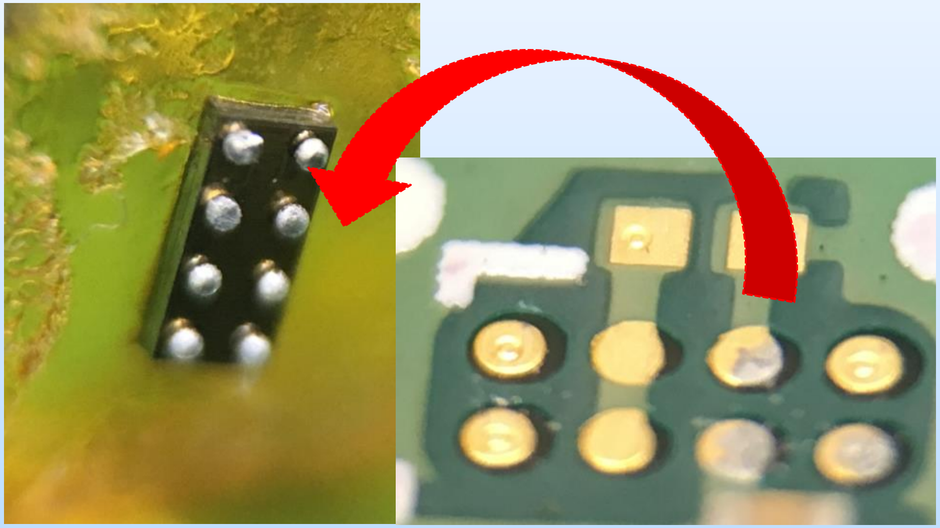
SnPb Sphere w/SnPb Paste

Pb-free Sphere w/ SnPb Paste No Melting

Pb-free Sphere w/ SnPb Paste Partial Mixing

COTS Assembly Challenges

- COTS assemblies are becoming increasingly common in flight missions.
  - Some of current class-D missions are using COTS assemblies.
- COTS assemblies are not built or inspected to NASA requirements. Insufficient and inconsistent workmanship.
  - Ex)



** This assembly passed initial electrical test (with no solder wetting).*

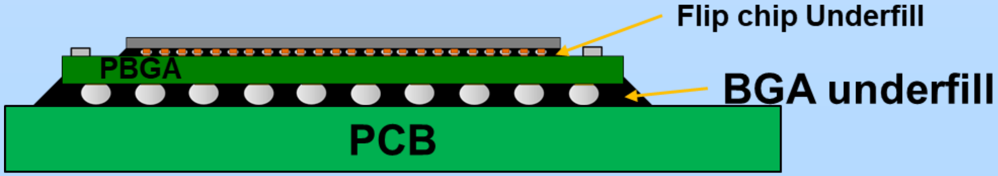
- Developing an adequate ruggedization methodology can bring up the reliability of COTS assemblies.

Underfill Properties

- **Key BGA underfill material properties**

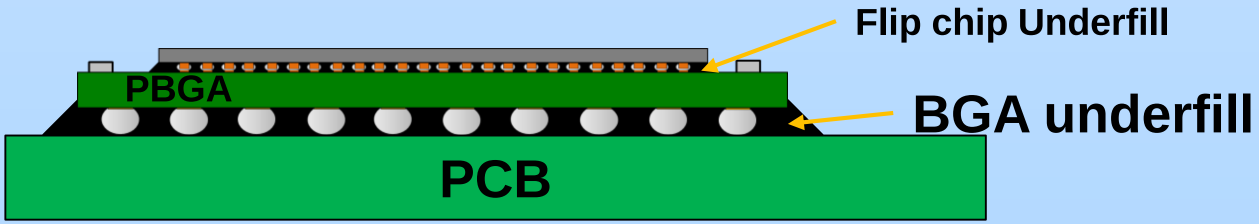
Underfill	Tg (°C)	CTE (ppm/K)	Modulus	Cure time (min)	Reworkability	Outgassing
SUF1589-1	120	23/80	Bending / 13 GPa	80	No	Pass
UF3811	124	61/190	Storage / 2.45 GPa @25C	60	Yes	Pass
Loctite 3549	38	55/177	Storage / 2 GPa @22C	5	Yes	Fail
SMC-386GM	75	60	Flexural / 2.5 GPa	30	Yes	TBD
Loctite 3563	130	35/110	Tensile / 2.8 GPa	7	No	TBD
UF3800	69	52/188	Storage / 3.08 GPa @25C	8	Yes	TBD
UF3810	102	55/171	Storage / 2.99 GPa @25C	8	Yes	TBD
Loctite 3128	45	40/130	Tensile / 3.9 GPa	20	No	TBD

- **Desired properties**
  - **Low outgassing**
  - **Reworkability**
  - **Ease of dispense**



Things to Consider When Using Underfill at the Board Level

- **Underfill compromises reworkability.**
  - **Underfill has to be applied at the final step, after electrical testing**
- **Underfill's cure temperature has to be compatible with parts and materials already on the assembly.**
  - **For underfills with high cure temperature, cure schedules for lower temperatures (80~100°C) need to be developed.**
- **When qualifying assemblies with underfill, electrical testing is required during qual tests.**
  - **Solder joint is encapsulated. Visual inspection of solder joint is impossible.**
  - **Underfill may transfer CTE mismatch stress between PCB and part to internal flip chip/wirebond. Parts may have to be electrically tested for internal failure.**



Underfill material down selection plan

- **Outgassing**
- **Cure temperature compatibility with other parts and polymers in assembly.**
- **Check for lower temperature cure viability.**
  - **Ex) 150C/7min to 100C/2hours**
- **Check for flexibility in application requirements.**
  - **Required equipment**
  - **Dispense temperature**
  - **Ventilation requirements**

COTS Assembly Ruggedization Demonstration Plan

I . Path 1

- Procure COTS assemblies with known quality issue.
- Ruggedization by strategic underfill application.
- Reliability demonstration.

II. Path 2

- Procure COTS style dummy parts.
- Attach parts, mimicking workmanship issues found in COTS boards. (Controlled introduction of workmanship defects.)
- Ruggedization by underfill application.
- Reliability demonstration.

Summary

- **Underfill can enhance reliability.**
- **COTS BGA parts & assemblies present new reliability challenges.**
- **Ruggedization of COTS assemblies will be demonstrated.**