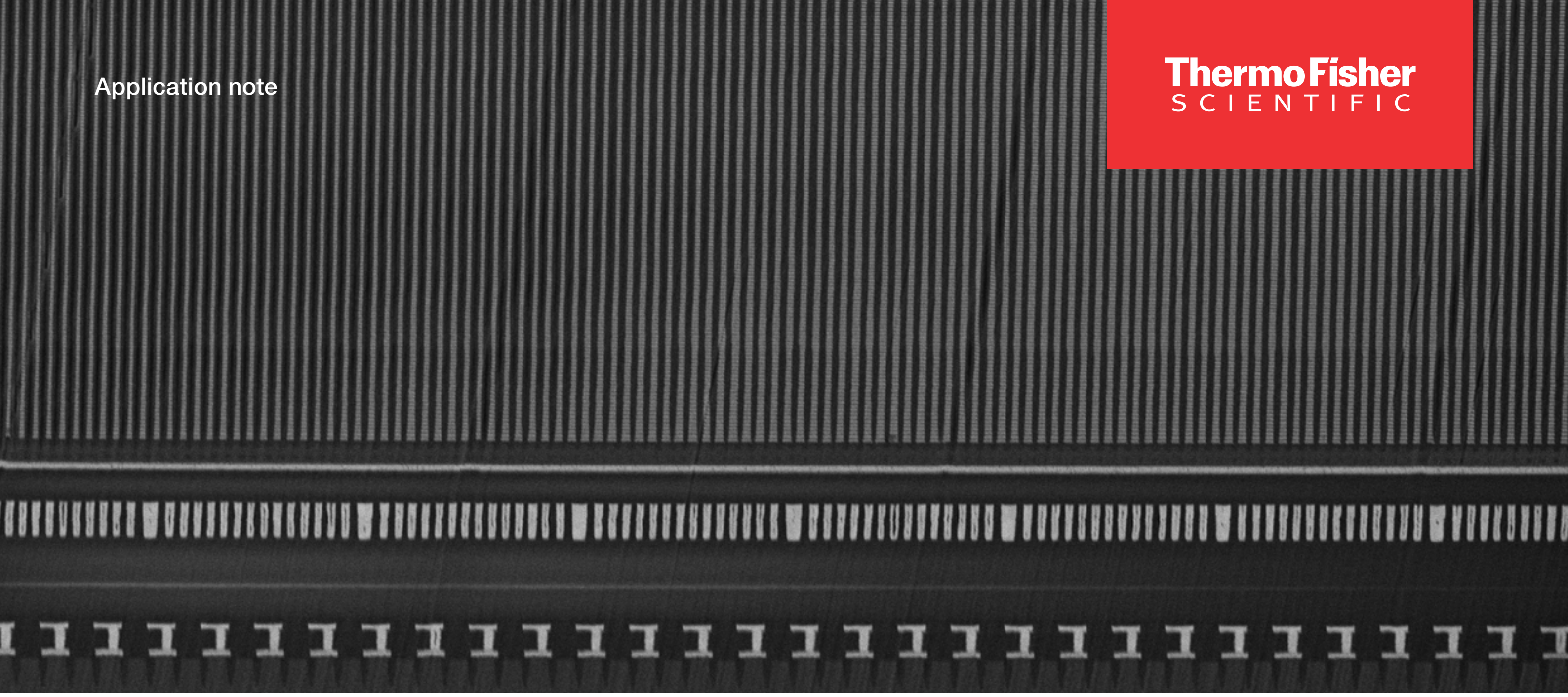

Application note

Automated defect analysis using a wafer-level Ga-FIB-SEM DualBeam

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Background

In the pursuit of high yield on semiconductor production with shrinking device features and complex 3D structures, defect inspection and root cause analysis are critical for yield learning. While top-down scanning electron microscopy (SEM) imaging of the E-beam inspector provides an estimate of wafer defectivity, root cause analysis using focused ion beam and scanning electron microscopy (FIB-SEM) DualBeam™ instruments reveals the ground truth for the defects captured by the E-beam inspector. A large variety of defect types are present for different devices, such as memory (ex. 3D NAND, DRAM), logic, or MEMS. Defect root cause analysis is necessary for all because high-resolution imaging is often indispensable on the cross-sections of defect locations.

Traditionally, defect root cause analysis has been completely manual. The process is both cumbersome and time-consuming for engineers. This application note introduces the pivotal and innovative workflow on a wafer DualBeam instrument that automates every step of defect root cause analysis, from defect navigation to mill preparation and milling, to final imaging of defect cross-section. This new technology provides analysis that is based on precise defect location; vertical milling on a deep structure; planarity across the defect plane; and crisp imaging by SEM on the cross-section.

This application note also discusses the two automated workflows of defect root cause analysis. **Deep mill** exposes a cross-section designed for fast turnaround time (TAT) of high-aspect-ratio device defect analysis with high-resolution SEM images. **Piece extraction** provides an easy TEM sample preparation method for intensive defect analysis. Both methods allow wafers to stay in the fab instead of breaking in the lab environment.

Auto deep mill cross-section

Auto deep mill cross-section is a type of automated defect root cause analysis workflow that is used when defects are SEM-resolution size, typically on 3D NAND, MEMS wafer, etc.

As shown in Figure 1, it enables automation at every step, from defect redetection and navigation to mill preparation and milling to final imaging of defect cross-section. This is a revolutionary leap from the traditional method in which every step is manual. It not only enables precision cutting and crisp SEM imaging, but also saves three times the manpower and time.

Results of auto deep mill cross-sectioning on a commercial 3D NAND sample are shown in Figure 3. In Figure 3(A) (deep mill cross-section image), the overall health of channel holes is shown. Zoomed-in images at the top, middle and bottom (outlined in red) expose the inner channel hole view, where connection at the top, each layer of wordline and oxide, middle layer interconnection, channel hole under- or over-etching at the bottom, and any other defect modes can be clearly seen.

Similarly, Figure 3(B) shows deep mill cross-sectioning at another site on the same wafer. Deep mill cross-sectioning

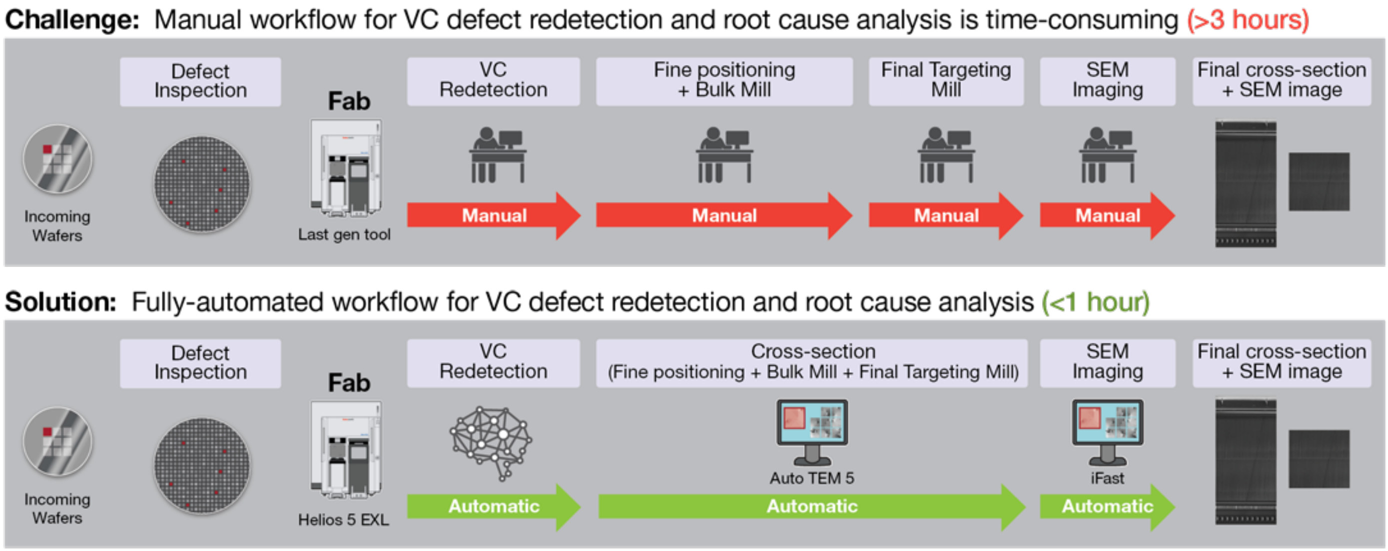

Figure 1. Auto deep mill cross-section workflow benefits[1].

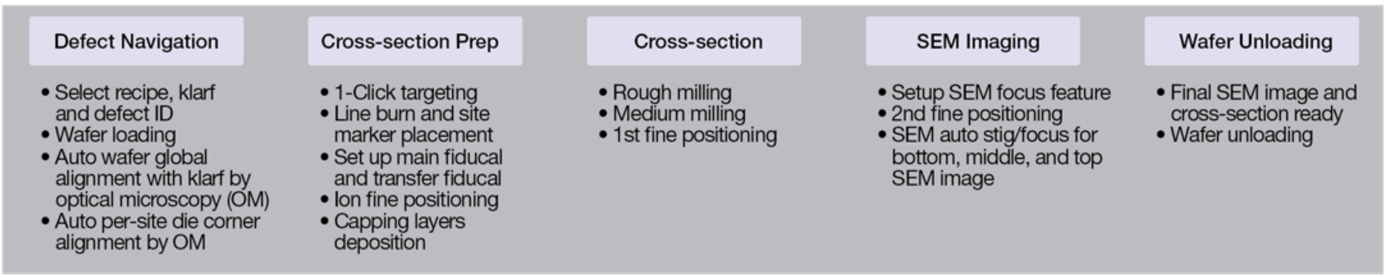

Figure 2. Auto deep mill cross-section workflow.

The auto deep mill cross-section workflow consists of five parts, shown in Figure 2: voltage-contrast (VC) defect navigation, cross-section prep, cross-sectioning, SEM imaging, and wafer unloading. In VC defect navigation, the wafer is loaded and the coordinate system is aligned with the inspector's. In cross-section prep, VC defect is detected, marked, and protected by a capping layer for following milling. In cross-sectioning, milling proceeds from bulk volume to final cross-section face polishing. In SEM imaging, SEM auto focus assists in taking crisp SEM images on top, medium and bottom parts of the cross-section face for a complete view. Finally, the wafer is unloaded from the Thermo Scientific™ Helios™ 5 EXL DualBeam with final cross-section and SEM images ready.

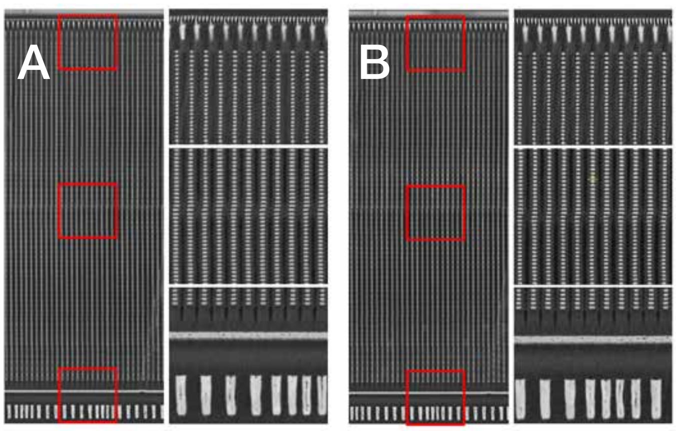

Figure 3. (A)–Deep mill cross-section image of a 3D NAND wafer showing whole ROI view, and zoomed-in view at 5 um FOV. (B)–Deep mill cross-section image of the same wafer at another site.

allows for consistent imaging across wafers, which is crucial for data analysis by yield enhancement engineers.

Result of auto deep mill cross-section on another 3D NAND wafer is shown in Figure 4. The vertical cross-section shows full channel is completely etched.

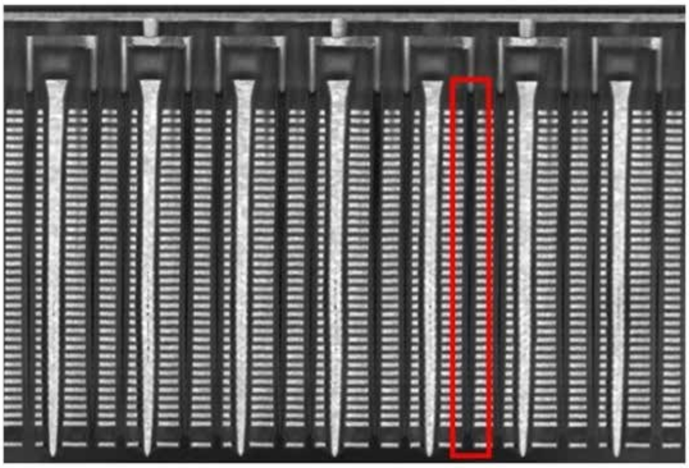

Figure 4. Deep mill cross-section image of a 3D NAND wafer showing completely etched channels[2].

1-Click piece extraction

1-Click piece extraction is a type of auto defect root cause analysis workflow on the Helios 5 EXL DualBeam that allows material chunks to be automatically extracted at the defect location directly from the wafer, so that TEM samples can be thinned after the sample grid is transferred onto a small DualBeam (SDB) instrument, as shown in Figure 5.

1-Click piece extraction is used when defects are transmission electron microscopy (TEM)-resolution size, typically for DRAM as well as 3D NAND layers. This application is extremely useful since the Helios 5 EXL DualBeam enables wafer-level navigation, which ensures higher defect location accuracy and maximizes productivity of a TEM defect analysis workflow.

This workflow offers two significant advantages when compared to the traditional workflow: One, it eliminates the need for wafers to be cleaved, as the Helios 5 EXL DualBeam allows for the direct extraction of material chunks containing defect locations from the wafers. This means that users can keep the wafers intact in the fabrication facility even after the extraction process. Two, the automated workflow on the Helios 5 EXL DualBeam enables you to complete most of the required steps on a single tool, thereby expediting the analysis of multiple wafers. The users can then proceed to perform TEM sample thinning on a laboratory SDB instrument. This approach optimizes the utilization of resources and facilities, leading to improved efficiency.

Detailed procedures of 1-Click piece extraction are shown in Figure 6 on the next page.

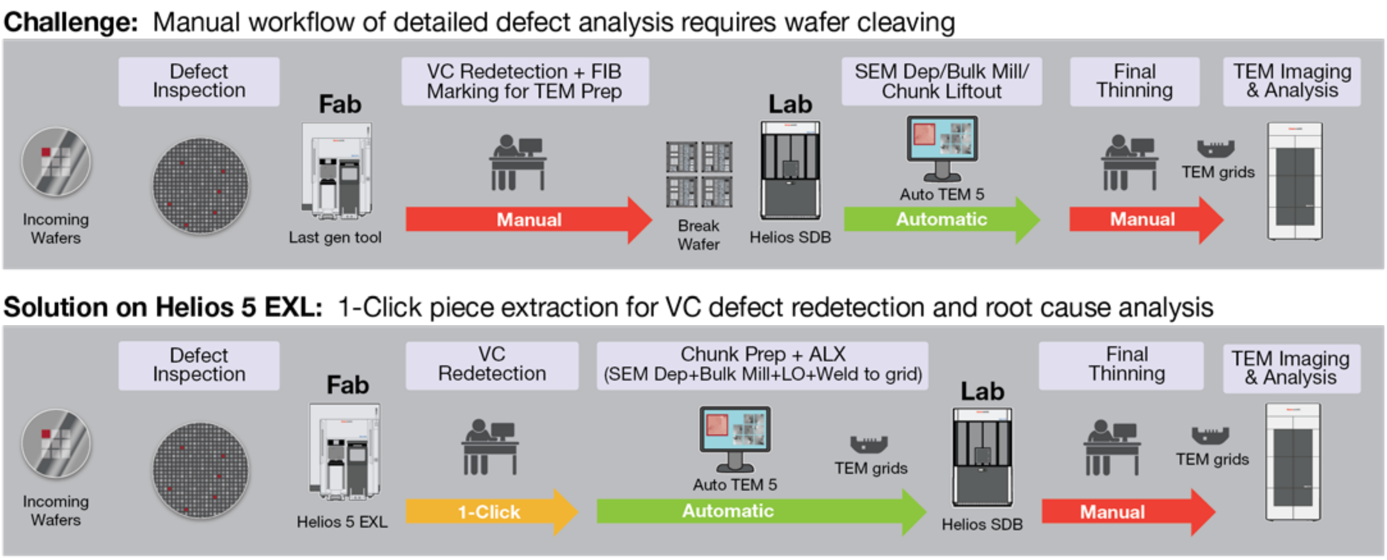

Figure 5. 1-Click piece extraction workflow benefits.

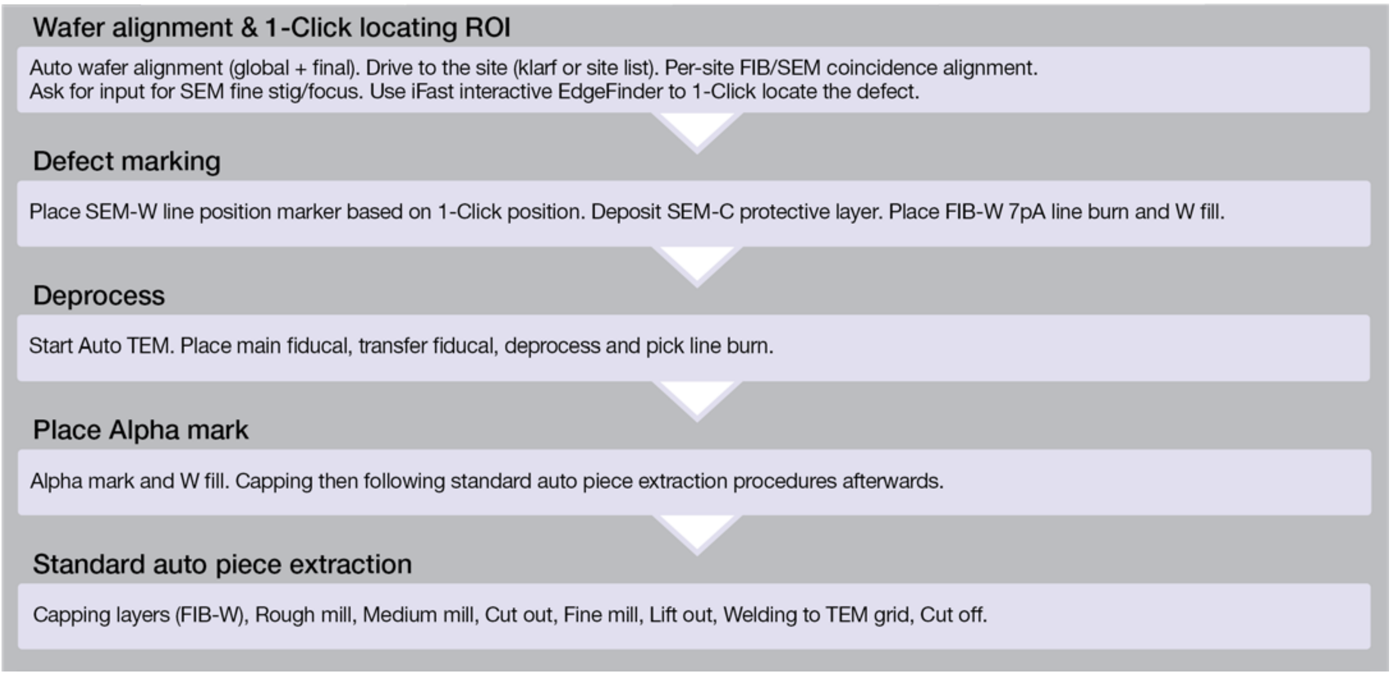

Figure 6. 1-Click piece extraction workflow.

Summary

In this application note, we introduced two automated wafer-level workflows for defect root cause analysis using the Helios 5 EXL Wafer DualBeam.

Auto deep mill cross-section enables automation, from defect navigation, mill preparation, and milling to final imaging of defect cross-section. This streamlined workflow is ideal for 3D NAND, MEMS, and other wafer types.

1-Click piece extraction allows material chunks at the defect location to be automatically extracted from the wafer and enables the users to complete TEM sample preparation on a SDB instrument. This workflow ensures higher defect location accuracy, maximizes productivity, and optimizes resource utilization. This workflow is well-suited for the analysis of defects at TEM-resolution size, typically for advanced memory devices such as DRAM or 3D NAND.

References

1. Zhi Hui Zhu, Arun Sundar, Sarah Gollub, Mahmoud Amin, John McPhillips, Pete Carleson, Mary Wu, *Advancement in DualBeam (FIB/SEM) technologies for automatic defect root cause analysis,* **Proc. SPIE 12955, Metrology, Inspection, and Process Control XXXVIII, 129553Q** (9 April 2024) https://doi.org/10.1117/12.3014195
2. A. Tilson and M. Strauss, *STEM/EDS Metrology and Statistical Analysis of 3D NAND Devices*, **2018 IEEE International Symposium on the Physical and Failure Analysis of Integrated Circuits (IPFA),** Singapore, 2018, pp. 1-5 doi: 10.1109/IPFA.2018.8452545