Metrology-Driven Sample Preparation for Advanced Microelectronics Using TESCAN FemtoChisel with Intelligent Multigas Processing, LPL, and AI-Enabled Correlative Workflows

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Abstract

Advanced microelectronics metrology increasingly depends on how the sample is prepared before inspection. In heterogeneous packages, the region of interest may be buried beneath combinations of mold compound, silicon, copper, redistribution layers, dielectrics, underfill, and organic substrate materials. The measurement challenge is therefore not only one of imaging resolution, but also one of physical access: the sample must be opened to the correct level, the exposed structures must remain interpretable, and the preparation geometry must provide useful views of internal layers and interfaces.

This paper presents a metrology-driven sample-preparation workflow using the TESCAN FemtoChisel ultrashort-pulsed laser platform. The workflow combines femtosecond laser machining, intelligent multigas processing, laser protective layer strategies, imaging feedback, and AI-enabled process development. The broader platform capability includes controlled package opening, layer exposure, access-window creation, cross-section preparation, and correlative workflows with optical, confocal, SEM/FIB, and X-ray imaging. In this paper, the experimental results focus specifically on demonstrations relevant to metrology access: controlled laser delayering. Specifically, it is shown that the laser process can expose selected package levels and provide intermediate inspection states. Through creation of inverted pyramid structures we demonstrate the ability to stop at the layer of interest.

The results support a preparation-to-measurement framework in which laser machining is used not simply to remove material, but to create measurement-ready sample states. Intelligent multigas processing and protective-layer concepts expand the usable process window by improving debris management and boundary preservation. AI-enabled process development and correlative navigation provide a path toward more repeatable and target-aware preparation. Together, these elements position FemtoChisel as a platform for creating controlled access geometries that support advanced package metrology, failure analysis, and process development.

Key words

Sample preparation, metrology, femtosecond laser, delayering, laser machining, AI-enabled process development

I. Introduction

Advanced packaging has changed the nature of microelectronics metrology. Many structures that must be inspected are no longer accessible from a single surface or a simple polished section. Instead, important features may be buried within three-dimensional assemblies that contain silicon, copper, solder, dielectrics, underfill, mold compound, organic substrates, redistribution layers, and other materials within the same local volume. These structures must often be reached without losing their spatial relationship to the rest of the package.

For this reason, metrology increasingly begins before the final inspection tool is used. The sample must first be brought into a useful physical state. A layer must be exposed,

a plane must be created, a window must be opened, or a cross-sectional wall must be generated. If this preparation step produces excessive debris, removes the wrong level, changes the boundary condition, or obscures the target, the final measurement becomes less reliable regardless of the resolution of the imaging instrument.

Focused ion beam methods remain essential for highly localized nanoscale finishing and TEM specimen preparation. Mechanical sectioning and polishing remain useful for many broad material-preparation tasks. However, advanced packages often require access volumes and preparation geometries that fall between these conventional modes. The area may be too large for efficient ion-beam removal, but the target may be too specific for coarse mechanical preparation. Laser-based preparation, especially with ultrashort-pulsed lasers, provides an important bridge because it can remove material rapidly while also defining localized geometries such as delayered fields, trenches, windows, and cross-sectional walls.

This paper presents a metrology-oriented workflow based on the FemtoChisel platform. The central concept is that laser machining should be designed around the measurement need. Instead of viewing laser ablation only as a high-speed removal step, the workflow treats it as a way to create controlled sample states. These states may include exposed package levels, partially opened regions, or inverted pyramid structures whose walls reveal internal layers and interfaces.

The platform also includes enabling technologies that support this goal. Intelligent multigas processing is used to influence the local ablation environment, assist debris removal, and stabilize machining across material changes. A laser protective layer can be used when nearby regions or boundaries must be preserved during aggressive removal. AI-enabled process development can support recipe selection by learning relationships between process parameters and measurable outcomes. Correlative imaging workflows can connect laser machining to optical, confocal, SEM/FIB, and X-ray information.

Although the broader platform supports several preparation modes, this paper limits the presented experimental results to controlled delayering and inverted pyramid preparation. Other capabilities, such as CT-guided targeting, TEM precursor preparation, nanoCT pillar shaping, and downstream FIB finishing, are discussed as extensions of the same preparation-to-measurement framework rather than as experimental results presented here.

II. Metrology-Driven Preparation Concept

The workflow proposed here begins with a simple question: what sample state is needed for the measurement? For some measurements, the desired state is a flat exposed layer that can be inspected from above. For others, the desired state is a sidewall that reveals the vertical relationship between layers. In more complex cases, the desired state may be a local access window or a geometry that prepares the sample for another tool.

The results in this paper focus on the delayered state, where selected regions of the package are exposed progressively. This allows the user to inspect the sample at intermediate levels and evaluate whether the process has reached the desired material or structural layer. In a particular demonstration, we showcase the inverted or stepped pyramid state, where laser machining creates nested openings with cross-sectional walls. This highlight that ability of the workflow to stop at different depth of interest throughout the delayering process. Further, the walls provide side views into the package stack and reveal material transitions in a way that complements top-down imaging.

In this framework, preparation quality is evaluated by metrology usefulness. Important outputs include the ability to reach selected layers, visibility of internal features, clarity of cross-sectional walls, preservation of surrounding context, and compatibility with downstream optical, confocal, SEM, or FIB inspection. Removal rate is important, but it is not the only metric. The prepared geometry must support interpretation.

III. FemtoChisel Platform and Process Elements

A. Ultrashort-Pulsed Laser Machining

The FemtoChisel platform uses ultrashort-pulsed laser machining to remove material from microelectronic samples. The short pulse duration enables controlled ablation with reduced thermal spreading compared with longer-pulse laser processes. In practice, the quality of the prepared region depends on the full process recipe, including fluence, pulse overlap, hatching pattern, scan speed, focus condition, number of passes, scan order, wavelength, gas environment, and sample material.

For advanced packaging, the process must often move through materials with very different laser responses. Mold compound, silicon, copper, dielectrics, and organic materials may exist in the same preparation region. A useful process must therefore be adjustable and must provide intermediate feedback. The ability to inspect after partial removal is especially important for delayering, where the objective is not simply to cut through the package, but to stop at or near selected levels.

B. Intelligent Multigas Processing

During laser ablation, the local environment affects the final condition of the prepared sample. Ablated material can accumulate near the machining zone, plume behavior can change with material type, and local heating or particle redeposition can affect the clarity of the exposed features. Intelligent multigas processing treats gas delivery as part of the process recipe rather than as a passive cleaning step.

Gas type, flow direction, timing, and sequencing can be

selected to improve debris evacuation, reduce accumulation of ablation products, and stabilize the machining process. In the context of this paper, the main role of multigas processing is to support clearer layer exposure and better-defined walls in the delayered and inverted pyramid structures.

C. Laser Protective Layer

A laser protective layer can be used when the surrounding region must remain intact while the laser removes material nearby. This is relevant for metrology because the region outside the machined area may serve as a visual reference, alignment feature, or comparison surface. If surrounding features are modified during preparation, interpretation of the final result becomes more difficult.

The protective layer is applied before machining and removed after processing. Its role is to reduce unwanted peripheral interaction and support more aggressive laser removal while preserving nearby surfaces. In this paper, the protective-layer concept is discussed as part of the broader FemtoChisel workflow. The primary experimental results remain focused on delayering and inverted pyramid formation.

D. Imaging Feedback

The preparation workflow relies on imaging feedback at multiple stages. Optical microscopy provides rapid inspection of the exposed surface and overall geometry. Confocal or optical profilometry provides height maps and cross-sectional profiles, allowing the depth and shape of laser-prepared structures to be measured. SEM provides higher-resolution views of cross-sectional walls, surface texture, and exposed material transitions.

This combination of imaging methods is important because delayering and inverted pyramid formation are three-dimensional preparation tasks. A top-down optical image alone may show the exposed area, but it does not fully describe depth, wall shape, or step transitions. Profilometry and SEM help confirm that the intended geometry was created and that the internal layers can be viewed from useful directions.

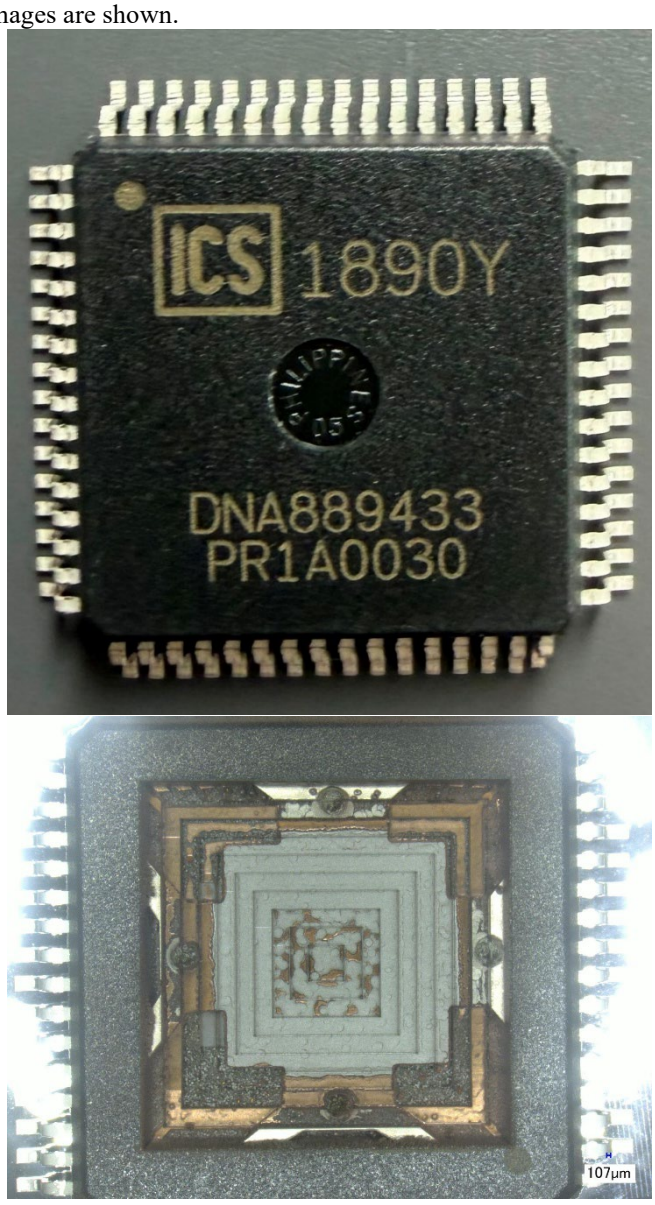
IV. Experimental Demonstrations

Three instances of a package samples were processed to demonstrate controlled delayering and inverted pyramid preparation. The samples were used to evaluate how the laser workflow can expose internal package levels suitable for metrology inspection. The demonstrations are not intended to present all possible FemtoChisel capabilities. Instead, they focus on the specific preparation states that are most relevant to this paper: layer-selective exposure and visualization.

The prepared structures were evaluated using optical microscopy, height mapping/profilometry, and SEM imaging. Optical images were used to document the visible exposed regions and nested machining patterns. Height maps and line profiles were used to evaluate the stepped nature of the prepared regions and the relative depths of exposed levels. SEM images were used to inspect the wall geometry, surface condition, and sidewall visibility.

V. Results

Figure 1 highlights some of the sample-preparation results using the FemtoChisel workflow. The figure consolidates three representative package samples and illustrates controlled delayering to expose selected package levels, particularly through inverted or stepped pyramid machining to showcase the ability to stop at different depths of interest. Together, these results show that the laser process can be used not only for material removal, but also for creating inspection-relevant sample states that support both top-down and sidewall-based metrology. Optical, confocal and SEM images are shown.



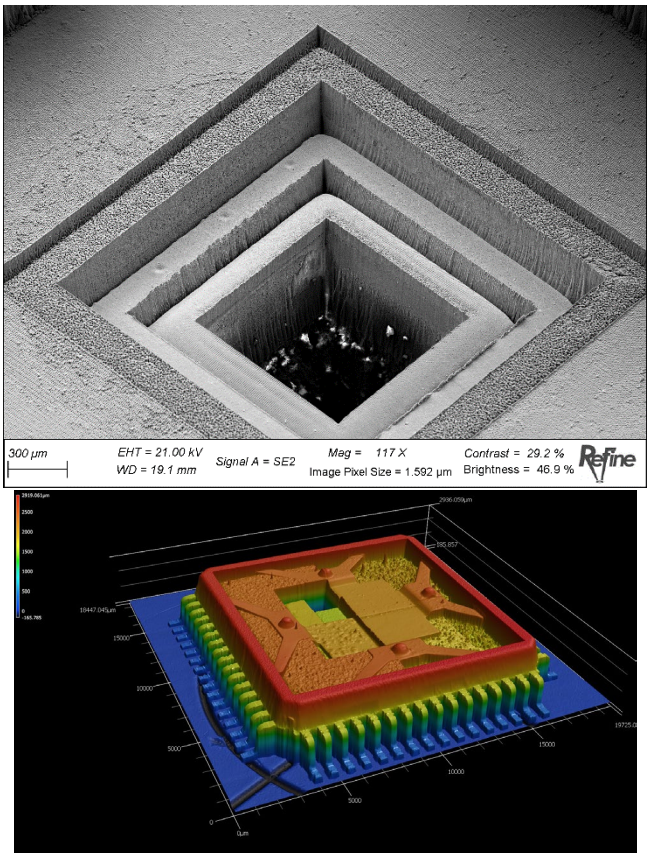


Figure 1: Targeted delayering and inverted pyramid structure creation using FemtoChisel, demonstrated via optical, confocal and SEM imaging.

VI. Discussion

The results support a metrology-driven interpretation of laser sample preparation. In this view, the value of the laser process is not only its ability to remove material, but its ability to create useful sample states. A useful state may be a delayered surface, a partially opened package, a stepped region, or a cross-sectional wall. Each state provides a different type of information.

Controlled delayering is valuable because it allows the sample to be inspected at intermediate depths. This is important in advanced packages where the correct stopping level may not be known precisely before preparation. By exposing layers progressively, the workflow allows the user to make decisions based on observed sample condition rather than relying entirely on precomputed removal depth.

Inverted pyramid preparation adds another dimension to this workflow. By creating nested steps and sidewalls, the process provides vertical context while preserving top-down navigation. This is useful for understanding material transitions and layer relationships. It also provides a practical route to cross-sectional inspection without requiring the entire preparation volume to be produced by a serial ion-beam process.

The laser-generated walls should be understood as metrology access surfaces. For some inspection tasks, they may be sufficient for direct optical, confocal, or SEM evaluation. For higher-resolution analysis, they may serve as a starting condition for FIB finishing. This division of labor is important: the laser creates the access geometry quickly, and FIB can be reserved for the specific region where nanoscale finishing is required.

Intelligent multigas processing and protective-layer strategies support this workflow by improving the process window. Gas control helps manage the material-removal environment and can reduce debris-related limitations. Protective-layer strategies can help preserve nearby surfaces or boundaries when the process must remove material aggressively. Although the present results focus on the final prepared geometries, these process elements are important for making the workflow more repeatable across different packages and material stacks.

AI-enabled process development provides a future path for formalizing recipe selection. Delayering and inverted pyramid preparation involve many process parameters, including fluence, overlap, hatching pattern, scan speed, pass count, gas condition, focus position, and scan order. The best recipe depends on the desired sample state. A recipe optimized for broad delayering may not be optimal for sharp wall formation. A recipe optimized for speed may not provide the best exposed-layer clarity. By linking process parameters to measured outcomes such as depth, wall angle, debris level, surface quality, and layer visibility, AI models can help recommend starting recipes and improve repeatability.

Correlative workflows also fit naturally into this framework. Although the experimental results here are not presented as CT-guided targeting demonstrations, the same preparation modes can be combined with CT, optical, confocal, and SEM/FIB data. CT can identify buried regions before machining. Optical images can guide surface registration. Confocal maps can measure the prepared geometry. SEM can verify wall condition and exposed features. This creates a preparation chain in which the target remains connected to its original package context.

VII. Conclusion

This paper presents a metrology-driven sample-preparation workflow using the FemtoChisel ultrashort-pulsed laser platform. The workflow is built around the idea that advanced package metrology requires controlled physical access before final measurement. The experimental results focus on two preparation modes: controlled delayering and inverted or stepped pyramid formation.

The delayering results show that laser machining can expose selected package levels and create intermediate

inspection states. This supports workflows where the user must stop at or near specific internal layers. The inverted pyramid results show that laser machining can create nested three-dimensional access structures with cross-sectional walls.

Intelligent multigas processing, laser protective layers, AI-enabled recipe development, and correlative imaging workflows are presented as enabling elements of the broader platform. However, the results in this manuscript are intentionally limited to delayering. Together, these demonstrations show how FemtoChisel can be used not only to remove material, but to create measurement-ready sample states for advanced microelectronics metrology, failure analysis, and process development.

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