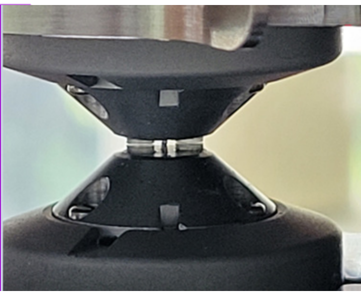
Application Note

KLA INSTRUMENTS

Implant Variation Mapping and Laser Annealing Characterization

Filmetrics® R54-Series Sheet Resistance Mappers



Introduction

Sheet resistance monitoring is vital to ion implant doping and anneal characterization. Many processes, including ion implantation, metal deposition, diffusion and epitaxial silicon growth, use sheet resistance measurement to help develop, monitor, and control them, and the Four-Point Probe (4PP) technique remains the most common measurement method. Maintaining its popularity due to its simplicity and inherent accuracy, 4PP is the go-to technique for monitoring the ion implant process. As the latest addition to over 45 years of KLA's resistivity innovation technology for semiconductor applications, KLA Instruments™ offers the benchtop R54-Series sheet resistance mapping systems. The light-tight, production-ready R54-4PP series is part of the KLA Instruments™ Sheet Resistance family of products.

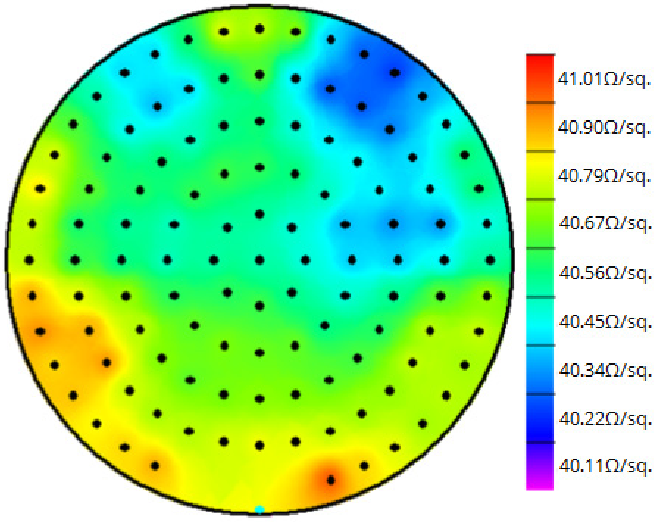


Figure 1. Sheet resistance map of an As-doped substrate; this high density, high uniformity contour map provides a quality check on the deposition process, where the required uniformity is < 0.5%. The accuracy and repeatability of the R54 delivers the performance required for monitoring the sensitive doping process.

Four-Point Probe Measurement Technique

The four-point probe technique is a mature technology that has been used for monitoring the implant process for many years. In a linear array four-point probe design, electrical current is passed between two pins in contact with a conductive surface while the voltage is measured between two additional pins also in contact with the surface, as shown in Figure 2.

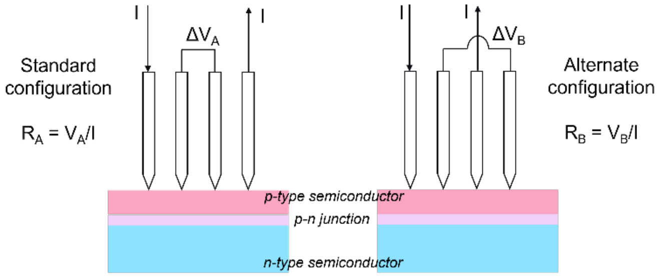
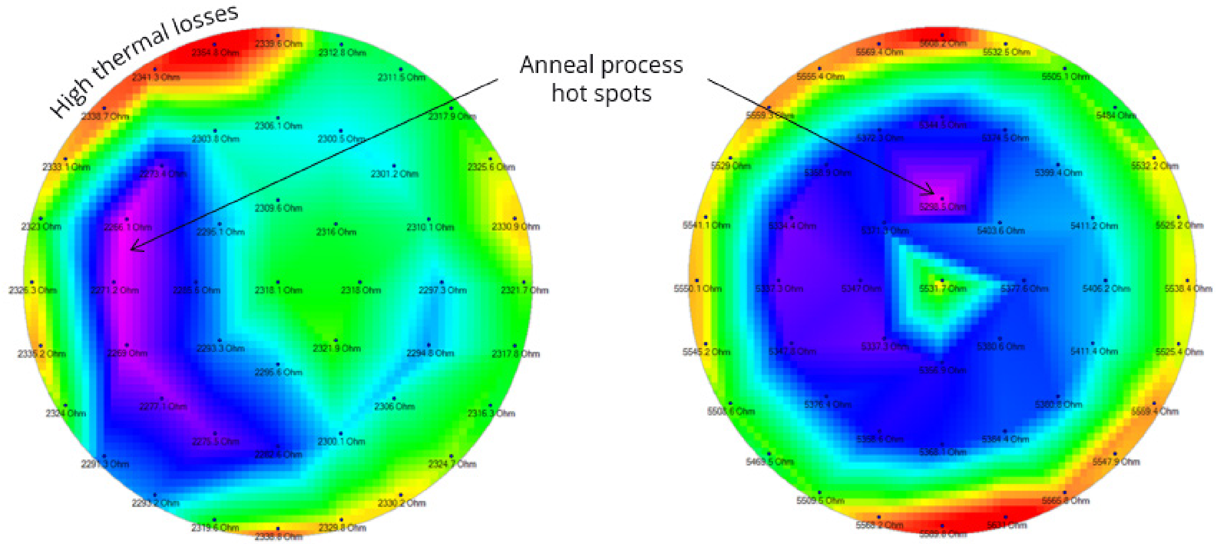


Figure 2. Four-point probe pin schematic for the Dual Configuration measurement method, which is typically used in cases of current crowding at the edge of a film or when pin spacing variation requires correction.

The four-point probe requires an isolating junction or blocking layer to the DC current used for this technique. For ion implant processes, it is a p-n junction. For an ion implantation layer, a p-n junction is normally formed between the implanted layer and the substrate. For an ultra-shallow implant layer, this junction is close to the surface and may require special considerations to minimize probe penetration. To form the junction and activate the ions, an anneal is required prior to four-point probe measurements, which can be performed on the implant monitor wafer.

Implant Process Shifts

4PP contour maps of sheet resistance (Rs) can help identify ion implant process shifts, such as identifying higher Rs due to high thermal loss, where an anneal process may not reach the required temperature to completely activate the ions in the ion implant layer. Another concern is "hot spots" on the wafer that, due to areas of locally elevated temperature, result in greater ion activation in those areas, driving down the junction, as shown in Figure 3. 4PP uniformity mapping can also assist with troubleshooting a lamp array, where a lamp may have degraded or failed. This problem results in outer edge cool spots that have poor coupling with the platen and can be identified by the higher relative sheet resistance.



3E13 BF2 ion implant at 50keV

1E13 BF2 ion implant at 50keV

Figure 3. Identifying hot and cold spots is critical to detecting and resolving lamp failures and poor wafer/platen contact, which lead to semiconductor device failure.

Laser Annealing Characterization

As discussed previously, the annealing process is used to activate the implanted ions. A laser anneal melts the silicon in a small area on the surface of the wafer, and the ions are then activated as the silicon recrystallizes. Figure 4 shows a graph of sheet resistance as a function of radial location, where the sawtooth (stitching) pattern of high-to-low sheet resistance indicates that the width of the laser beam is too narrow relative to the scan pattern over the surface of the wafer. This issue can only be discovered using a high density 4PP measurement pattern with a very repeatable 4PP signal with a high signal-to-noise ratio, such as that offered by the R54. If the laser beam diameter and scanning patterns are not properly adjusted, a resistance "ripple" is created, resulting in cross-die resistance variation and degraded device performance.

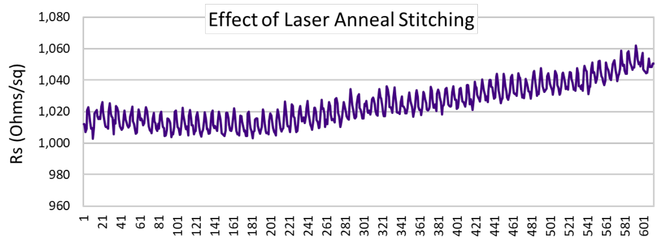


Figure 4. This 600-site diameter sheet resistance scan exposes an issue with a laser anneal of ion implanted silicon by revealing the periodic variation caused by the laser beam width.

Short-term lateral variations can best be identified with the use of high-density maps or line scans across the area of interest. Measurement probes with narrow pin spacing improve lateral resolution, with a 0.65mm pin spacing yielding < 1mm effective measurement spot size.

Four-Point Probe Performance

Due to the need to guarantee probe performance on implant wafers, repeatability tests provide a means to quantify system performance. Four-point probe performance is influenced by several factors, including proper sample preparation and the use of the appropriate probe head (many different probe head types are available for the R54, depending on the application). It is important to eliminate these error sources so that they do not contribute to sample measurement uncertainty. With careful preparation of implant monitor samples and a properly conditioned probe head, it is expected that reliable performance is achievable for ion implant doses down to 1E12 ions/cm^2.

Probe qualification tests are commonly used as 4PP performance tests. Each probe should be conditioned until the desired probe qualification value is achieved (repeatability typically < 0.2%). The ability to achieve < 0.2% requires attention to the pin tip ohmic contact with the sample but will result in high quality measurement of a wide range of implant layers. For very shallow implant layers, increasing the tip contact area will typically improve the repeatability.

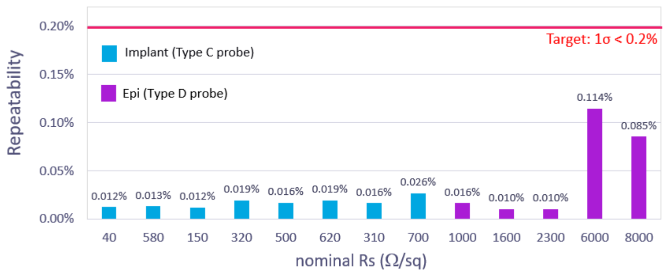


Figure 5. It is important to use the proper probe with sufficient conditioning to produce probe qualification standard deviations of < 0.2% on the R54-200.

I-V Curve Plotting

The vertical distance from the wafer surface to the depth at which the embedded dopant type changes to that of the background dopant type is defined as the junction depth. In some cases, higher current may penetrate through the implanted layer and leak through the junction barrier. By monitoring the voltage or Rs response curves, problems such as currents with low signal to noise, joule heating or junction breakdown can be avoided. The KLA Instruments Filmetrics R54 RsMapper software is equipped with additional functionality for implant characterization by plotting sheet resistance or the measured voltage as a function of applied current, as shown in Figure 6. This feature provides verification of the linearity of the pin contacts and stability of Rs, thus ensuring that an appropriate current has been selected.

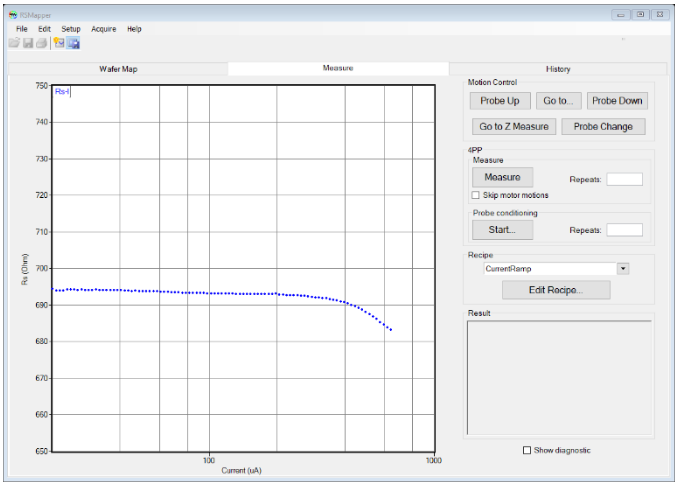


Figure 6. The RsMapper software for the R54 can be configured to run a current ramp routine to ensure that the appropriate current is selected for measurement, targeting optimal signal to noise and avoiding regions of current leakage. This dataset indicates current leakage above 100mA.

Conclusion

Combining probe qualification tests and I-V curve monitoring, R54 users with light-sensitive samples can feel confident in the reliability of their implant characterization on monitor wafers. The Filmetrics R54-series delivers dependable data acquisition and analysis features, providing a critical function for semiconductor metrology by detecting equipment performance variation at various stages of the ion implant process.

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