QUANTUM DIAMONDS
SENSOR TECHNOLOGY

Beyond LIT: Localizing Low-Ohmic Shorts with 2D and 3D Depth Estimation in Packaged ICs with QDM

Quantum Diamond Microscopy (QDM) is an emerging, non-destructive technique for visualizing electrical activity in advanced semiconductor devices. As device architectures become increasingly complex, conventional failure analysis methods face significant limitations in localizing defects within buried or inaccessible interconnect structures. This challenge is particularly acute for low-ohmic shorts - defects that dissipate little power and therefore produce limited thermal contrast, leaving Lock-in Thermography (LIT) unable to reliably localize them either laterally or in depth. QDM overcomes these challenges by visualizing electrical activity in both 2D and 3D, providing quantitative spatial information, that enables the localization of defects not only laterally but also in the vertical (Z) direction within multi-layer stacks.

Techniques such as thermal-based imaging provide different mechanisms for inferring depth information, typically through thermal wave propagation and phase delay behavior. So, in stacked die architectures, the technique becomes more challenging because multiple material interfaces, TSVs, and bonding layers distort heat flow and reduce spatial resolution.

This is where Quantum Diamond Microscopy offers a distinct advantage. QDM directly images the magnetic field generated by the device's operating currents and reconstructs the underlying current distribution. In this application note, we demonstrate how QDM was used to localize low-ohmic short defects on two customer devices with complex architectures, providing full X, Y, and Z localization on intact, biased, operating units - including cases that LIT alone could not resolve.

Case Study 1: 2D Imaging and 3D Depth Reconstruction on a Stacked-Die BGA

In this first case, the device under test (DUT) is a BGA-packaged IC, containing a two-die stack. The unit exhibited a low-ohmic short between VCC and VSS, with a measured pin-to-pin resistance of approximately 16 Ω - a defect class that produces little thermal contrast and is therefore difficult to localize reliably with LIT alone.

The device was kept fully intact, with no decapsulation, thinning, or backside polish. Electrical access was established by soldering copper wires directly to the relevant BGA balls. An initial LIT measurement was performed and identified a thermal hot spot in a defined lateral region. As expected, LIT resolved the fault only in

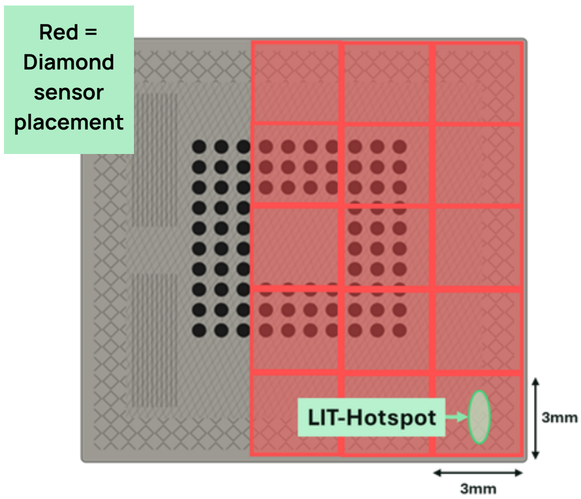

Figure 1: Top-view illustration of the customer BGA sample showing the QDM acquisition strategy. The diamond sensor was placed sequentially at 15 positions (red boxes, 3 × 5 grid), each acquiring a magnetic field map with a 3 × 3 mm field of view; the individual maps were then stitched together to cover the full region of interest. The green ellipse indicates the defect location previously identified by LIT.

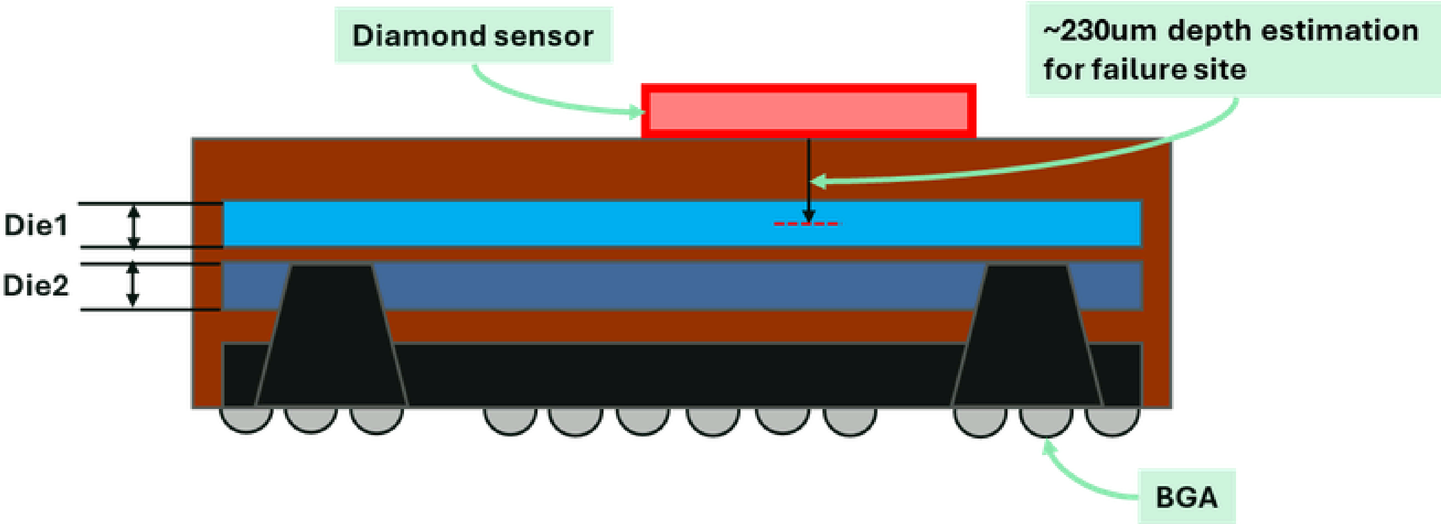

Figure 2. Schematic side-view of the stacked-die BGA package. The red box indicates the diamond sensor placed above the package surface during QDM acquisition. The dashed red line marks the QDM-estimated failure depth of approximately 230 µm, which corresponds to the position of Die 1 within the two-die stack (Die1, Die2). BGA solder balls are shown at the bottom.

X–Y; the Z position within the stacked-die assembly remained ambiguous. QDM imaging was then carried out with a 3 × 3 mm field of view. A total of 15 adjacent spots were acquired and stitched, extending the imaged area to 9 × 15 mm and providing improved context around the LIT hot-spot and across the entire device. The resulting magnetic field map showed a clear anomaly at the same lateral position flagged by LIT, providing an independent confirmation from direct current imaging.

The QDM workflow then moved beyond what surface-biased techniques can offer. The acquired field data were used as input to a 3D current reconstruction based on a machine-learning model combined with an optimization routine. For this device, this returned a fault current source at a depth of ~230 µm below the imaging surface, corresponding to the position of Die 1 within the stacked assembly. Combined with the lateral position from the magnetic field map, this delivered full X, Y, and Z localization of the low-ohmic short on an intact, biased device.

The depth-resolution capability has been independently characterized on a daisy-chain reference structure with known interconnect geometry, (see daisy-chain application note) using QDm.1. Quantum Diamond is actively advancing its 3D reconstruction capabilities, with ongoing development focused on further improving depth resolution, accuracy, and applicability across a broader range of package geometries.

Case study 2: QDM testing in multi-chip package

In this case study, a multi-chip packaged device, exhibiting a low-ohmic short between VCC and VSS, was tested under QDm.1. For the analysis, the device was mounted on an evaluation board, with all electrical contacts established through the board itself.

An initial LIT image, provided by the customer, showed a thermal hot-spot peeking through the edge of the die due many metal layers. While this localized the failure laterally, it offered no information on the depth of the dissipating defect within the device.

To confirm the electrical signature in situ, IV characteristics were measured directly through the QDM setup, verifying the short under the same biasing conditions used for imaging. A full magnetic field map and a corresponding current flow map were then acquired over the ROI using QDM. The reconstructed current-flow streamlines revealed several major short locations within the ROI, with significant current passing through individual points that coincided with

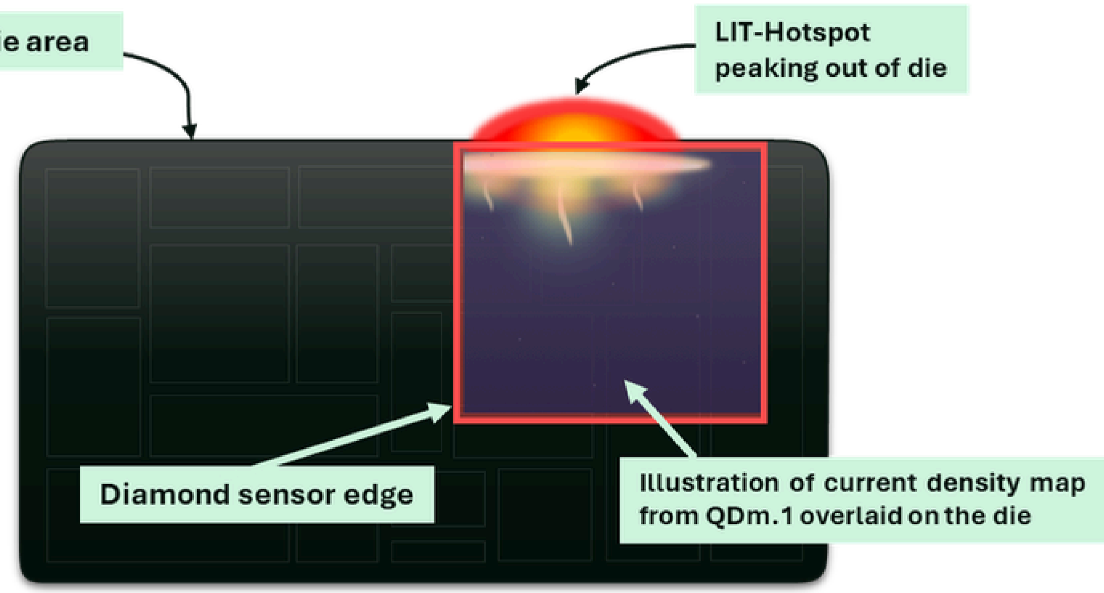

Figure 3: Illustration of QDM current density map overlaid on the die area of device from second case study. The imaged region (red outline = diamond sensor edge) was positioned to capture the area flagged by LIT, where the thermal hot-spot was observed peeking out of the die. The abstracted current density shows a clear concentration along the upper edge of the imaged area, providing direct, current-based confirmation of the LIT result.

the spots visible in the LIT image - providing a direct, current-based confirmation of the LIT result.

For depth analysis, two complementary approaches were applied. Using the QDM's existing 2D depth approximation feature, a fault depth of ~62 µm was estimated which aligned closely with the actual fault depth subsequently confirmed by the customer, validating the accuracy of the approach for this device. The 3D reconstruction model, applied to the same data set, returned a fault depth of ~80 µm. The 3D capability is continuously under development, and access to device layout information, even partial GDS data, can significantly enhance the reconstruction and model prediction accuracy. The discrepancy between the 2D and 3D depth estimates is currently under investigation along these lines.

Conclusion:

On two independent customer devices, both exhibiting low-ohmic VCC–VSS shorts, QDM provided fault information that LIT alone could not. This defect class produces limited thermal dissipation and is therefore difficult for LIT to localize reliably, particularly in depth. In each case, QDM delivered full X, Y, and Z localization: on Device A, the failing die in a stacked-die BGA was dentified at approximately 230 µm depth; on Device B, depth estimates of ~62 µm (2D) and ~80 µm (3D) were obtained on a packaged device measured on its evaluation board. Both measurements were non-destructive and performed under normal operating bias.

For FA labs working on modern packaged ICs, advanced packaging, QDM combines two capabilities that conventional techniques do not: direct, quantitative current imaging and depth localization (X, Y and Z) without destructive preparation. QDM closes the depth gap that has historically driven destructive trial-and-error cross-sectioning.

The QDm.1 is available in the US and Taiwan at the respective testing labs

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