# Reliability Evaluation of Under Bump Metallugy (UBM) in Flip-Chip Interconnects

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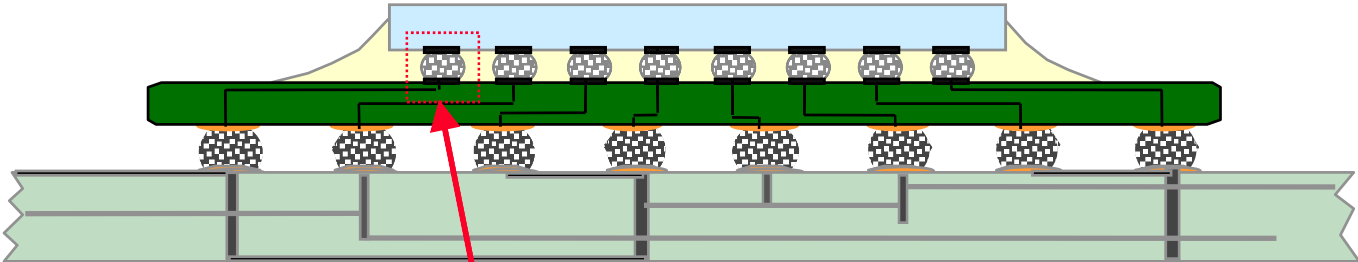
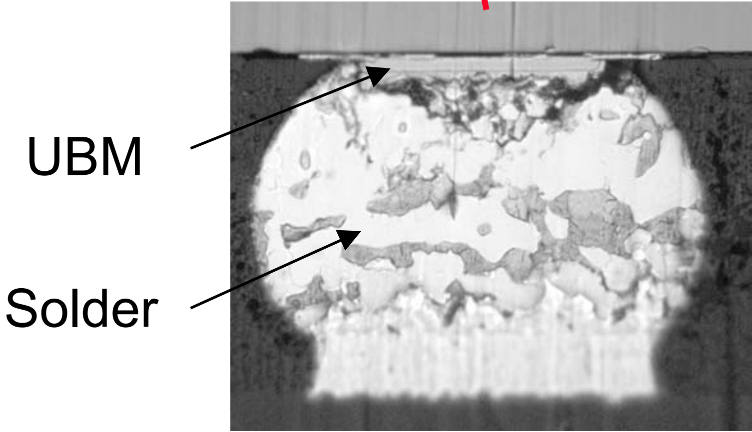
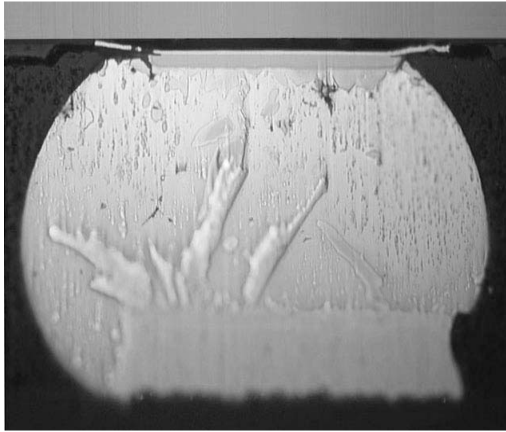
# INTRODUCTION

## Interconnect Failure Modes in Different Solder Systems





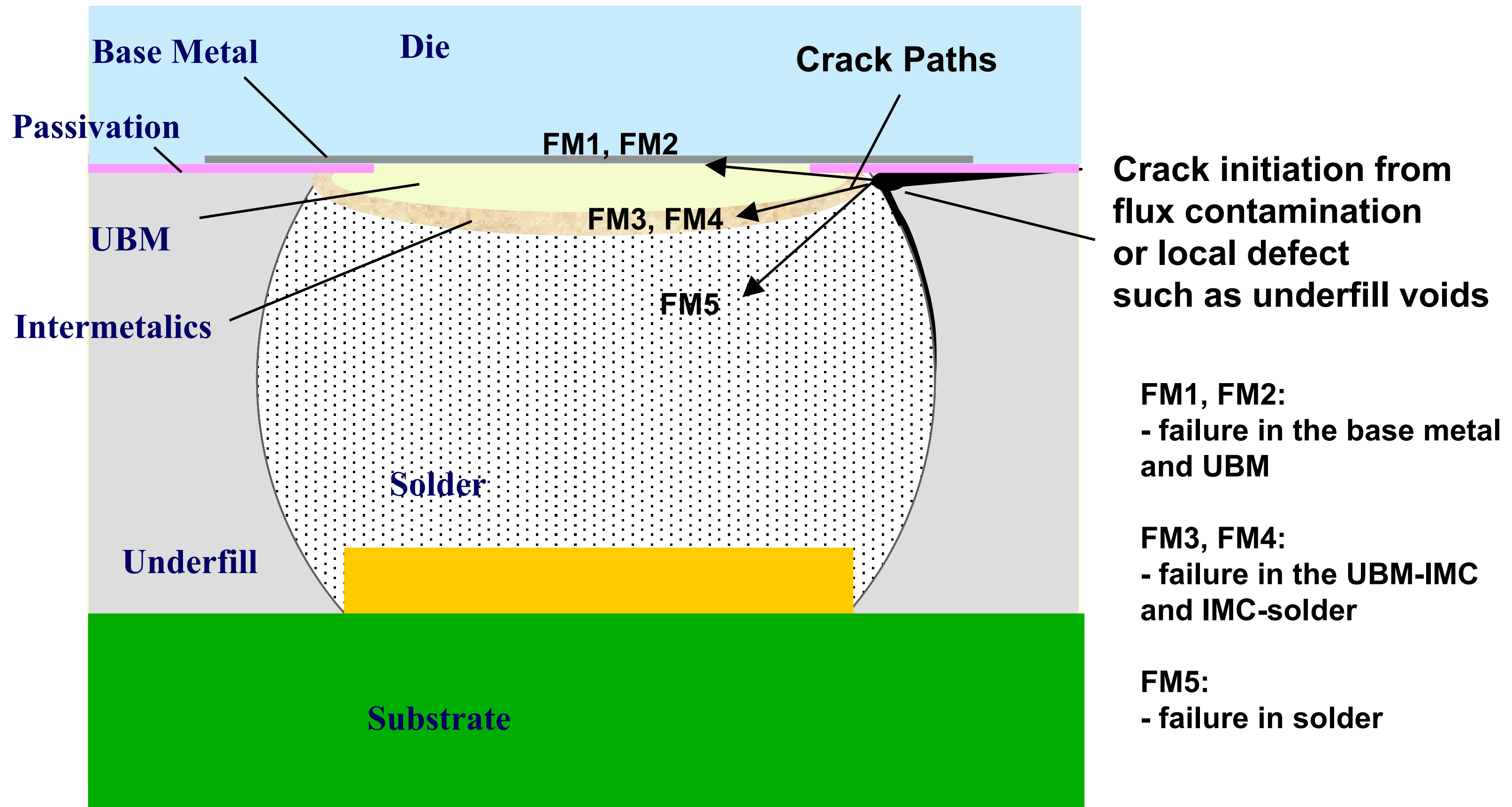

Sn-Pb Solder



Sn-Ag Solder

# Interconnect Failure Modes

Interconnect: base metal, UBM, intermetalics and all the interfaces



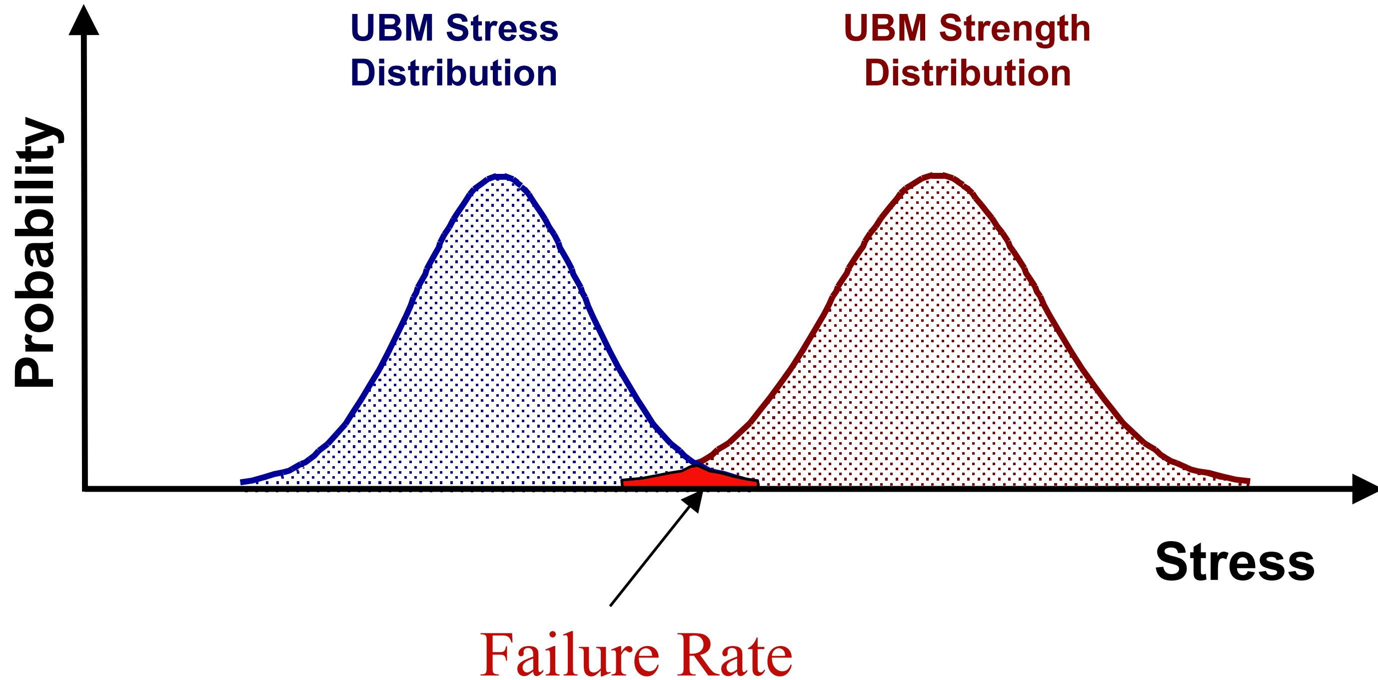

**FM1, FM2:**
- failure in the base metal and UBM

**FM3, FM4:**
- failure in the UBM-IMC and IMC-solder

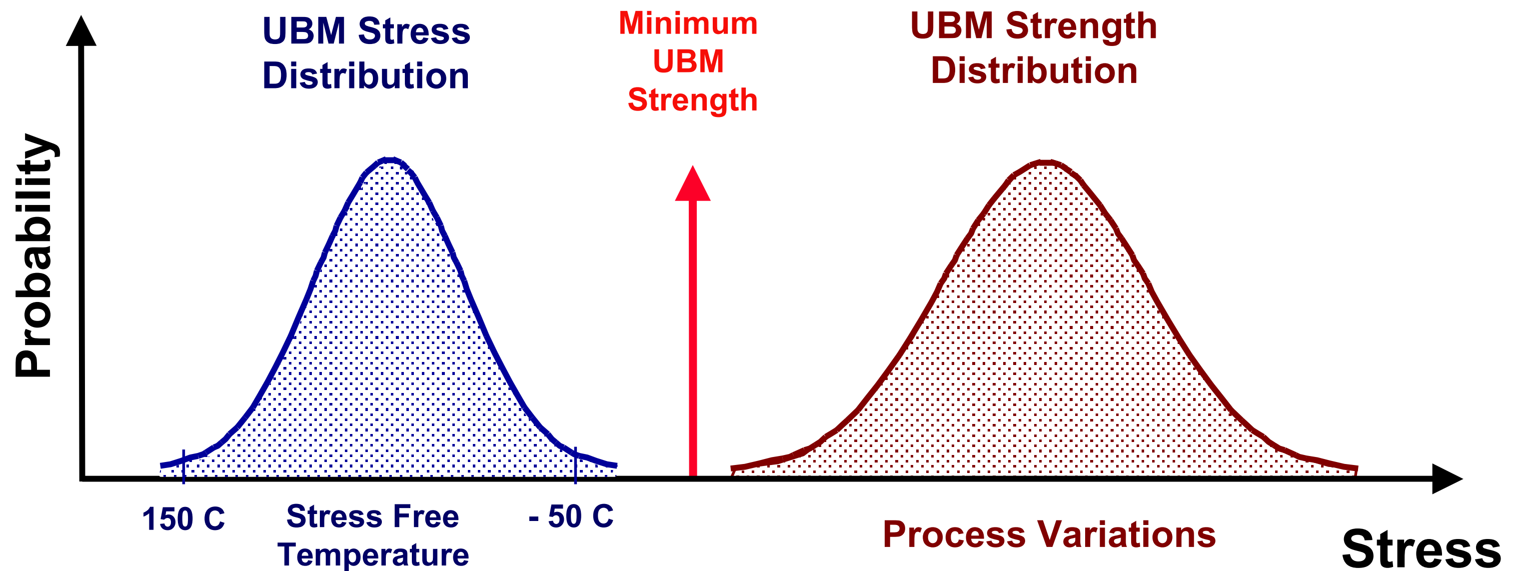
**FM5:**
- failure in solder

**For a robust and reliable interconnect system, the crack should propagate through the solder, because solder usually has better fatigue resistance than the interconnect.**

# UBM Reliability

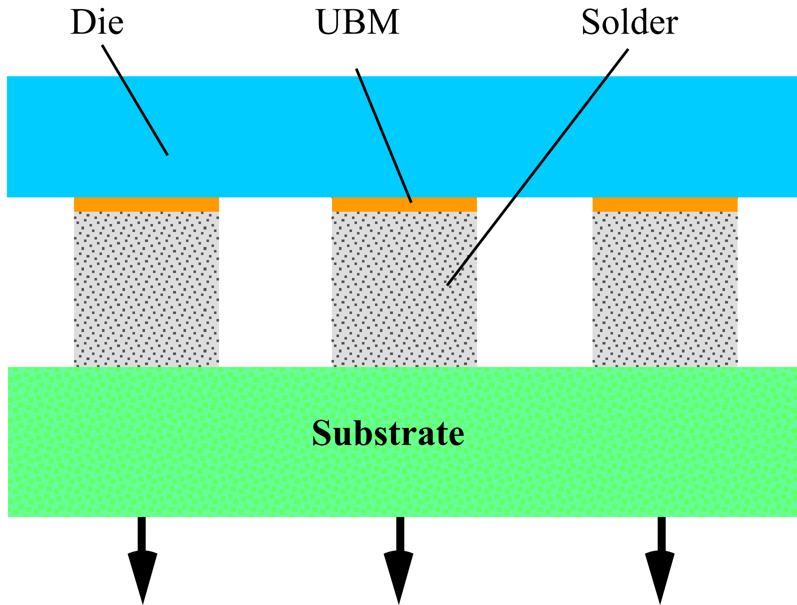


# UBM Reliability

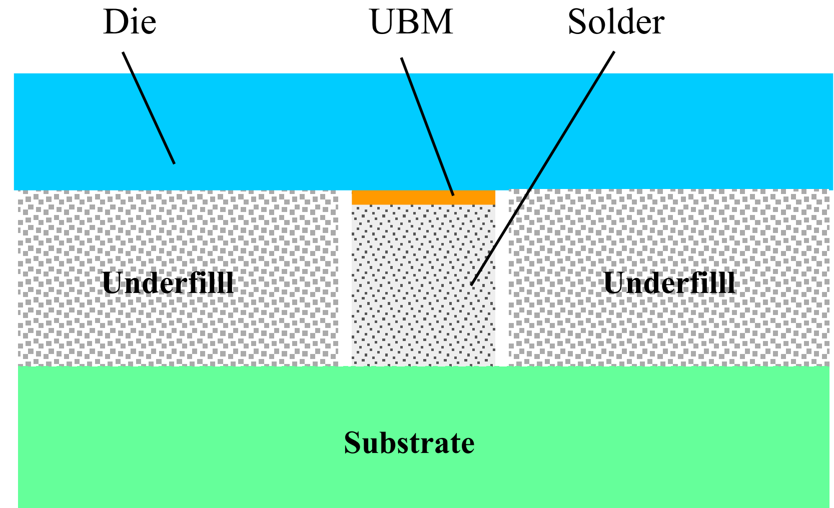


# UBM Strength and Stress

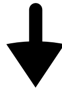
Die Pull




Thermal Cycle




Force at Break



**UBM Strength**

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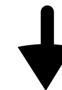
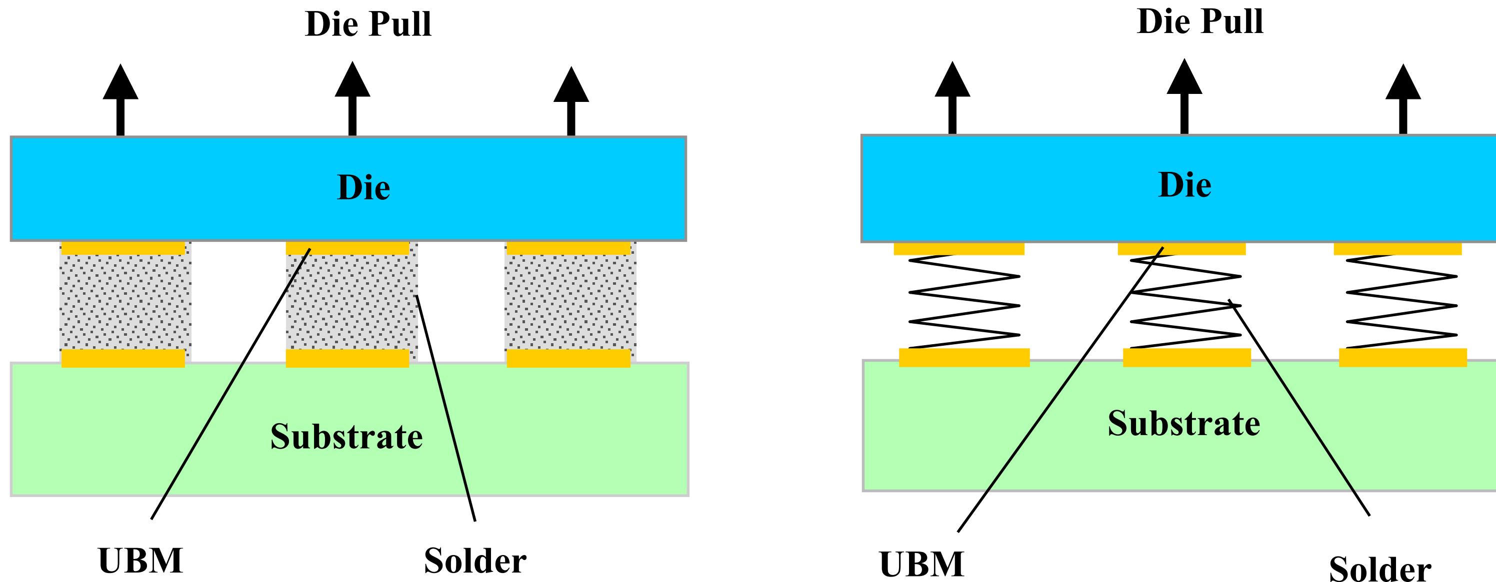
Applied Force from Thermal Mismatch



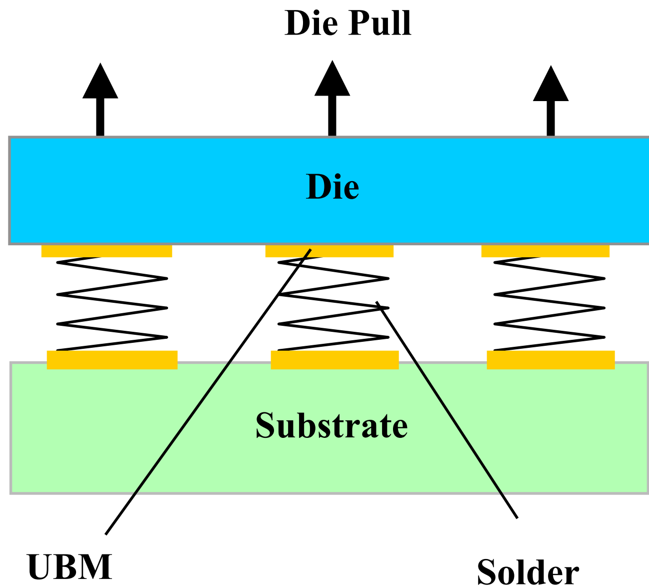
**UBM Stress**

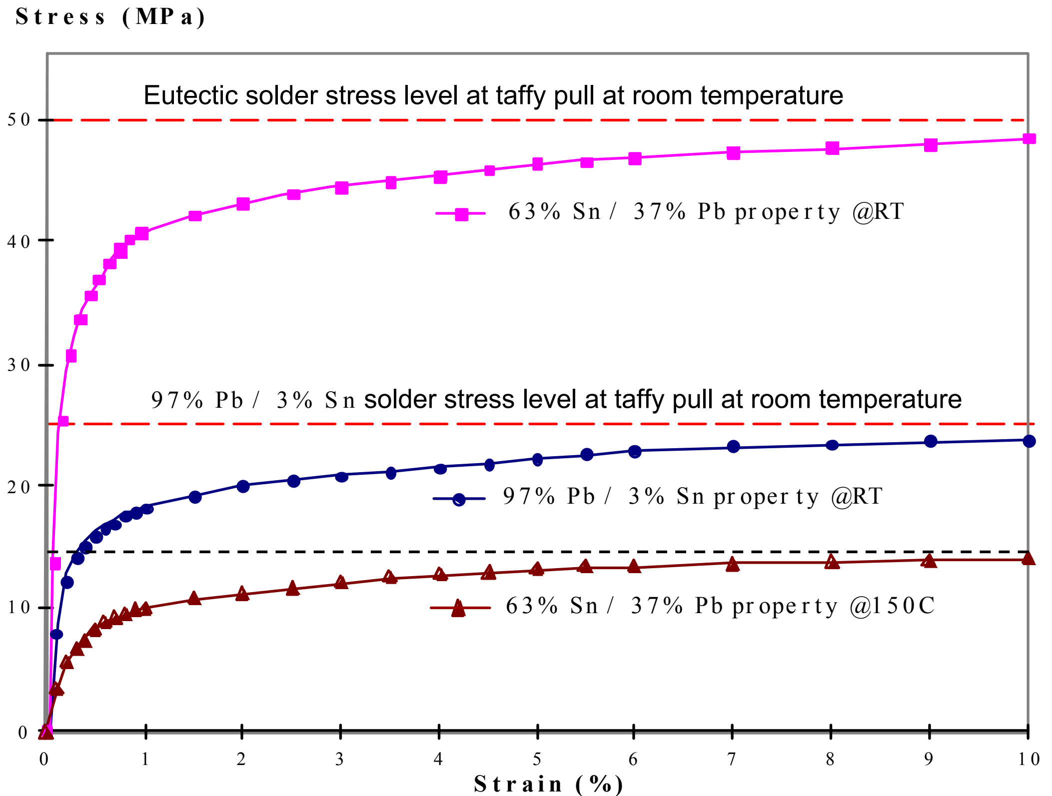
# UBM Strength Test




- Tensile stress is applied to the UNB through solder
- The stress level in the UBM is the same as in the solder

# Minimum UBM Strength



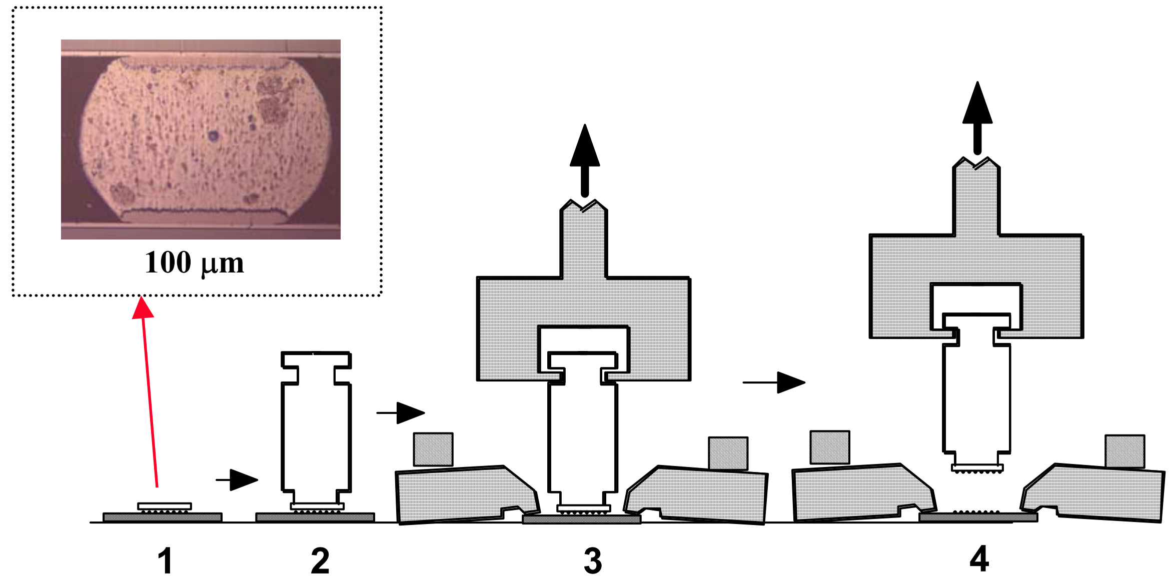




If solder fails when UBM is still intact:

UBM Strength > Solder Ultimate Strength

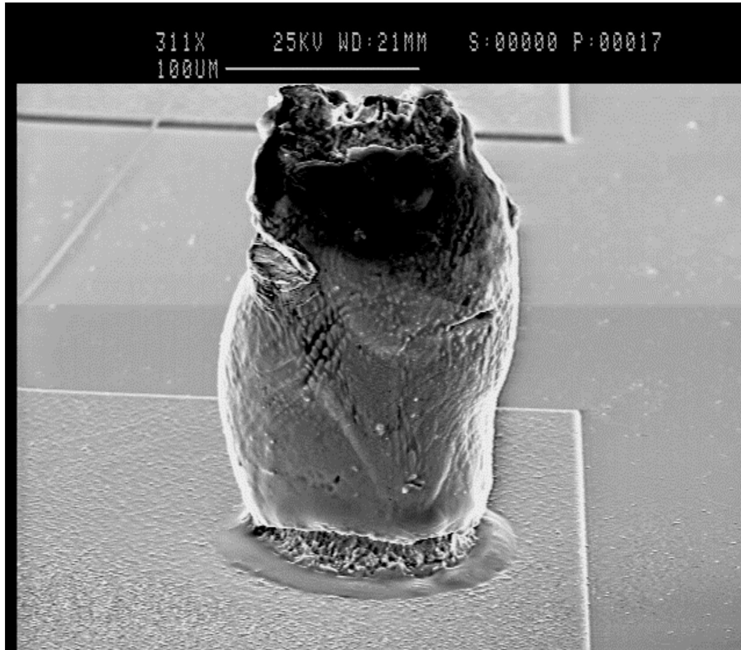
— The Minimum UBM Strength is established

# Die Pull Equipment & Process

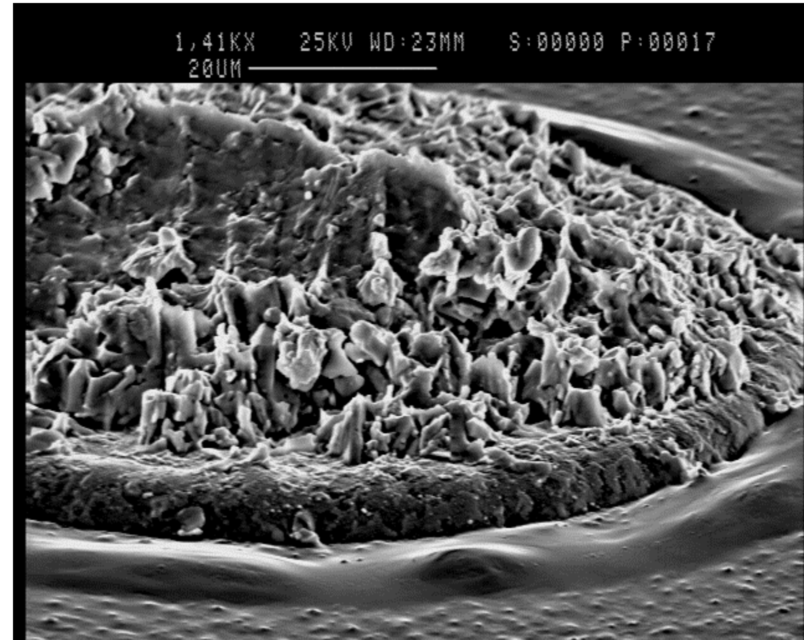



- **Self centering fixtures**
- **Cross-head speed of 5.1 mm/minute +/- 0.1**
- **Failure Modes: Solder failure or UBM failure**

# Failure in Solder Material during Die Pull




Fail in Solder

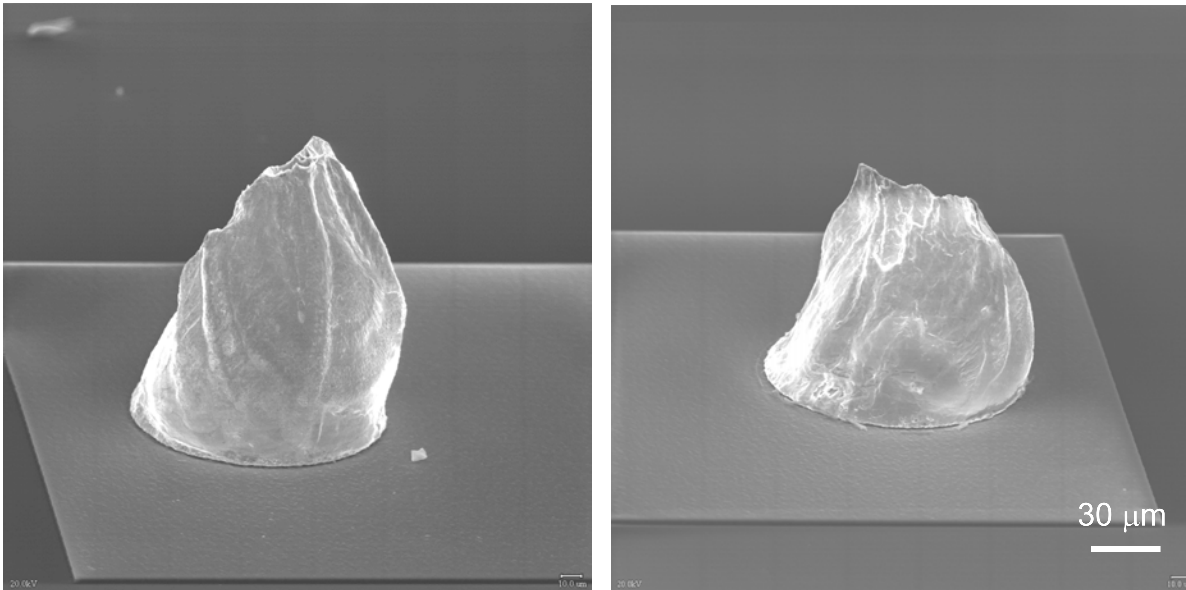



Solder Fracture Surface

**( Courtesy of A. De Silva, Motorola Inc. )**

# Failure in Solder Material during Die Pull

( SnCu bumps on electroplated Ni )




- 'Taffy' Pull in Solder
- Average failure force (Newton) :15.42, SD: 1.36
- UBM Fail: 0/168 (6 die x 28 bumps/die)

(Jin-Wook Jang)

# Failure in UBM during Die Pull

945X 25KV WD:21MM S:00000 P:00017
50UM

Eutectic
SnPb

Ni
UBM

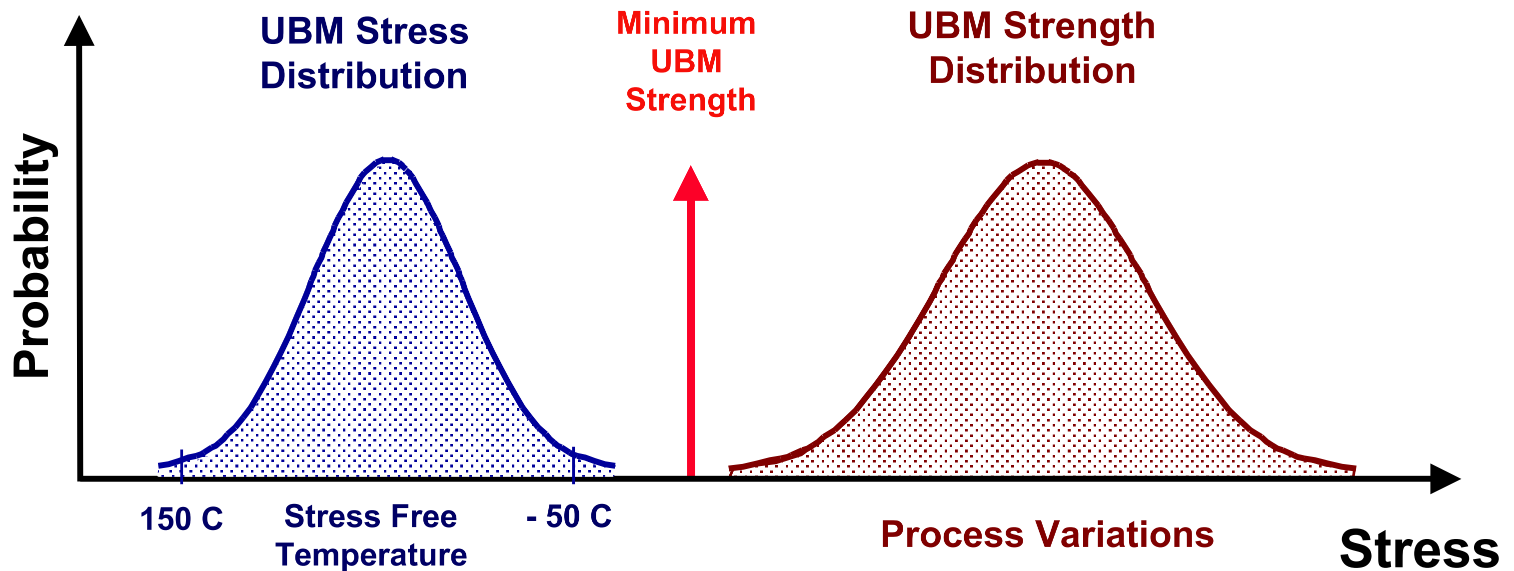
IMC

688X 25KV WD:16MM S:00000 P:00019
50UM

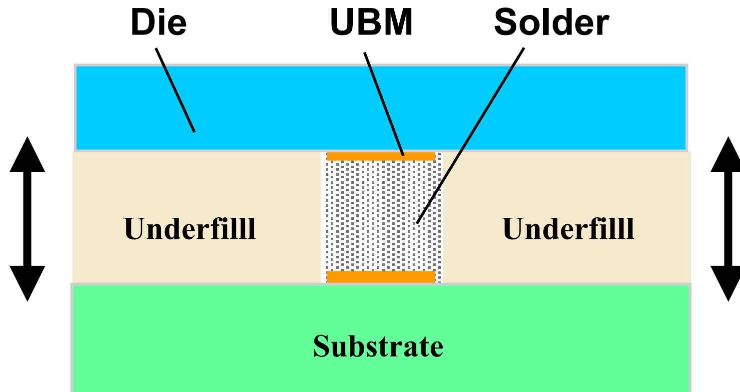
( Courtesy of A. De Silva, Motorola Inc. )

# UBM Reliability

Test 495 bumps with zero failure in UBM (100% failure in solder)
--- 99% confidence on 99% reliability



# UBM Stress Model



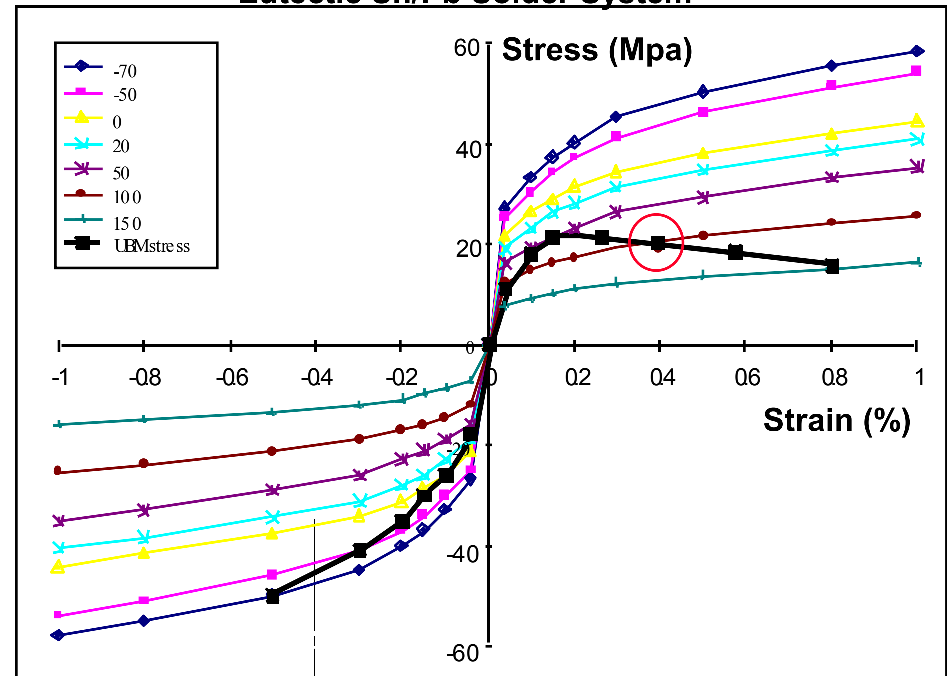

( Stress-free temperature = 20 C )

| Temp. | ΔT from Stress-free Temp. | Underfill CTE Strain(%) | Solder CTE Strain(%) | Solder Mechanical Strain(%) | UBM Stress (Mpa) |
|---|---|---|---|---|---|
| -50 | -70 | -0.49 | -0.14 | -0.35 | -40 |
| 20 | 0 | 0 | 0 | 0 | 0 |
| 100 | 80 | 0.56 | 0.16 | 0.40 | 20 |

*Solder Strain:*

$$\varepsilon_{mechanical} = \varepsilon_{total} - \varepsilon_{thermal}$$

- Stress-free temp. = 20 C
- Solder CTE = 20 ppm/C
- Underfill CTE = 70 ppm/C
- Mechanical strain = 50 ppm/C



# Interconnect Reliability in Flip-Chip Packages

Interconnect Stress (MPa)

50
40
30
20
10
0
-10
-20
-30
-40
-50

-100 -50 0 50 100 150

Temperature (ºC)

37Pb/63Sn
97Pb/3Sn

**Strength of 37Pb/63Sn @ RT**

**--- Min. UMB Strength if 100% solder failure in die pull test**

**Strength of 97Pb/3Sn @ RT**

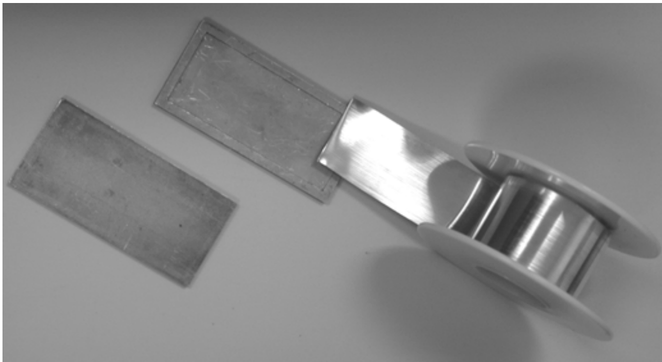
**--- Min. UMB Strength if 100% solder failure in die pull test**

**An interconnect system is reliable if 100% solder failure is achieved in die pull test at room temperature.**

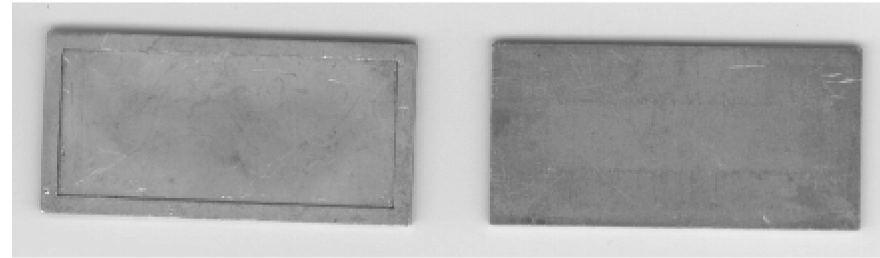
# UBM Reliability in Lead Free Solder Systems:

## SnAg
## SnCu
## SnAgCu

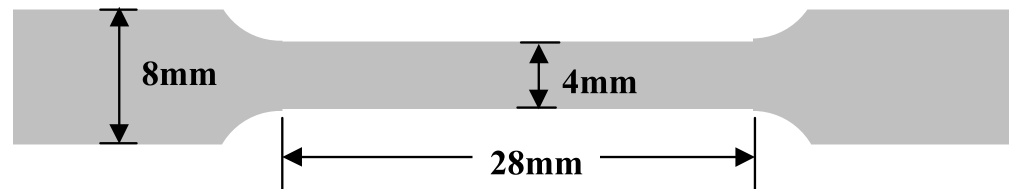
# Sample Preparation for Lead-Free Solder Material Property Tests



Solder tape from Indium Corporation used for specimens

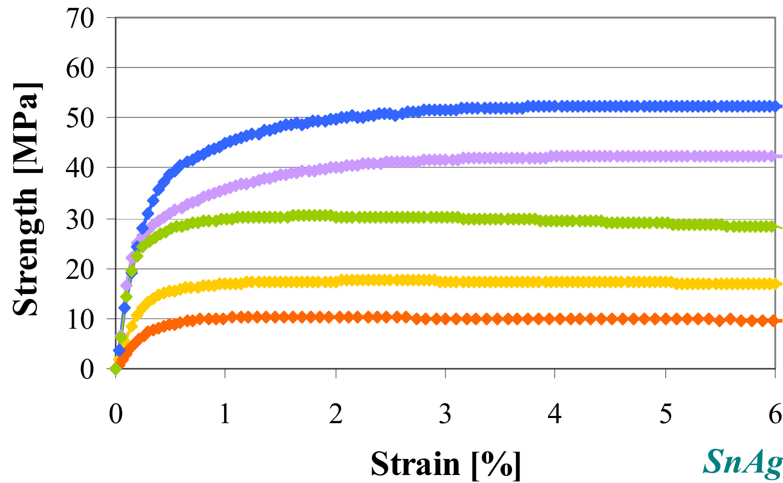


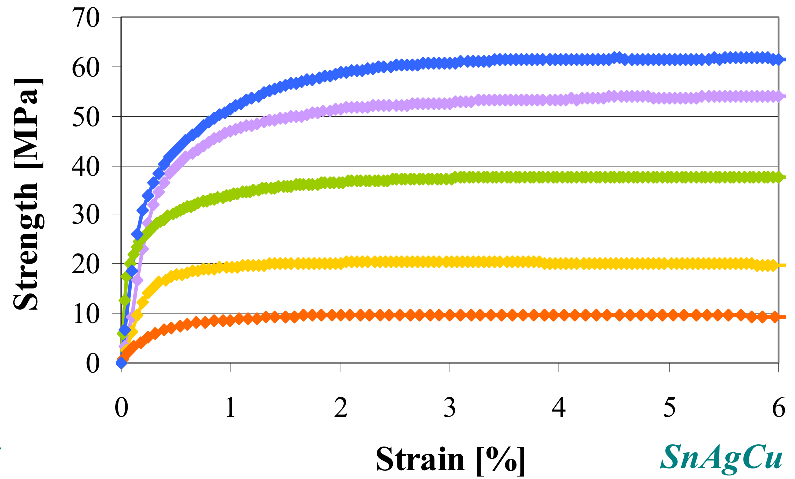
Opening and cover of Teflon-coated mold for reflow processing of solder

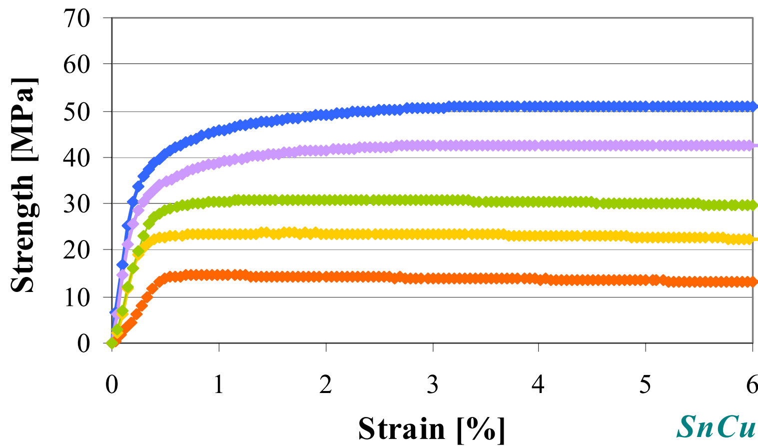



Solder Sample Geometry

# Material Properties for Three Lead-Free Solders



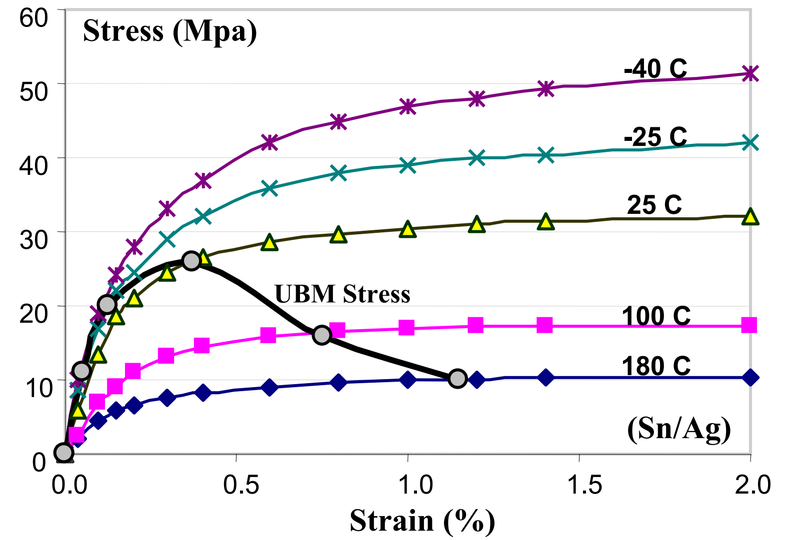



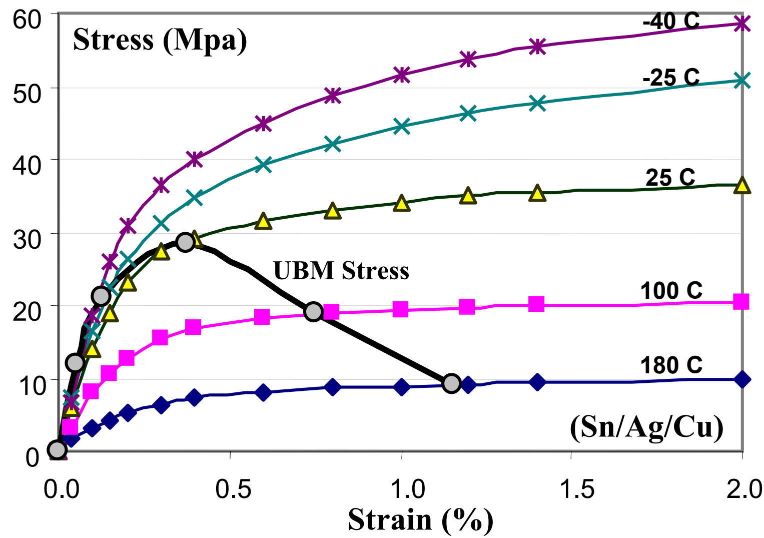

-40C -25C 25C 100C 180C

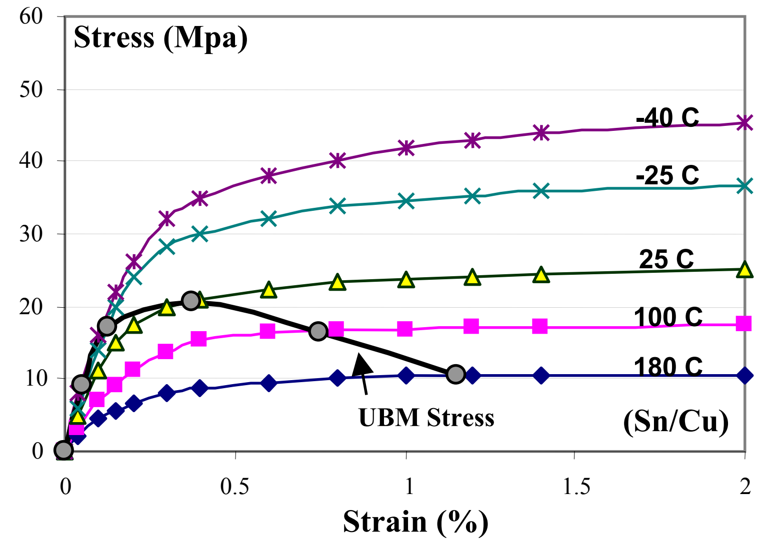
**Temperature-dependent stress-strain properties of Sn-Ag, Sn-Ag-Cu, and Sn-Cu**

# UBM Stresses in Three Lead-Free Solder Systems in Thermal Cycles

( Stress free temperature = -50 °C )

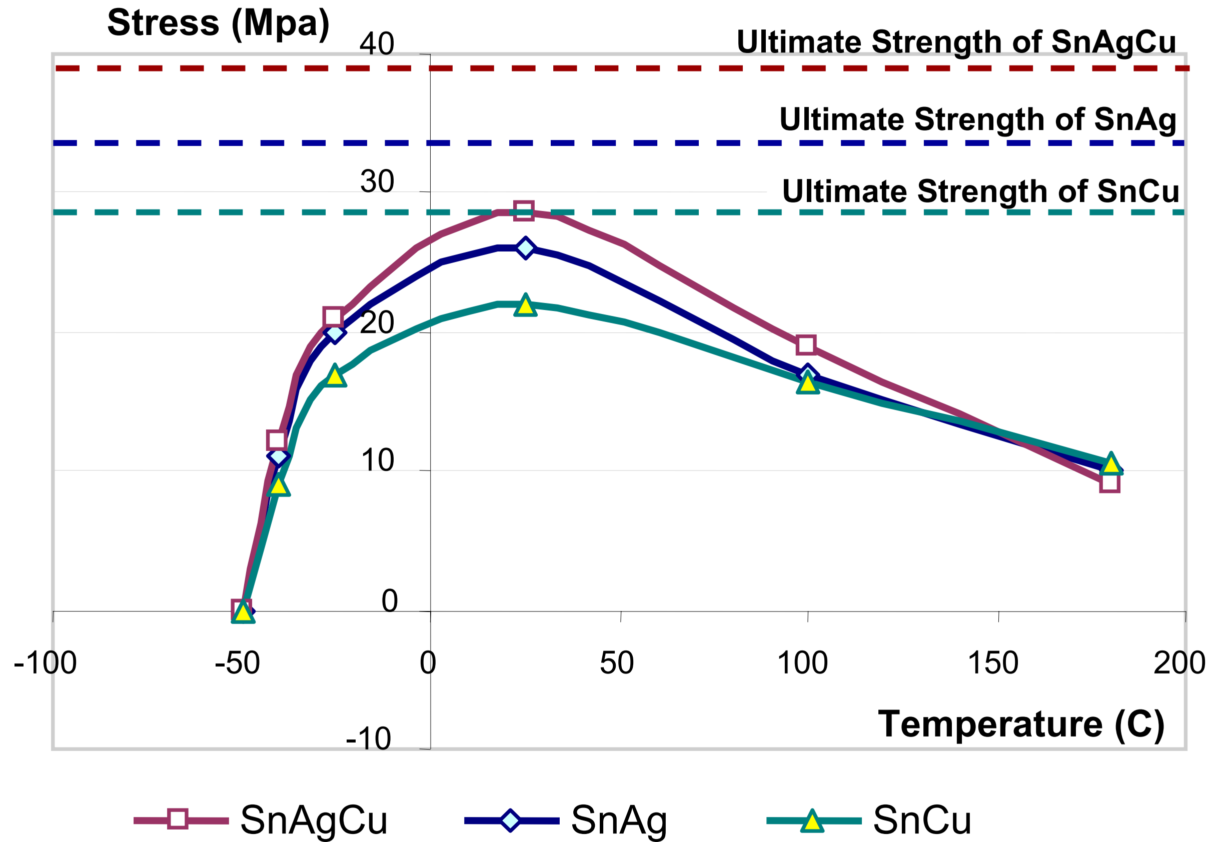


# UBM Stresses in Three Lead-Free Solder Systems

**( Stress free temperature = -50 °C )**



# INERCONNECT RELIABILITY
## — in Three Lead-Free Solder Systems

Interconnect Stress (Mpa)

Strength of SnAgCu @ RT (Mixed failure mode)

Strength of SnAg @ RT (Mixed failure mode)

Strength of SnCu @ RT
= Min. UBM Strength

SnAgCu SnAg SnCu

40 30 20 10 0 -10

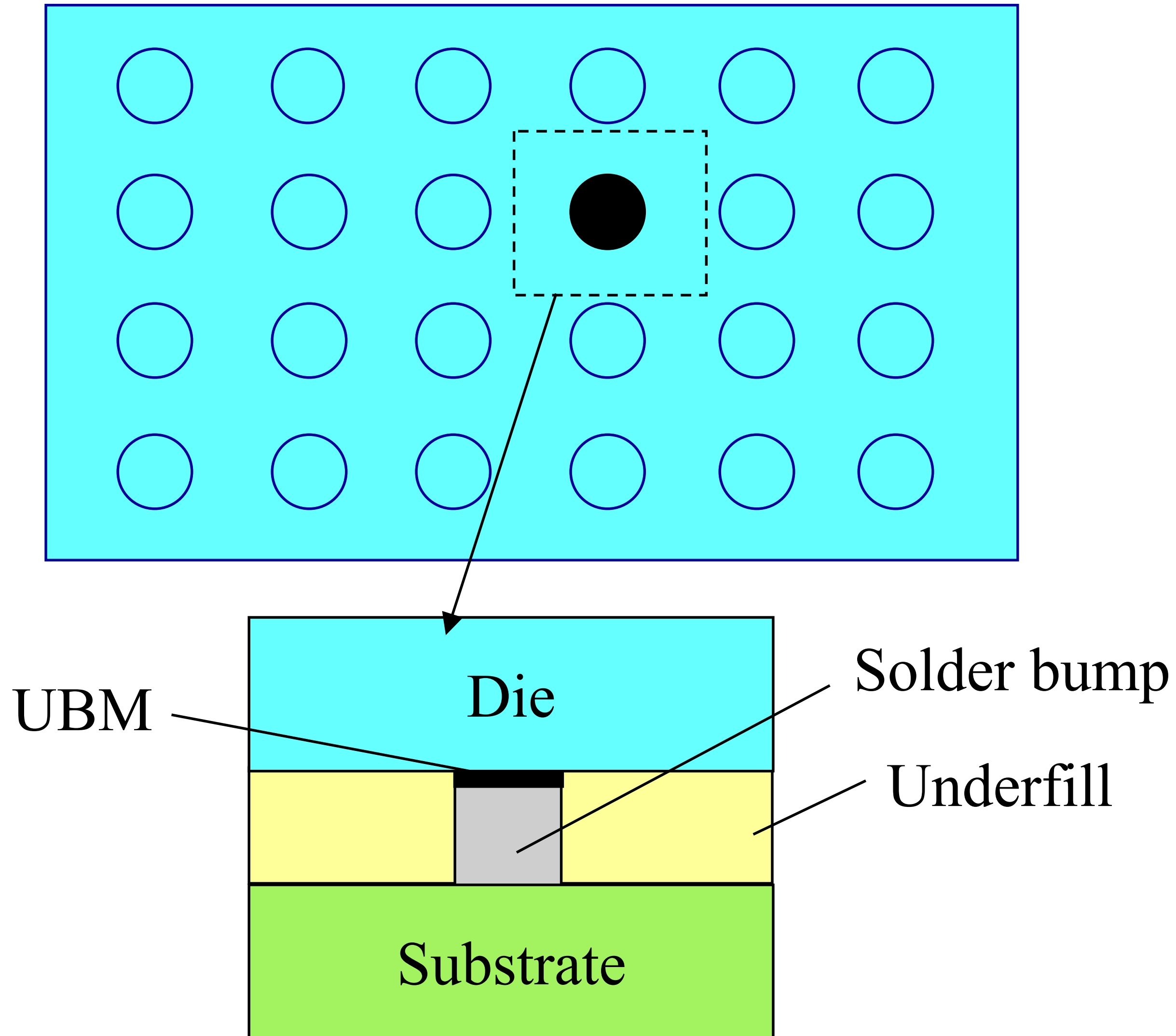
-100 -50 0 50 100 150 200

Temperature (C)

100% solder failure was only achieved in the SnCu system
In the die pull test at room temperature

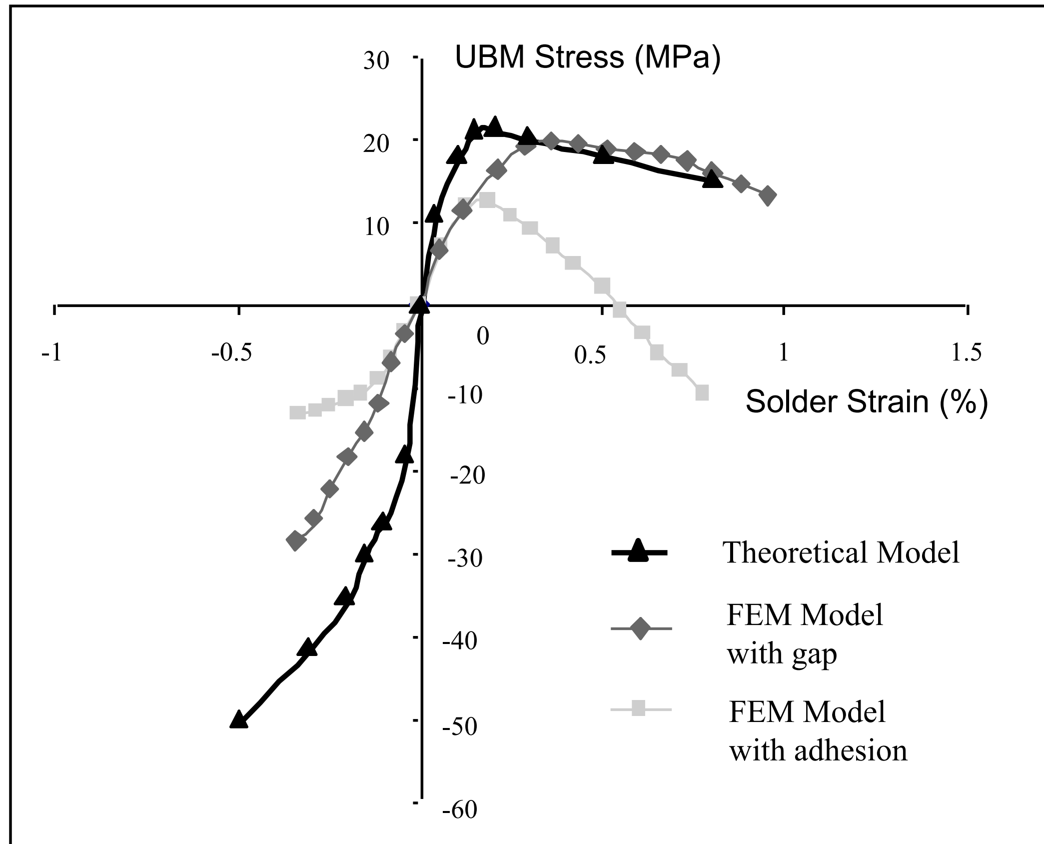
# FEM Model on UBM Stress

## Validation of the Simplified Stress Modle



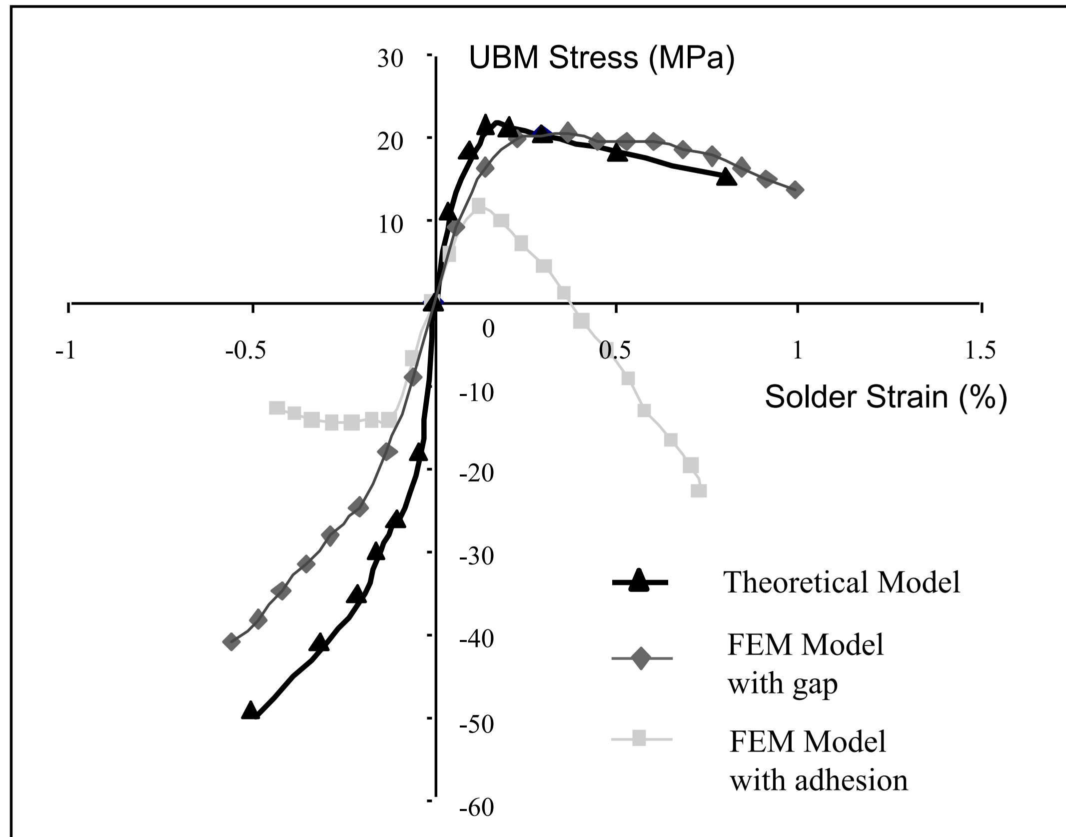
# FEM Validation on the Stress Model

## ( FEM Using FR-4 Substrate Property )



# FEM Validation on the Stress Model

( FEM Using Ceramic Substrate Property )



# CONCLUSIONS ( I )

- A methodology was established in evaluating UBM reliability when different solder systems were used
- UBM Strength (minimum strength) was determined from die pull test
- UBM Stress (stress distribution) was determined form stress model
- By comparing the minimum Strength and the Stress distribution, UBM reliability was determined

# CONCLUSIONS ( II )

- Solder material has strong impact on the interconnect reliability.

- An interconnect system is reliable if 100% solder failure is achieved in die pull test at room temperature.

- This methodology can be used in reliability evaluations and predictions of different bumping technologies with different solder systems.

# Acknowledgement

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- Shun-Meen Kuo
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- Lei Mecardo
- Ananda De Silva