Quantification of Underfill Influence to Chip Packaging Interactions of WLCSP

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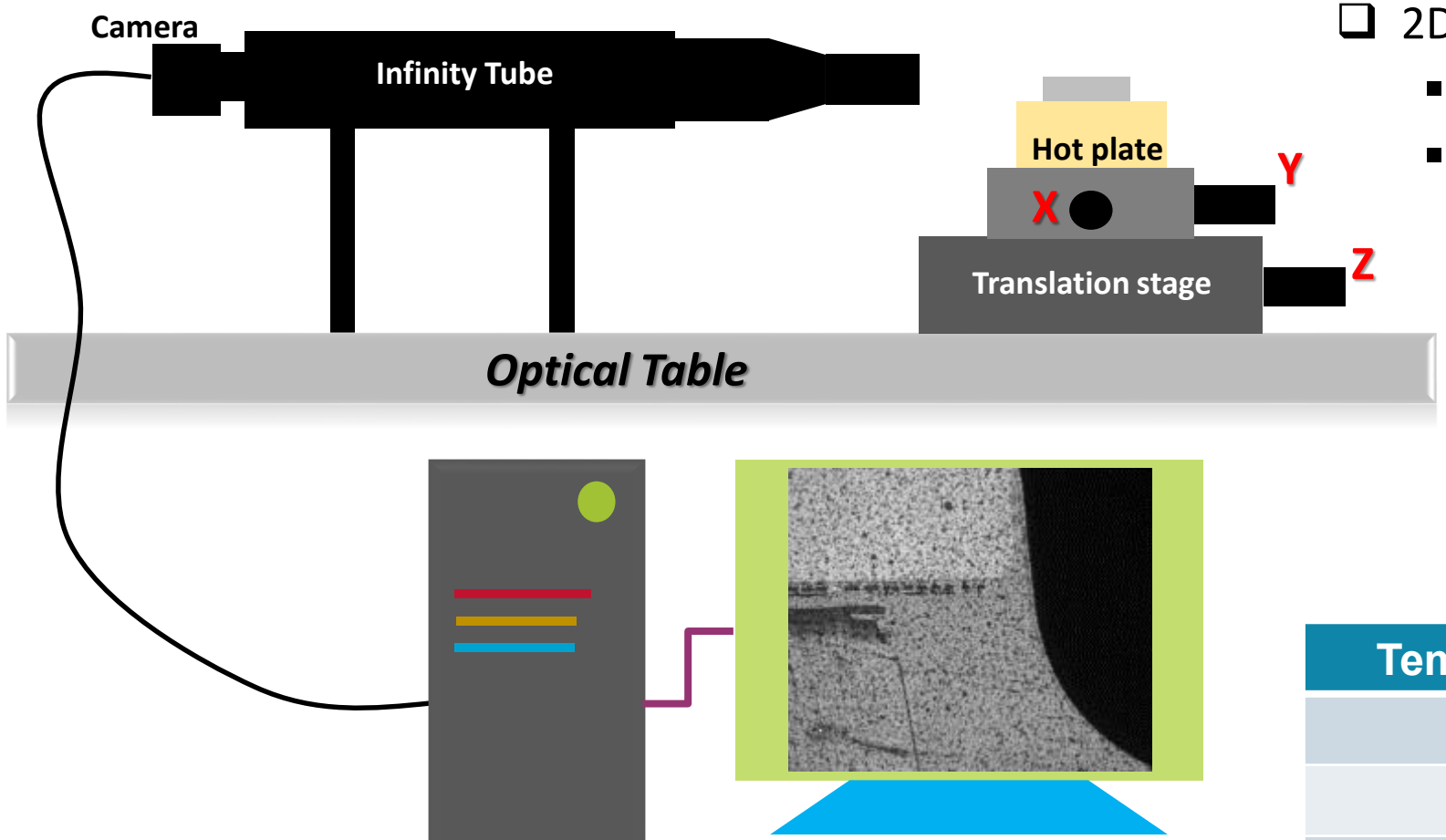
- Objectives
  - 2D displacement mapping at the Die Corner and Fillet Zone.
  - Quantification of chip-packaging interactions (CPI) through measurement of pkg deformation during thermal ramp (23˚C-125˚C).
  - Evaluating the CPI influence on ELK layer's deformation. Design factors include underfill height and material.
- Methodology
  - Experiment setup
  - Sample preparation
- Results
  - Two failure modes of ELK crack propagation
    - High underfill fillet Vs. low underfill fillet
    - 1A underfill material Vs. 3811 underfill material
- Summary

Experiment setup

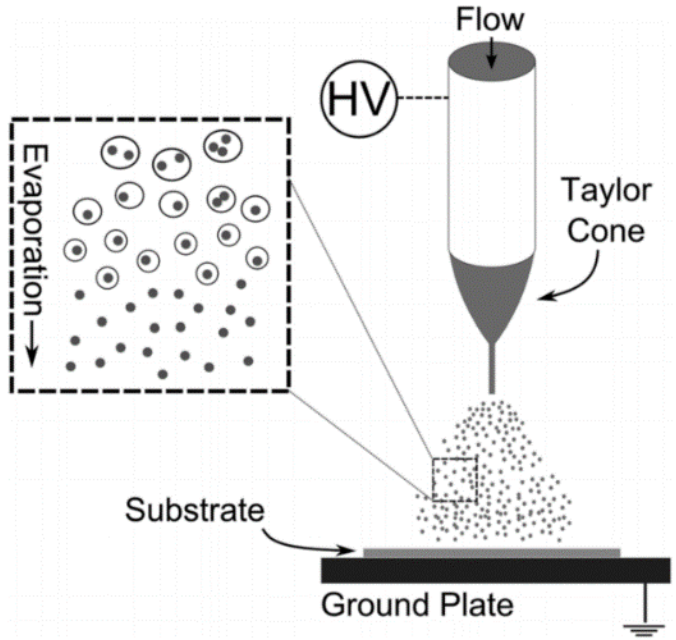


- 2D DIC Measurement Specification:
  - FOV: 230um
  - In-plane Displacement Sensitivity: ±3nm

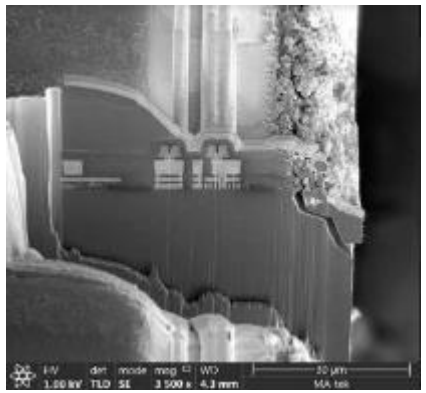
Temperature(˚C)	Stages
23	1~10
50	11~20
75	21~30
100	31~40

Sample preparation

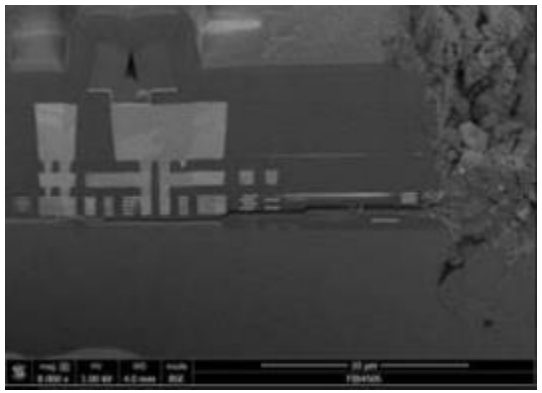
- X-section to the interested site
  - The die & underfill material has different hardness, the relative soft underfill is consumed faster by the sand paper during grinding.
  - It is very important to get a planar x-section to meet the plane assumption for a 2D measurement
  - Diamond lapping film is used to ensure that the die and underfill are consumed at the same speed.
- Carbon coating
  - The inherent contrast of the polished die, solder& underfill are totally different.
  - Coating a layer of 60nm thickness carbon to make them have similar contrast under the microscopy lighting condition.
- Electro spray for carbon coating
  - 2.3kv voltage between the nozzle and the ground plate
  - 3.8x10^9/ml 250nm golden nanoparticle
  - 0.5ul/min flow rate
  - Spray for 10min



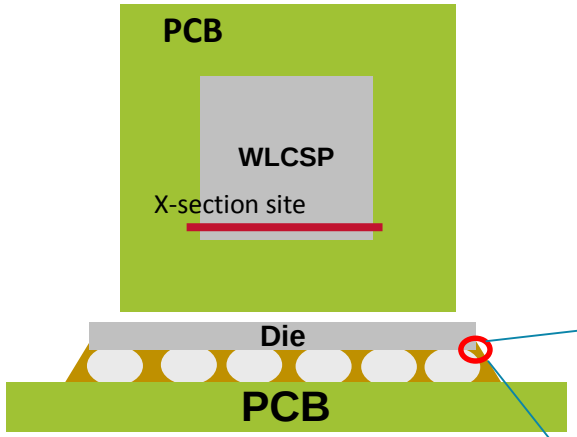
Failure mechanism



Laser ablating & dicing damage

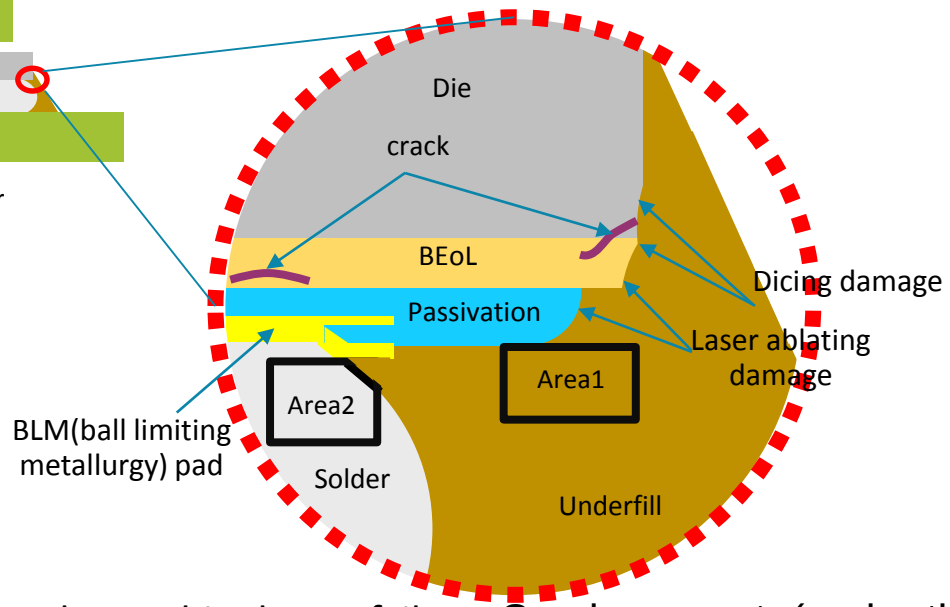


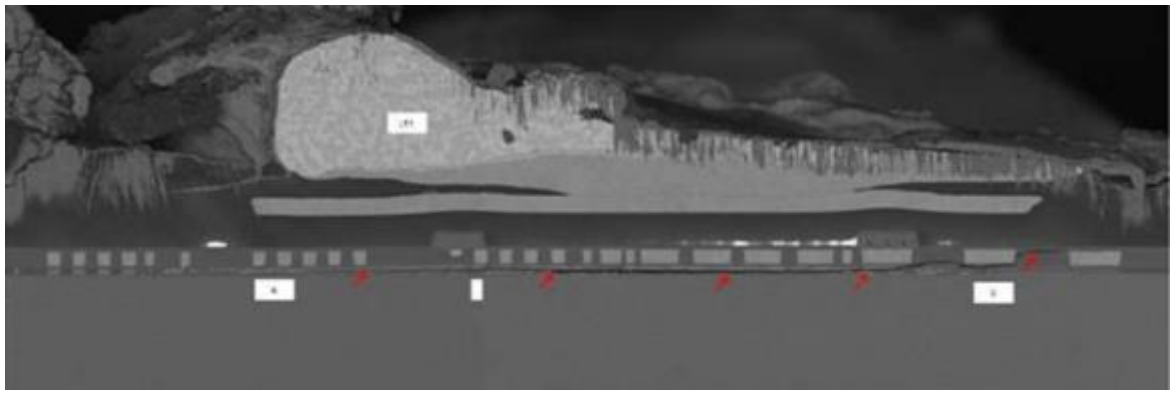
ELK delamination



X-section of first row solder

- Failure mode I: ELK Damage. Inter layer delamination during cool down cycle(underfill shrink more after solder solidify after reflow)





White bump issue

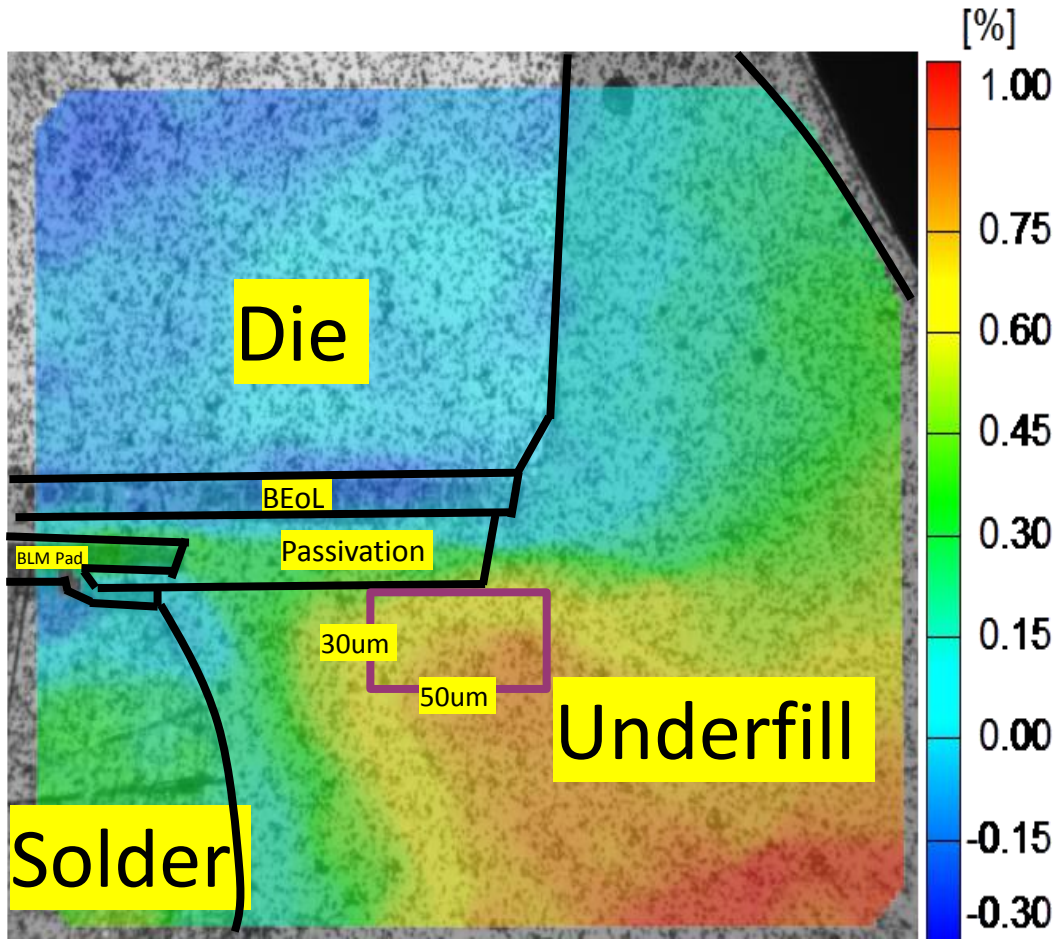
- Failure mode II: White bump failure. Crack generate(under the bump area) during heat up cycle, underfill is being pushed up more than solder(24ppm/˚C) and crack shall initiate at the corner of BLM(ball limiting metallurgy) pad

❑Failures are attributed by stress(relative cumulative deformation or strain between solder and underfill times moduli):

$$\sigma = \int_{T_0}^{T} E\alpha dT$$

Measurement of underfill area strain

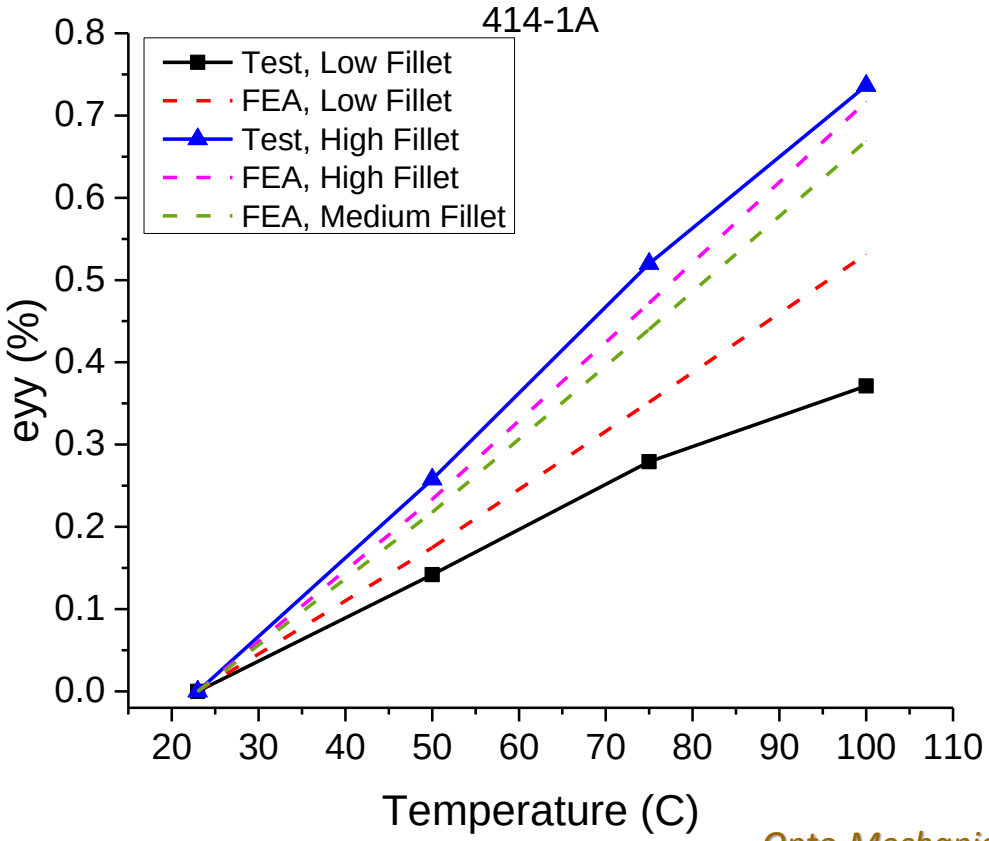
- Underfill's influence on the die corner during thermal cycling was analyzed
  - The strategy is through measuring the die corner area underfill strain change and combine its young's modulus to estimate the stress that the underfill applied on the die corner ELK.
  - A 30*50um area was chosen as the analysis target.
  - The area is right under the passivation layer, its right edge is aligned with the die edge.
  - The 1A underfill sample were measured from RT to 125˚C
  - The 3811 underfill sample were measured from RT to 50˚C. (large deformation of unerfill happens at higher temperature and the image failed to correlate.)
  - The average strain of the area(350 data points) described above were extracted to be analyzed.

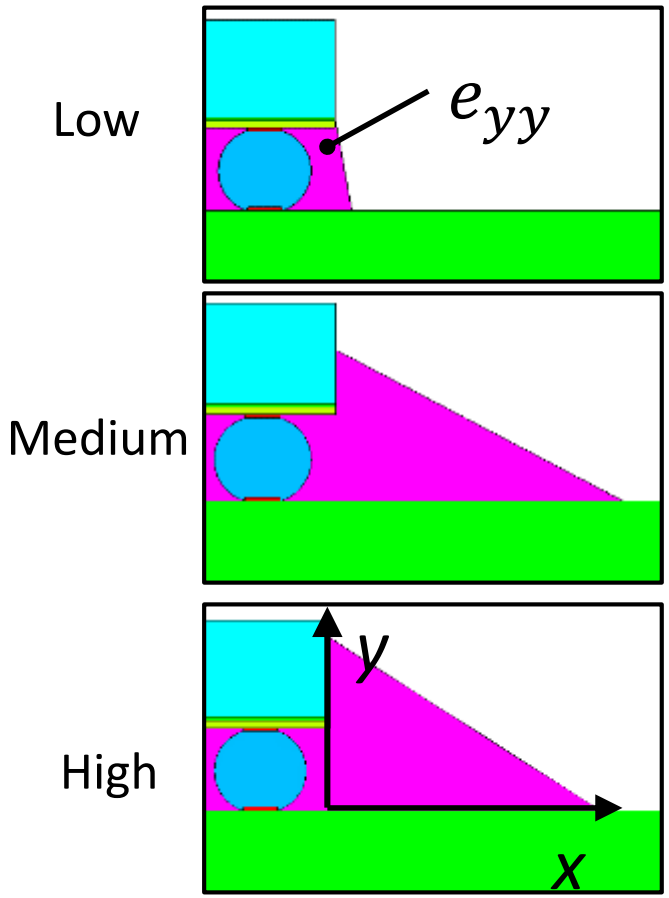


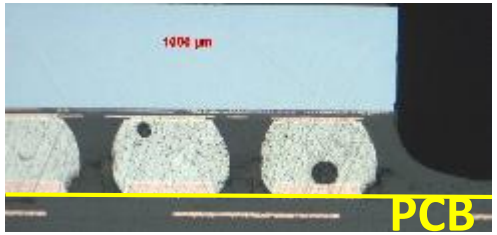
eyy strain contour @ 100˚C

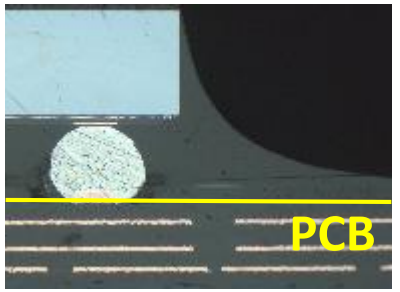
FEA correlation by 2D DIC measurement

- At elevated temperature, tensile strain (thermal + mechanical) occurs within the underfill beneath die edge
- Higher fillet gives higher tensile strain in underfill beneath die edge. However, this effect reduces as fillet height increases.
- Higher strain here does not necessarily indicate easier failure



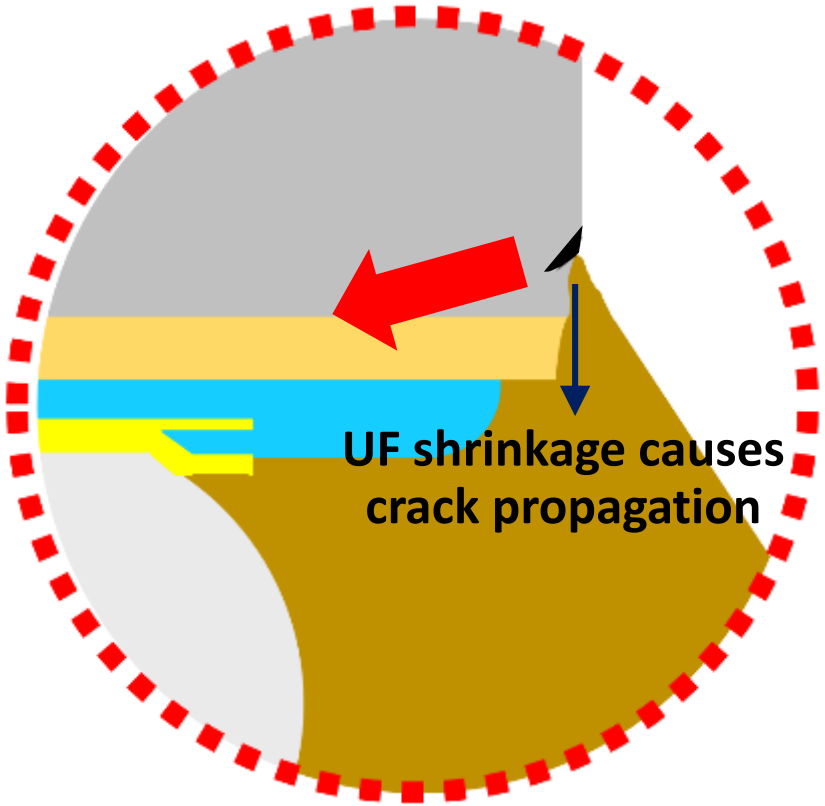


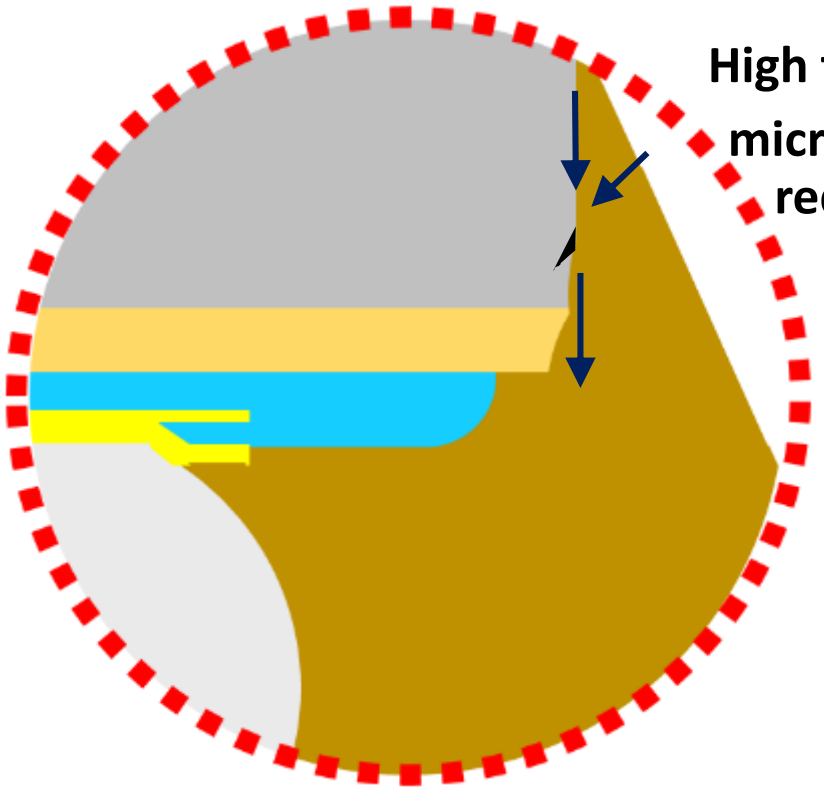




Risk of microcrack on die edge during cooling down

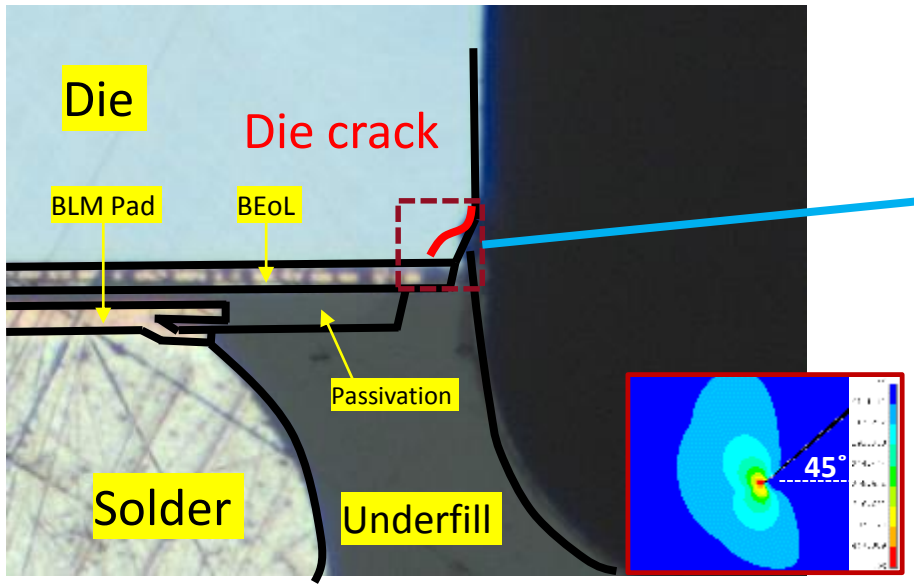
- After underfill dispense at 150 °C ~ 160 °C, underfill shrinkage during cooling down may cause microcracks to propagate at die edge, considering $\Delta T_{max} = 200$ °C for TC of -40 °C ~ 125 °C.
- High fillet of underfill reduces the risk of crack propagation compared to low fillet
- Once fillet is high enough to cover the zone with microcracks, additional effect with extra fillet height is limited.



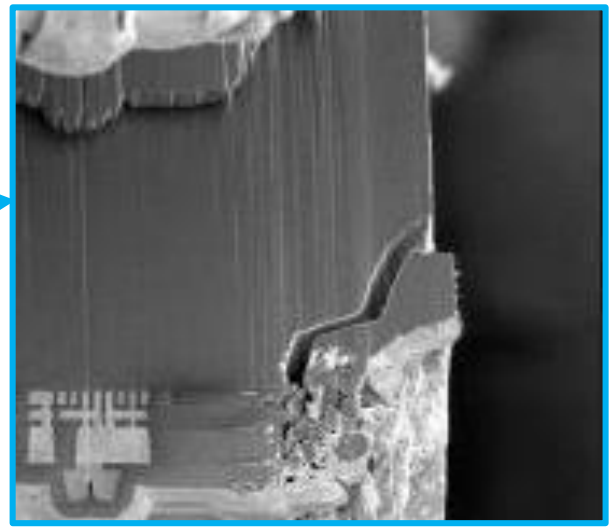


Die Crack - Fracture Analysis

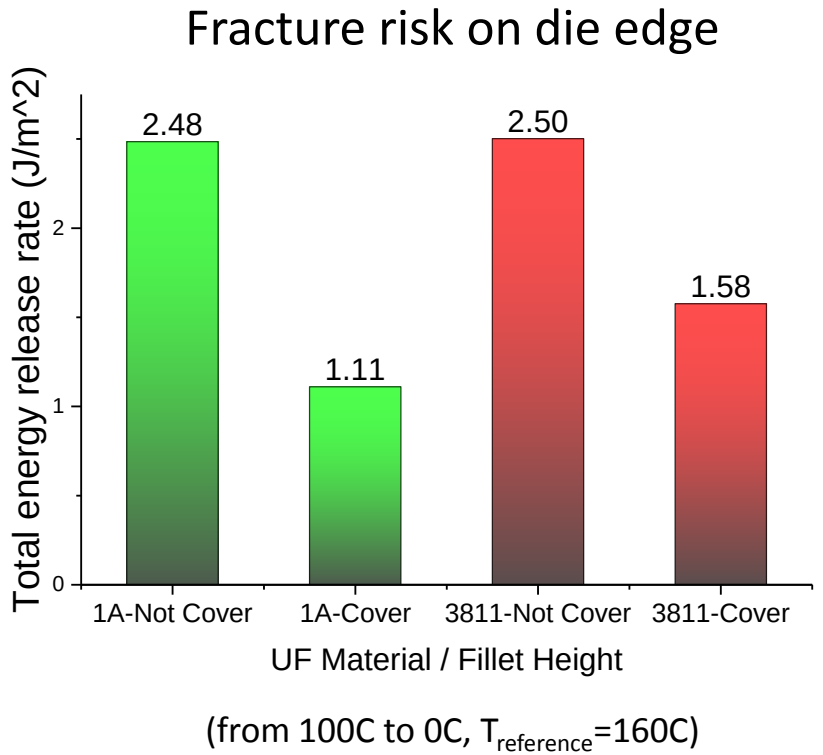
- Die edge crack energy release rates are compared for 3811 and 414-1A underfill material with low and high fillet
- High fillet covers the initial die crack and low fillet is below die crack location
- In FE modeling, two fillet heights are built so that one just covers the microcrack and the other one just not.
- Whether covering microcrack or not is important. Underfill fillets of both materials effectively lower energy release rate, when covering microcrack zone



Die corner image



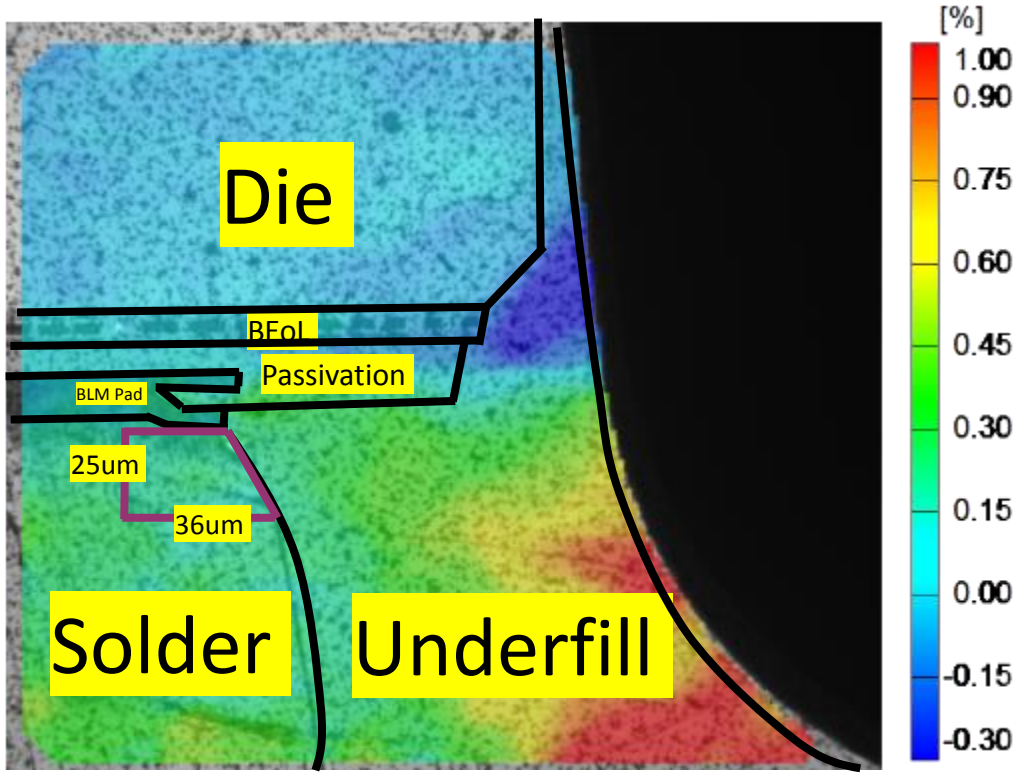
1st principle stress at crack tip



(from 100C to 0C, $T_{reference}$=160C)

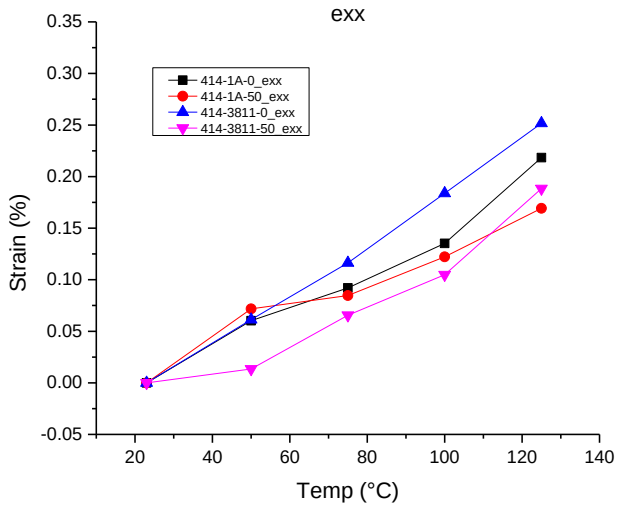
Measurement of solder corner area strain

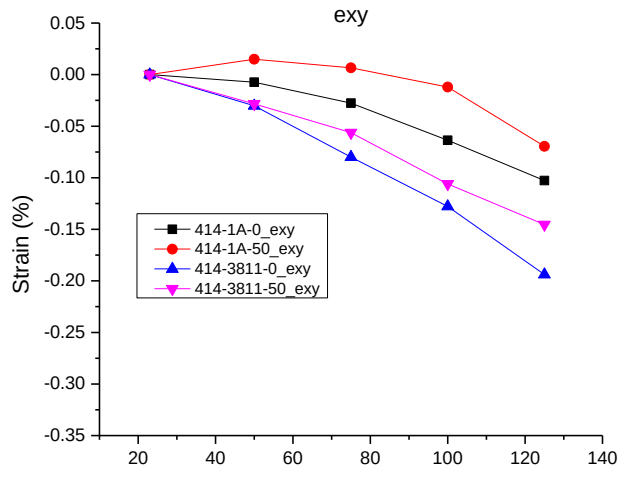
- Underfill's influence on the solder corner during thermal cycling was analyzed
  - The strategy is through measuring the corner solder's right up corner area strain change during thermal cycling to estimate the stress that the solder corner applied on the passivation and ELK.
  - A 25*36um area was chosen as the analysis target.
  - The area is right under the copper pad, its lower edge is 25um away from the copper pad, and its left edge is 36um away from the solder edge.
  - All units was measured from RT to 125˚C
  - The average strain of the area(250 data points) described above were extracted to be analyzed.

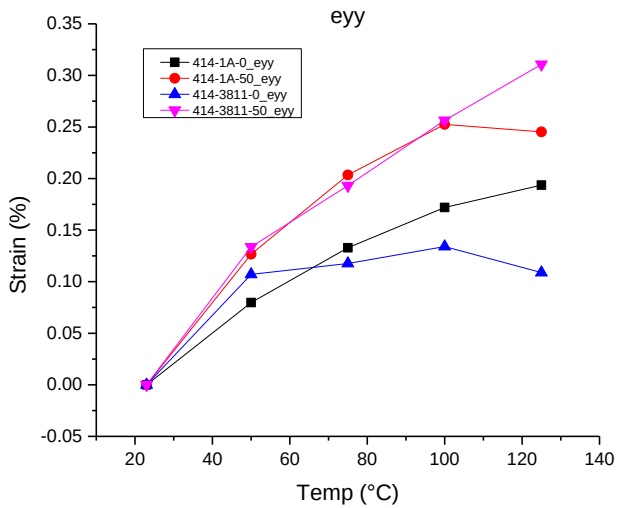


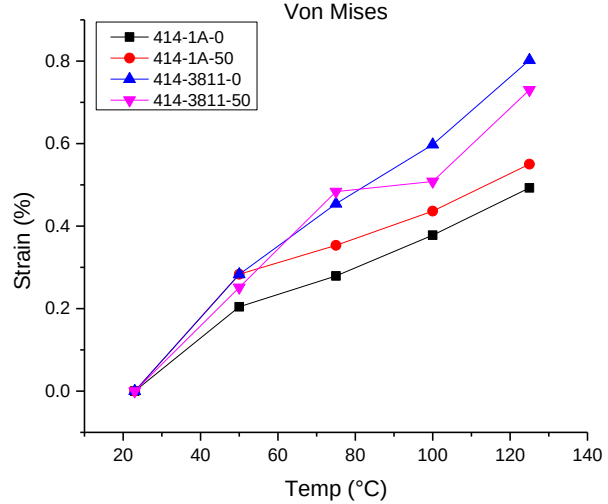
eyy strain contour @ 100˚C

Comparison between two underfill material









- Compared to 3811 underfill, 1A underfill gives lower shear strain at the corner solder. It also gives lower von mises strain.

Summary

- 2D displacement/strain mapping at the Die Corner and Fillet Zone were achieved.
- Die corner and solder corner strain were quantified to evaluate chip-packaging interactions.
- With validated model, die corner crack propagation risk was evaluated for high and low underfill fillet configuration. Although high underfill fillet gives higher tensile strain at the die corner ELK, it can dramatically reduce die corner crack propagation risk. It is recommended that the underfill should at least cover 60 to 100um higher than the dicing defects region.
- Compared to 3811 underfill, 1A underfill gives lower shear strain at the corner solder. It also gives lower von mises strain. Which indicates it will apply lower stress on the ELK layer above it.