3D electrical activity mapping of a daisy-chain buried under 650 µm remaining silicon with quantum diamond microscopy

Current reconstruction is a powerful technique for localizing electrical faults in semiconductor devices because it reveals the actual electrical conduction path within a structure. In defective devices, current often flows through unintended nodes, layers, or parasitic structures. Identifying these unintended paths allows engineers to better understand the underlying failure mechanism and determine which device structures carries abnormal current.

In this application note, we demonstrate current reconstruction of a buried daisy-chain structure in a flip-chip BGA device using Quantum Diamond Microscopy (QDM). Magnetic field measurements were acquired from a structure located approximately 650 µm below the measurement plane. By reconstructing the current density from the measured magnetic field, both two-dimensional (2D) and three-dimensional (3D) current maps were obtained. The reconstructed current paths closely match the available partial design information provided by the customer.

Despite the significant stand-off distance and large field-of-view requirements, QDM successfully captured the current distribution, demonstrating the capability of QDM to image electrical activity in deeply buried semiconductor structures and highlight its potential as a practical tool for semiconductor failure analysis and device characterization.

Case study: Device and Sample Information

The device analyzed in this study is a test chip in an F2BGA-436 and mounted on a printed circuit board (PCB). The flip-chip die is attached to a four-layer package substrate, with a daisy-chain interconnect routed through layers 3 and 4 (L3 and L4) of the package substrate. An illustrative cross-section of the device structure is shown in Figure 1.

The daisy-chain metal traces have an approximate width of 300 µm, a pitch of about 300 µm, and a metal thickness of approximately 20 µm. These traces form a long electrical path through the package substrate and are commonly used for reliability evaluation and electrical continuity testing. To enable magnetic imaging of the buried structure, the backside of the flip-chip die was exposed using a combination of laser and wet chemical decapsulation.

This process resulted in a stand-off distance of approximately 650 um between the exposed backside surface and the daisy-chain structure located within the package substrate. See Figure 1.

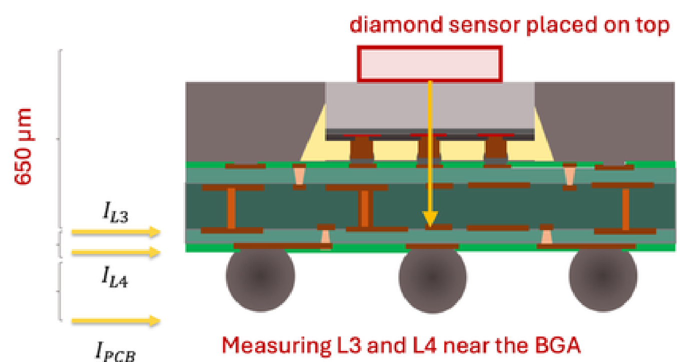

Figure 1. Device cross-section showing the flip chip die assembled on top of the four-layer package substrate with the molding removed and diamond placed on top.

QDM test setting:

Magnetic imaging was performed using a QDM system equipped with a 4 mm x 4 mm diamond sensor positioned on the exposed backside of the flip-chip die (see Figure 3). To capture the full region of interest, multiple measurements were acquired and stitched together to produce a larger composite magnetic map, and a total area of approximately 7mm x 7mm was stitched. Each acquisition required approximately 10 minutes. During measurement, the daisy chain was biased with 50 mA of current between nodes L10 and OUT. The specific daisy-chain segment analyzed in this test is indicated with the red box in Figure 4.

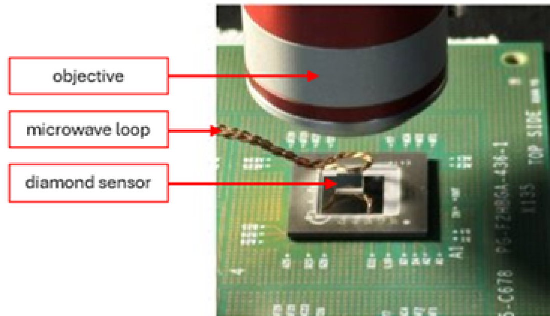

Figure 2. QDM set-up showing the diamond sensor on top of the device (left) and the microwave loop positioned over the diamond

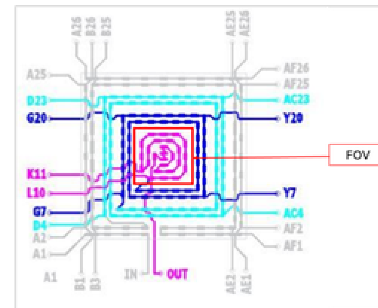

Figure 3. The daisy chain layout with the QDM Field of View highlighted in the red box (right)

QDM Results:

Figure 5 shows the measured magnetic field maps corresponding to the three magnetic field components: Bx, By, and Bz. These magnetic fields originate from the current flowing through the buried daisy-chain conductors.

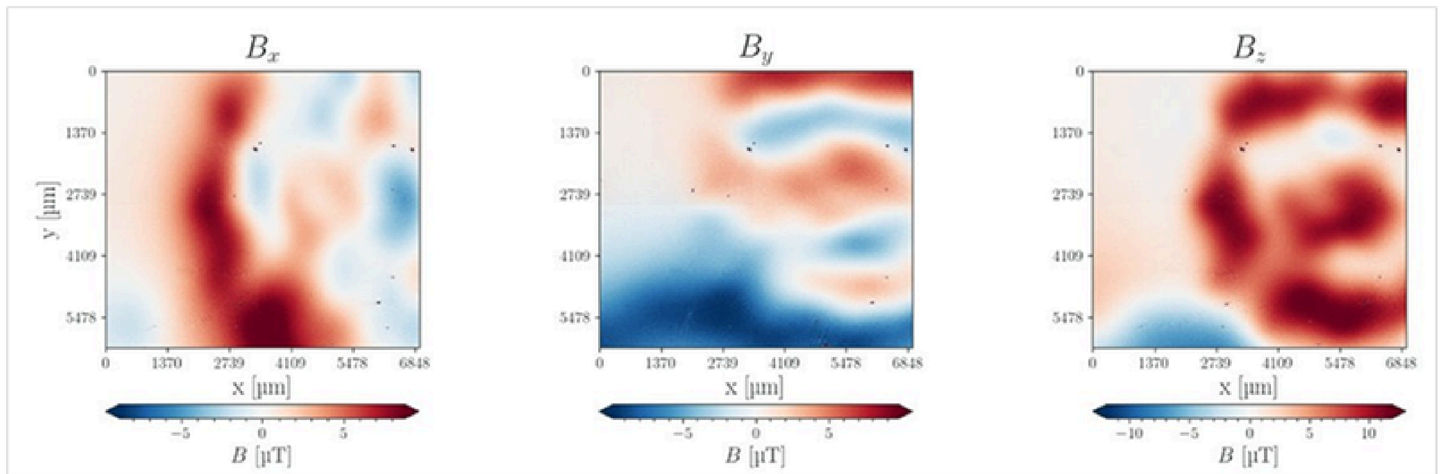

Figure 4. 3D Magnetic field maps of the daisy chain at 50mA. Bx indicating activity in y direction, whereas By indicates activity in the x direction. Bz reflects a combination of overall in-plane activity.

Using the measured Bz component, the two-dimensional current density distribution was reconstructed through the inverse Biot-Savart Law. The resulting 2D current density map is shown in Figure 6. When compared with the partial design layout, the reconstructed current distribution closely matches the expected routing of the daisy chain within the package substrate.

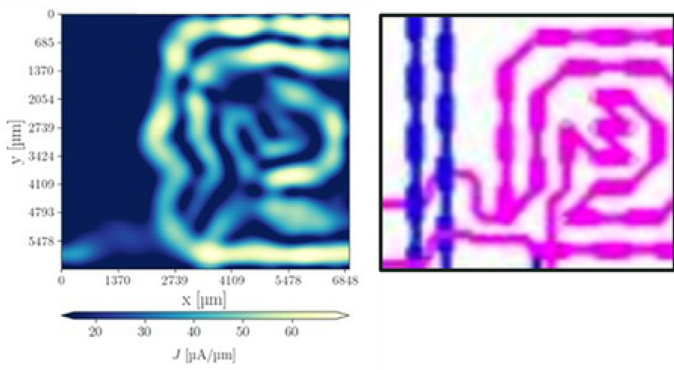

Figure 5. 2D current reconstruction using Bz magnetic field (left) and the actual daisy chain structure in the FOV (right)

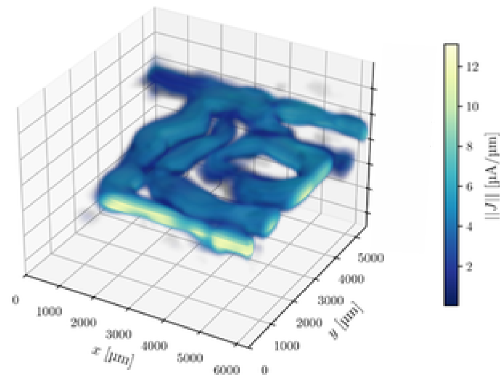

Figure 6. 3D current reconstruction (feature under-development)

Going Beyond 2D: 3D Current Density Reconstruction

While 2D current reconstruction already provides valuable insight into electrical activity within the device, further analysis enables reconstruction of the three-dimensional current distribution. Using machine learning–based modeling and optimization techniques, the magnetic field data was further processed to reconstruct the 3D current density distribution within the sample volume. The resulting 3D current model is shown in Figure 5.

The resulting 3D current distribution closely aligns with the known routing of the daisy chain in layers L3 and L4, providing strong validation of the reconstruction approach. This result demonstrates that meaningful 3D electrical information can be obtained even for structures buried hundreds of micrometers below the measurement surface.

Conclusion:

QDM is an emerging technology with strong potential for electrical failure analysis (EFA). It enables users to map electrical activity and visualize current flow in buried structures even at large stand-off distances. As shown in this AppNote, QDM successfully reconstructed the current path of a daisy-chain located approximately 650 μm below the measurement surface, demonstrating its usefulness for localizing electrical activity, which can be used to map defects such as shorts, leakage paths, and open interconnects in complex semiconductor structures.

The QDm.1 will be available in the US and Taiwan at the respective testing labs starting late April 2026

Interested in learning more?

contact@qd-st.com

https://www.qd-st.com

QuantumDiamonds GmbH

Friedenstr. 18
81671 Munich, Germany