Electrolytic deflash & high-pressure water jet simulation driven delamination risk assessment in plastic packages

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Abstract
Plastic molded lead frame products are widely used in the semiconductor industry. The Epoxy Mold Compound (EMC) selected for these products is designed to have excellent adhesion and integrity to the die and other materials in contact. In manufacturing, mold flash is often unavoidable, and cleaning is required to enhance mechanical and thermal functionality as well as cosmetic appearance. Deflash, the commonly used cleaning method, is typically integrated into post-plating operations that may also finish the package with Sn and other lead-free plating. Deflash typically consists of passing the molded package through an alkaline bath (such as KOH) that softens and degrades the adhesion of the EMC flash. This process can be energized using Electrolytic Deflash (ED) i.e., by applying DC current between the product and the alkaline bath. ED cleaning effectiveness increases with higher current density. Next, High-Pressure Water Jet (HPWJ) removes the loosened flash in line with the deflash process. An issue/risk is that ED and HPWJ processes can induce unwanted interface delamination between the leads and the EMC at the boundary of the package. In this paper, we propose a computational framework to study the mechanism of delamination during flashing process. During the two-step analysis, electrostatics and mechanical simulations are performed to assess the impact of ED and HPWJ processes and identify regions of the package that are susceptibility for delamination. Current density was predicted to vary widely across the lead frame in-plane features and with bath concentration. Regions of the lead frame at the package's boundary with high current density were identified as a risk for delamination. The electrolytic reaction results in crack initiation at these regions and furthermore the crack propagates under HPWJ. This is understood from HPWJ simulation where the high stress region coincides with high current density region in the ED simulation. Overall, the experimental observed delamination regions agreed with the deflash simulation predicted delam risk locations. This developed computational framework thus enables pathways to improve the strip designs and deflash process control maintenance.

Key words
Current density, Deflash, Delamination, EMC, Side leads, Simulation, Strip, Tin plating, Water jet

I. Introduction
RF high-power device comprises multiple active and discrete devices interconnected with wire (Fig. 1). The system is molded with an epoxy molding compound (EMC). The package configuration uses a high-conductivity heat sink that provides high performance thermal dissipation in a cost-effective, high-volume package. Another key feature is the platform CTE matching to the next level assembly and robust reliability given the package leads and heatsink plated in matte Sn.

Internal interfacial adhesion is critical to avoid issues throughout the product's life. Careful attention is paid to the package material selection and assembly processes to mitigate adhesion issues. Material selection and interactions are simulated to ensure the device's robust reliability. Process steps are included to ensure bonding requirements are achieved. Often, assembly activities such as pre-plasma or pre-baking before a given assembly step are used to maximize adhesion or bonding. It may also include post-thermal treatment, such as extended or post-mold curing cycles. In addition, careful attention to process window details in staged material handling, machine setup, buyoff, and monitoring is critical. These efforts maximize the strength of the interfacial and adhesion bond between the EMC and other materials in contact.

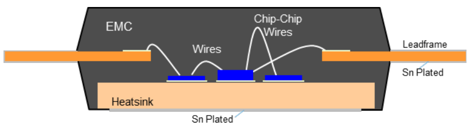


Fig 1. Cross-section illustration of package

Even with this due diligence, EMC delamination can occur in the Sn plating metal finishing processes. The purpose of the Sn plating is to provide protective plating over exposed metal such as the heatsink or lead frame. Sn plating is typically performed near the end of assembly but before singulation from the handling strip (Fig. 2). The strip is the carrier for a series or strand of molded packages. Only after singulation does the package unit become an individualized micro-electronic device.

Fig 2. Strip configuration for OM-platform before plating

A. Deflash process flow

Sn plating typically involves a series of steps, including strip cleaning, deflash, descaling, surface-activating, Sn-plating, rinsing, and drying. The strip is carried through this process using an automated carousel that is temporarily attached. For some designated time and temperature, the deflash process (Fig. 3) typically involves soaking or immersing the strip in an alkaline bath, typically a solution potassium hydroxide (KOH). The fluid in the bath will permeate, reducing or loosening the adhesion of surface debris or EMC remnants of molding, called flash. The strip is then sprayed and rinsed with a High-Pressure Water Jet (HPWJ). The loosened material is cleaned off the strip. This process is called Chemical Deflash (CD).
The speed of this soak time can be greatly reduced by electrifying the bath and strip. This is referred as Electrolytic Deflash process (ED).

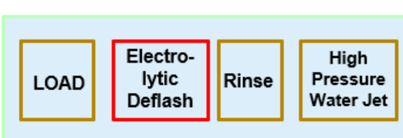


Fig 3. Typical electrolytic deflash process flow

ED is preferred for high-volume manufacturing. In the ED process, an DC electrical circuit is formed between the molded leadframe strip and the submersed conductive anode plates (Fig. 4). Depending on power source, ED processing can either be voltage or current controlled. CD and ED can coexist in same line.

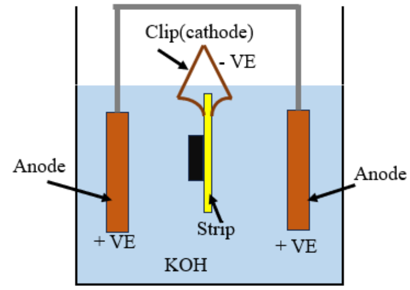


Fig 4. Electrolytic deflash circuit with KOH solution

The process creates an oxidation-reduction reaction [1] of the water molecules in the bath, given by (1-3). Hydrogen forms at strip (cathode) as H_2 dihydrogen molecule, which is not soluble in the bath. As a result, the H_2 bubbles out of ED bath solution (Fig. 5). This effervescent and scrubbing action of the bubbles can be vigorously enhanced with increased intensity of the electrification.

Cathode reaction (at strip or package)

$$4H^+ + 4e \rightarrow 2H_2 \quad (1)$$

Anode (Plate) reaction

$$O^{-2} \rightarrow 4e + O_2 \quad (2)$$

Overall Reaction

$$2H_2O \rightarrow 2H_2 + O_2 \quad (3)$$

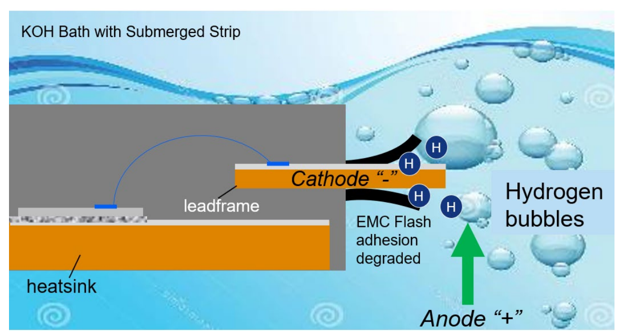


Fig. 5 Effervescent scrubbing action of H_2 bubbles at package and over entire strip

B. ED delamination hypothesis

The H_2 scrubbing can create an undesired and unintentional risk of penetrating beyond the mold flash and interior to the package. This has been discussed in past experimental studies [2-5]. The result is weakened adhesion between the EMC and leadframe, beyond the region of flash. Then, it follows, HPWJ is applied and may cause further damage. Fig. 6(b) & Fig. 6(c) shows the post-ED delam detected inside the package between the EMC and lead frame post assembly using Scanning Acoustic Microscope (SAM). Whereas, Fig. 6(a) shows No delamination pre-ED.

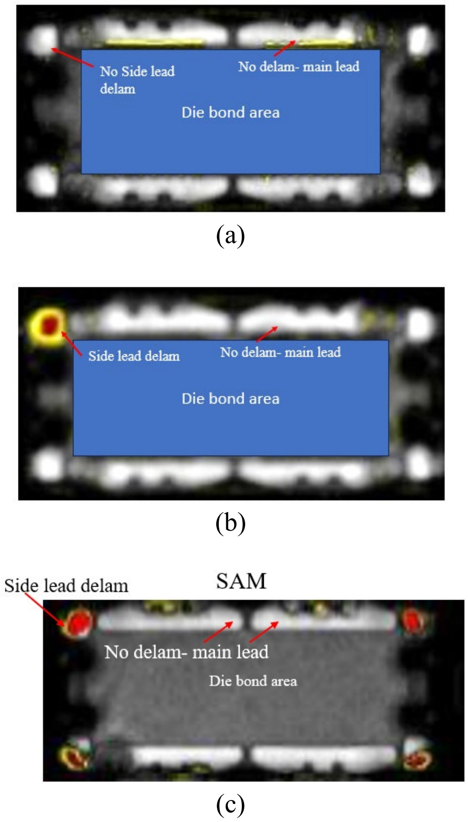


Fig 6. (a) No delam pre-ED process. (b) Delam post-ED process. (c) Additional delamination revealed in SAM post ED processing.

This paper will investigate and simulate the ED and HPWJ processes to help assess the delamination risk associated with these two processes. The simulation of ED is to create an electrostatics model of the ED process to predict current density patterns. A mechanical model was created to analyze the stress induced by the HPWJ. Together, these simulations will help provide insight as to key factors that might induce side lead delamination risk.

II. Electrostatics simulation-ED process

A. ED Simulation description

Ansys® finite element software is used to perform the electrostatics simulation. The software consists of a module called 'electric' which is suitable for this problem. The lead frame strip consists of several packages. Due to the periodicity of lead frame strip, only a representative unit is modeled for simplicity. The modeled unit consists of one complete package with the leads and its associated tie bars. The bath i.e., KOH is modelled as a solid block. The cartoon representation and simulation model are shown in Fig.4 and Fig. 7 respectively. The side and main leads are highlighted in Fig. 7(c). A voltage difference is applied between the anode and cathode and the appropriate regions are highlighted in Fig. 7(b) and Fig. 7(c). This potential difference generates an electrical field, initiating a current flow between the cathode and anode. Due to the nature of the strip with stamped features and sharp designs, the current density patterns can vary along the strip. The current density is responsible for breakdown of the KOH into bubbles which in turn acts as scrubber to remove the flash. Hence current density plots serve as the metric for risk assessment, with localized higher current density resulting in relatively stronger bubbling/scrubbing effect.

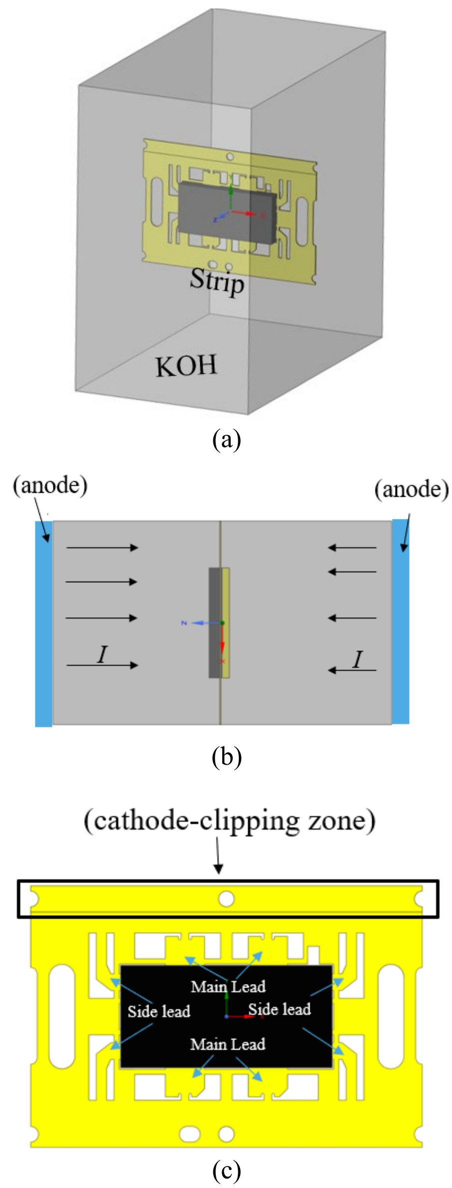
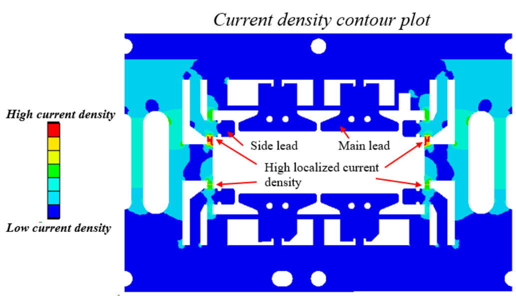


Fig 7. (a) Isometric view of the simulation model. (b) Top view illustrating the anode location. (c) Front view illustrating the cathode location.

B. Results & Discussion

As indicated in the earlier section, the metric used for risk assessment is current density. The regions with high current density will have relatively higher bubbling/scrubbing effect and thus increases the risk to initiate mold-side lead interface delam at the package boundary. The Fig. 8 illustrates the current density contour plots. The high current density regions are at the tie bars close to the side lead package boundary regions. This results in a relatively higher bubbling/scrubbing effect near the side lead-mold interface which in turn increases the interface delamination risk. This agrees well with the SAM observations in Fig. 6 which illustrates the side lead delam. The location of the delam in the SAM is close to the vicinity of the high current density region observed in Fig. 8. On the other hand, the low current density regions like the vicinity of the main lead are at a lower risk for delamination due to relatively lower bubbling/scrubbing effect. This too agrees with the SAM in Fig. 6(b) & Fig. 6(c) which show no delamination at the mold-main lead interface. Once the delam is initiated at the side lead, the interface can get further disturbed in the HPWJ step which is explained in the next section.



(a)

Fig 8. Current density contour plot.

C. Risk assessment of ED process variations

Process variations can increase delamination risks in the ED process. Here we assess the risk of two process variations namely: variations of KOH bath conductivity & improper lead frame clipping.

<u>1. Variation in KOH bath electrical conductivity</u>

The KOH bath electrical conductivity is a function of the bath concentration and temperature [6]. Simulation results in Fig. 9 show significant variation in the current density pattern for different KOH bath electrical conductivity. Thus, it is important to control the bath condition to prevent higher scrubbing/bubbling effect which can increase risk for mold-lead interface delamination.

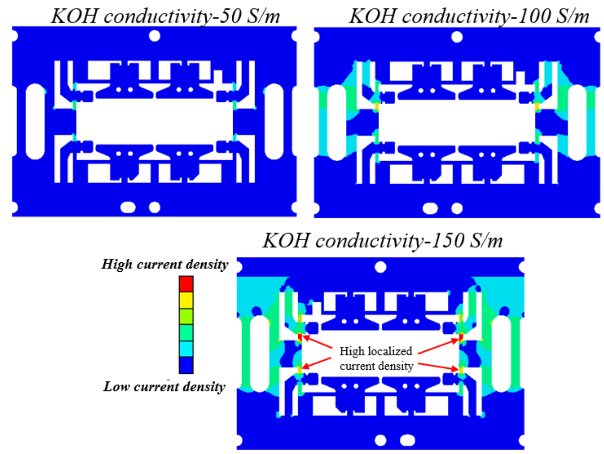


Fig 9. Current density plot for different KOH conductivities.

<u>2. Improper lead frame clipping</u>

In the deflash process, the strip is suspended at the top section of the strip with some clips which also acts as the cathode. The location of the clips is illustrated in Fig. 4 & Fig. 7(c) Overtime if the clips are not maintained or if the lead frame is improperly clipped, it can change the current density patterns in the strip during the deflash process. Fig. 10 shows the current density plot for different clipping conditions. The red box represents the clipping area. Damaged clips can end up with partial clipping area. The risk for the mold-lead delamination increases for improper/partial clipping due to increase in current density pattern as shown in Fig. 10

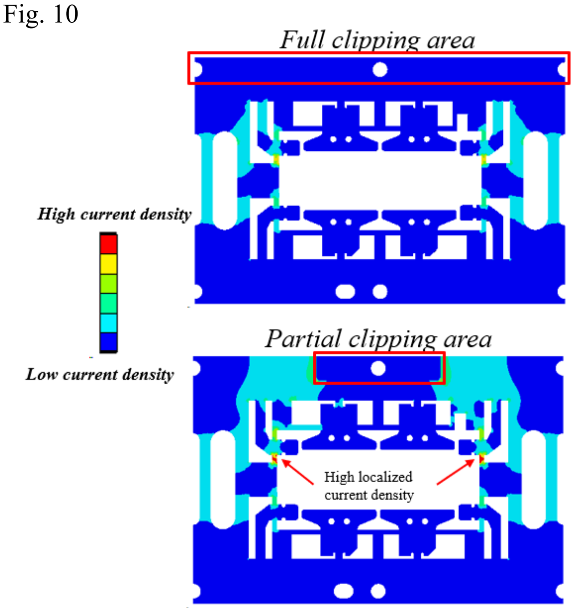
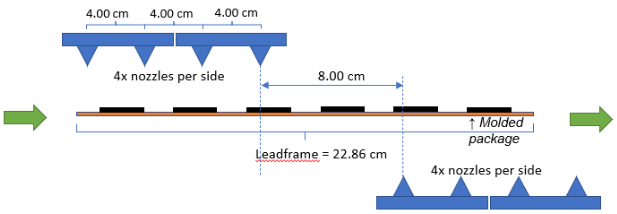


Fig 10. Current density plot for different clipping conditions

III. Mechanical Simulation-HPWJ

After the ED process, the lead frame is subjected to a high-pressure water jet (HPWJ) treatment. This can further propagate the interface delamination between the leads and the encapsulant molding compound (EMC) within the package boundary. The layout of the lead frame and the positioning of the nozzles are shown in Fig. 11.



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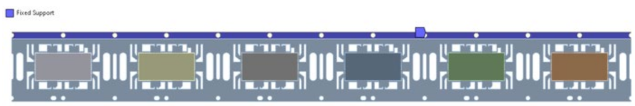

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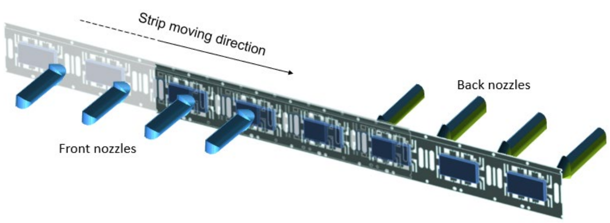
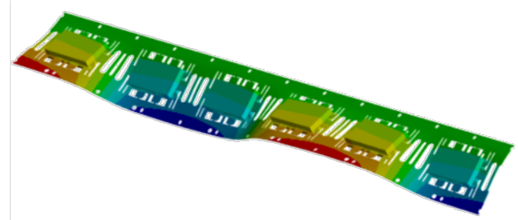


(c)

Fig 11. (a) Top View of lead frame and location of nozzles (b) Front view of lead frame (c) Illustration of lead frame movement

To assess the risk of delamination during the HPWJ treatment, Ansys® finite element software is used for mechanical analysis. To start with, a modal analysis was initially performed to evaluate potential vibrations induced by the water jet's periodic loading. To mimic the practical boundary condition, a thin strip on the top (purple part in Fig. 11(b)) was fixed. This analysis identified that the vibration modes could cause bending and torsion in the strip. The first four vibration modes are illustrated in Fig. 12. Given the clip's movement speed of 40 mm/s, which is considerably longer than the dominant natural vibration period of approximately 0.006s, modal excitement was determined to be minimal. Consequently, a static analysis was chosen for its simplicity.



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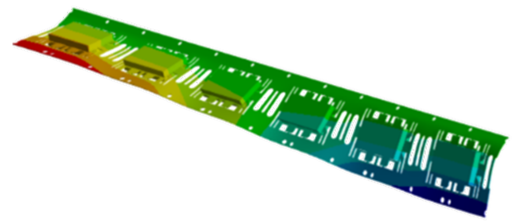

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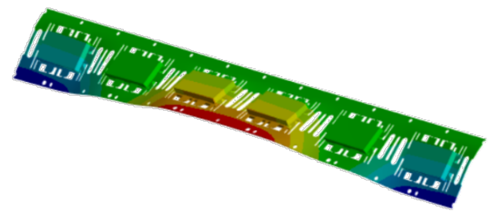

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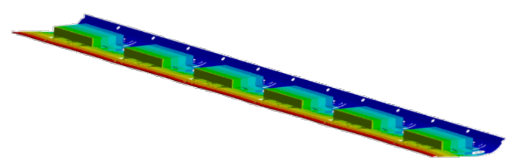


(d)

Fig. 12 First four vibration mode (a) Mode I (157 Hz) (b) Mode II (166Hz) (c) Mode III (189 Hz) (d) Mode IV (221 Hz)

In the subsequent step, the strip model was improted into the static analysis module. The nozzle positions were fixed while strip advanced in increments of 5mm. To achieve that, a new model was simulated for every advancement of the strip and the results were documented. The pressure exerted by each fixed nozzle was modeled as affecting a circular area with a 1mm radius, with peak pressure reaching 10MPa at the center and decreasing to zero at the perimeter, as depicted in Fig. 13.

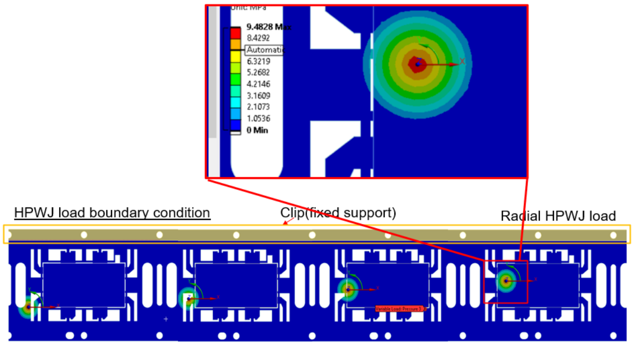
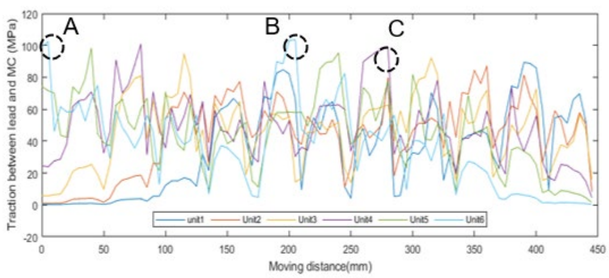
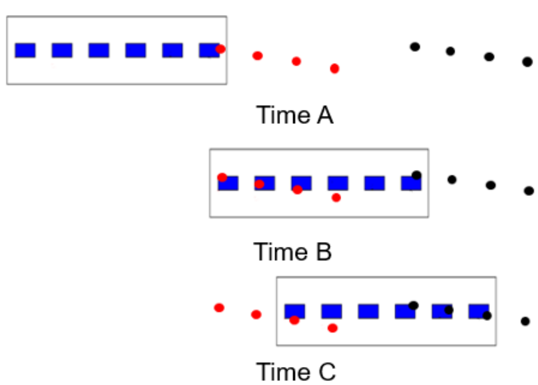


Fig. 13 Water jet pressure distribution

The maximum interface normal stress for each unit at every advancement step was charted in Fig. 14(a), showing fluctuations as the lead frame moved forward. Critical points for units 6, 1, and 4, labeled as A, B, and C respectively, are indicated. These points correspond to the relative nozzle positions shown in Fig. 14(b). Peaks in stress occur when the nozzle pressure is applied at the edge of a unit, as illustrated in Fig. 14(c). These critical stress points correlate with SAM results, confirming the accuracy of the analysis.



(a)



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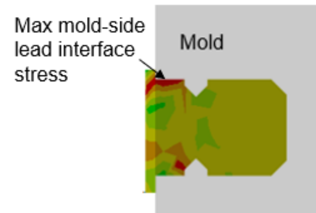

(c)

Fig 14. EMC/Lead frame interface normal stress (a) max. stress change with time for each unit (b) Relative location of strip with respect to nozzles (c) max interface normal stress contour plot at the side lead

IV. Conclusion

A computational framework was developed to assess the risk of mold-lead interface delamination at the electrolytic deflash (ED) and high-pressure water jet (HPWJ) process steps. Electrostatics simulation was conducted and localized high current density was identified to be near the vicinity of the side lead. These localized regions are prone to a higher bubbling/scrubbing effect and thus increase the mold-lead interface delamination risk. The HPWJ process was simulated and position of certain nozzles relative to the strip was identified to increase the mold-side lead interface normal stress. The combined predicted risk locations from ED and HPWJ simulation agrees well with the mold-side lead interface delamination regions illustrated in the SAM. Additional ED process variations simulations highlighted the importance of control on KOH bath conductivity & lead frame clipping to prevent the increase in risk of delamination. This detailed computational framework enhances our understanding of the risk factors in the deflash process and paves the way forward for better designs.

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