

DualBeam™ Solutions for Electrical Nanoprobing

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Electrical testing by physically probing device structures has grown more challenging with increasing circuit density and complexity. Nanoprobing with the aid of scanning electron microscopy (SEM) or a focused ion-beam (FIB) has been used for several years in advanced failure analysis labs to isolate and locate physical defects in circuit chips, both on wafers and in packaged devices. In this article, we describe a new approach—a DualBeam™ SEM/FIB with an in-situ probe system.

Introduction: The Need for DualBeam Probing

Testing and failure analysis of integrated circuits has traditionally been done by physical electrical probes guided by optical microscopy. However, today's geometries are too small for conventional electrical probing techniques. DualBeam systems have been adapted to solve nanoprobing challenges. The tools are routinely used to perform failure analysis, fault isolation, device debug, and circuit editing—enabling engineers to quickly diagnose design and production problems and to determine corrective actions [1]. DualBeam probe testing during development and production ramp-up can improve device yield and performance and greatly speed time-to-market.

A DualBeam system combining a FIB and SEM in the same chamber provides an environment for accurate positioning of probes by viewing by both SEM and FIB imaging. Relative to SEM-only probing, the FIB offers two additional key advantages: the ability to drill down, isolate, and reveal physical defects; and the capability to deposit electrically insulating regions or conducting contact areas large enough to probe. The ability to add and remove connections—called circuit editing—is invaluable in verifying circuit modifications prior to mask revision. By having an in-situ nanoprobe station within the DualBeam chamber, sample preparation, editing, and probing are done in one step. This eliminates doing FIB prep first and then removing the sample for probing under an optical microscope.

Advantages of DualBeam In-situ Probing

In addition to providing an environment for accurate positioning of probes, a DualBeam system can reveal the required contact locations. The first step was

to install a probe station within a SEM to allow positioning and probing of devices after preparation had been done in a FIB. It was soon realized that it would be advantageous to do probe testing within the FIB itself directly after preparation. The next step was to implement probing capability in a DualBeam system. Several important advantages accrue:

- Ability to probe very small contact areas, as the high resolution of the DualBeam imaging allows accurate probe positioning
- Faster real-time probing immediately after FIB preparation including isolation cuts, addition of interconnects, and localized deprocessing
- The removal of layers to reveal underlying structures within the FIB chamber—probing can be done immediately, thereby eliminating the need to transport the sample to a stand-alone lab for fault analysis
- Probing while imaging with either the SEM or the FIB—side views, as well as top views, are possible, revealing vertical positioning and greatly easing probe alignment
- FIB preparation and probe testing can be done in sequence—multiple locations can be probed and new probe locations can be based on initial results

Some illustrations of the use of DualBeam nanoprobing are shown in *Figures 1–4*. *Figure 1* shows the ability to precisely locate four probe needles within a 0.5 μm square area.

The approach and touchdown of the probe can be precisely controlled (*Figure 2*) and, if necessary, contact points can be revealed by ion milling using the FIB. Probe positioning can be viewed from two directions, as the SEM beam and FIB are 52° apart. In addition, the specimen stage can be tilted up to 20°, making it easy to observe the probe touchdown process. Piezo-controlled touchdown is very gentle, and is far superior to the best mechanical precision drive.

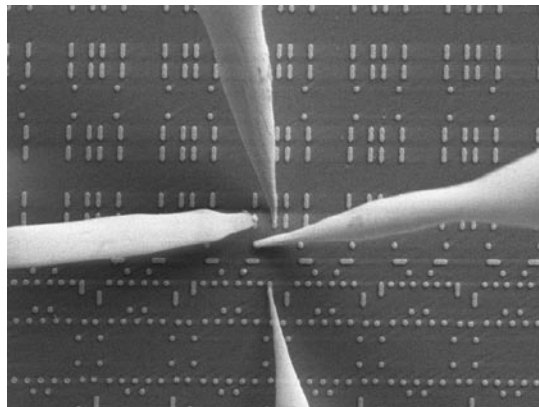


Figure 1 – SEM image during four-point probing.

The usual SEM and FIB imaging functions are available, including voltage contrast using nanoprobe contacts to apply the appropriate electrical biases.

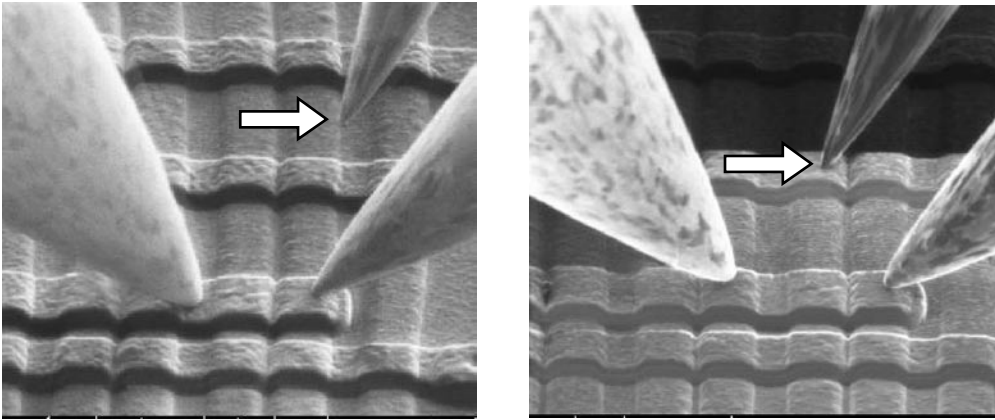


Figure 2 – Precise probe positioning and motion facilitated by ion-beam imaging. Left: Probe approach (arrow). Right: Final contact is accomplished by computer-controlled piezo actuators.

A simple electrical test example (*Figure 3*) shows the current-voltage characteristic of a diode structure measured by probing within a DualBeam chamber under vacuum. Leakage currents can be measured in the pA range. Two measurements were taken. The two curves differ slightly on the low voltage side, but precisely overlap at the higher voltage.

The FIB offers unique abilities for circuit editing, which is used to verify design changes prior to committing them to a mask set. Signal lines can be cut and rerouted by using the FIB to deposit conducting layers in precisely located positions [2-5]. Circuits are now being designed to take advantage of this

FIB “microsurgery” and the results can be checked immediately; the new design further debugged by nanoprobng. This is an essential and much-needed capability that is required for an effective design/debug strategy. Functional silicon for final verification can be provided in hours instead of weeks; saving valuable time when generating a new mask set to fabricate wafers [3].

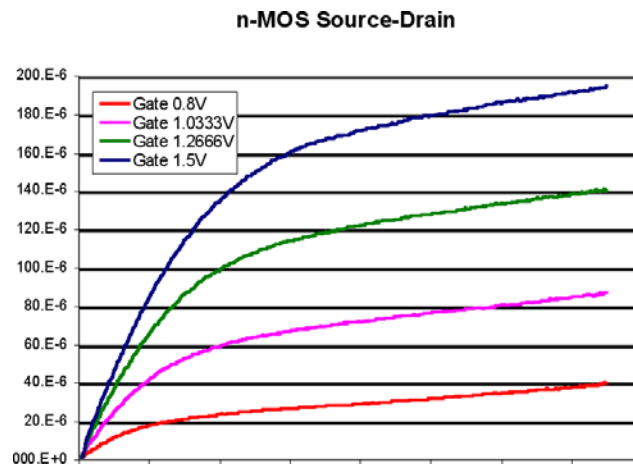


Figure 3 – A Zyvex S100 Nanomanipulator was used to make electrical contact and a Keithley 4200 was employed for the IV data acquisition. The measurements were taken approximately 15 minutes after the microscope was ready. Subsequent measurements were taken within seconds. The curves at left show the electrical response of an n-type FET with forward bias across the source and drain.

DualBeam Nanoprobe Station

The experience gained with SEM probe station design was used in engineering vacuum-compatible probers for FIB and DualBeam systems. The first modules designed for a FIB were nicknamed “mailbox” probers because they had to pass through an airlock door similar to a mail slot. A compact flat shape is also

required for FIB systems that do not have an airlock in order to avoid interference with the detectors and gas injection capillaries located within the FIB chamber.

A probe station for testing integrated circuits that makes optimum use of the specimen chamber of the DualBeam is shown in *Figure 4*. The unit has four motorized probe arms; the use of sub-miniature motors results in a very flat structure. The positioning accuracy is within 1 μm under visual observation. With optional built-in piezo translators, the positioning accuracy is increased to 4 nm. A small desktop controller operates three motors mounted to each one of the cross-tables, which drive the prober needles in X, Y, and Z, covering a range of 20 mm by 20 mm horizontally, and 5 mm vertically. The speed of movement can be precisely controlled. The probe module can also be used outside of the DualBeam while viewing with a light microscope.

Samples can be wafer pieces, bare circuit chips or packaged devices. The specimens are mounted on top of the rotation head of the DualBeam stage. The rotation head is independent from the prober module, and can rotate freely. The probing arms can be mechanically pre-aligned before loading into the DualBeam chamber to optimize their range of motion.

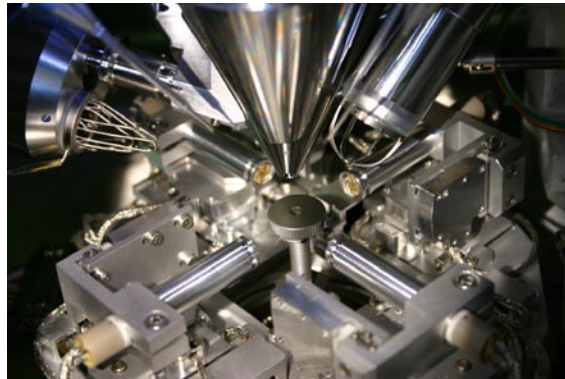


Figure 4 – Zyvex sProber module in FEI Nova NanoLab DualBeam system.

Conclusion

Circuits are now being designed to enable automated FIB functional analysis, debug, and circuit editing [3]. To take full advantage of these techniques, Nanoprobe stations are now being operated in situ in DualBeam systems. On-silicon editing and probe testing can be done using one tool—speeding the use of the DualBeam for failure analysis, debug, and circuit editing. Since the revised circuits can be verified prior to commitment to final tape-out and mask fabrication, the yield ramp and time-to-market are dramatically reduced.

References

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