Gallery of Four-Point Probe Measurements.

In the early 1980's, much better four-point probes with superior mapping capability became available -- a watershed event.

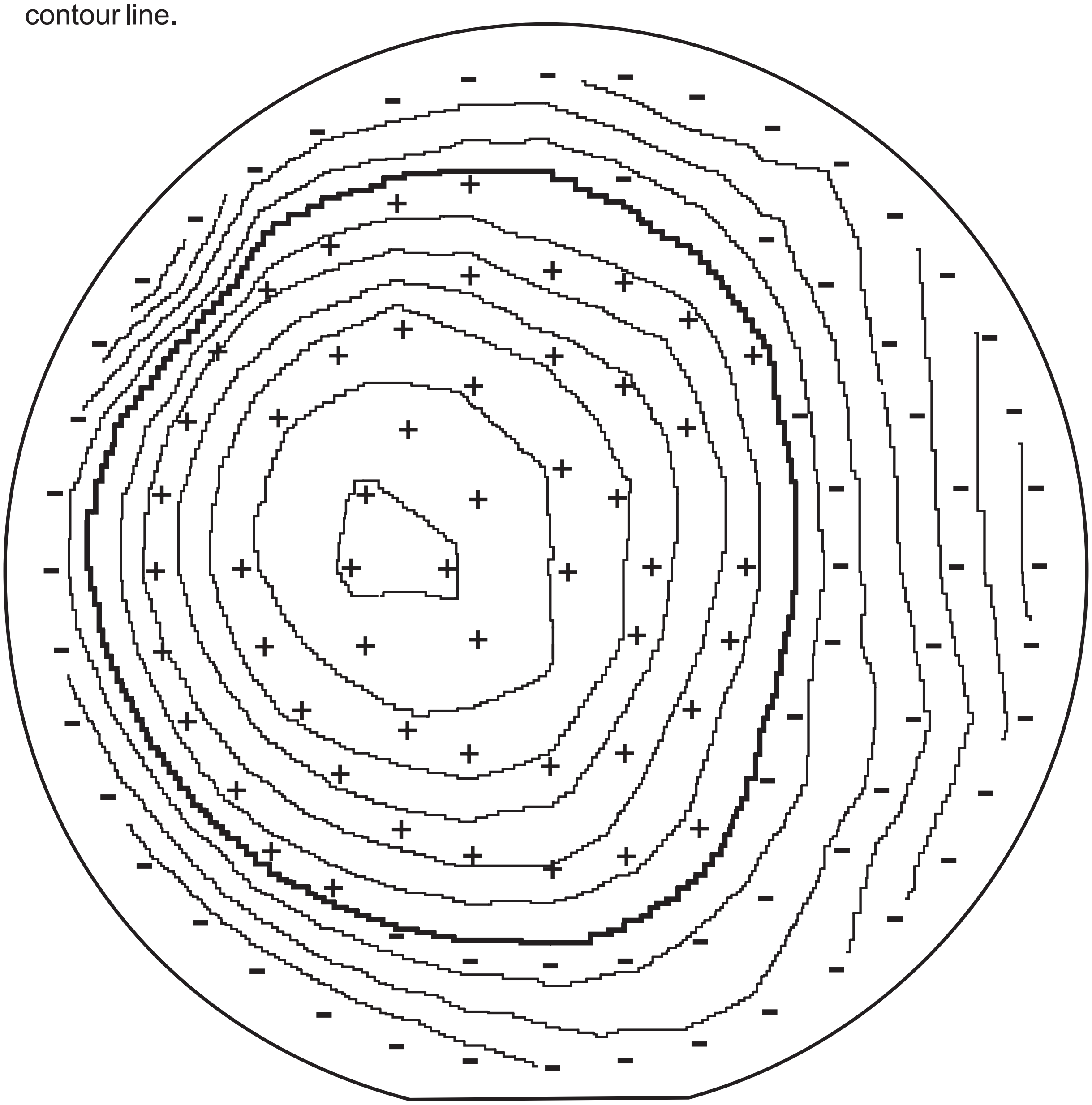
At the time, Solecon Labs wanted an independent, more accurate way of checking its profiling results. This new four-point probe provided a way of determining the sheet resistance of the top conductive layer of a test wafer -- usually within one or two percent. We purchased the second Prometrix OmniMap III produced and began using it for our internal QC. Having excess capacity available on the tool, we began offering sheet resistance mapping service as well.

Spreading resistance and sheet resistance mapping have proven to be powerful, complementary tools. Spreading resistance shows you the doping profile and four-point probe mapping shows you the uniformity over the wafer. Over time, both tools have evolved somewhat. We are now using a CDE four-point probe but the basic concepts remain the same.

The following pages contain some examples of four-point probe measurements retrieved from the Solecon Labs archives. The table below compares some of the aspects of four-point probing and spreading resistance analysis.

	Four-Point Probe	Spreading Resistance
Purpose	Measures the sheet resistance uniformity of the top conductive layer. Helpful in characterizing equipment performance.	Helps characterize the process. Invaluable aid in trouble shooting. Measures resistivity and carrier concentration to any depth with a dynamic range of eight decades!
Units	Ohms/square	Ohm-cm or Carriers/cm^3
Difficulty	Easy. If you want to do your own, just pony up ~ 100 grand and you can get results as good as ours within a couple of weeks.	Tedious. Invest several hundred thousand per system and then spend the rest of your life trying to get good at it.
Very Thin Layers	This one often fizzles out first -- at layer thicknesses something less than 1000A.	Can often profile junction depths as low as 300-500A. Can also provide a sheet resistance when the 4PP fails (not as accurate but much better than nothing).
Absolute Accuracy	About 1%	Typically ± 3% on depth scales, ± 20% or greater on resistivity.
Configuration	Four probes -- a current is forced through 2 of them and the voltage drop is measured across the other two.	Two probes. 0.005 volts is applied across them and the resistance is measured.
Probe Tip Material	Osmium or tungsten carbide. Makes nearly ohmic contact with both n- and p-type materials over about eight decades of resistivity.	The same except the contact area is very small, and the probe tips must not scrub. Also, the force used to contact the silicon is very small.
Current crowding at the silicon surface (i.e. spreading resistance)	A nuisance -- probe contact area is made large to minimize the effect.	Is maximized and exploited in the determination of resistivity.

This **FOUR-POINT PROBE CONTOUR MAP** was produced by Solecon Labs using an OmniMap Model 111. The sheet resistivity of the top layer on the wafer is measured at some 120 locations with a special 4-point probe using configuration switching to minimize probe wobble and edge effects. To a first order approximation, sheet resistivity varies inversely with the electrically active doping density (holes/cm^2 or electrons/cm^2). A heavy line is drawn connecting the points having average resistivity. Additional lines (called control interval lines) are drawn indicating regions where resistivity is one interval higher (+) or one interval lower (-) than the adjacent contour line.

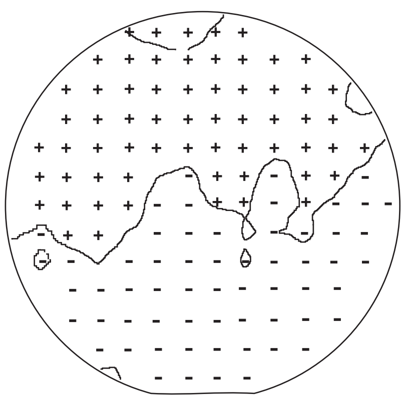


Furnace phosphorus pre-deposition
(Contour interval = 1%,
average sheet resistivity = 50.8 ohms/square)

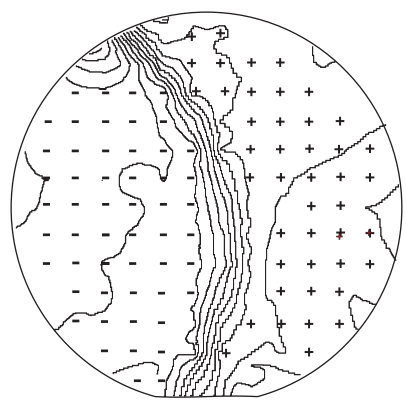
ION IMPLANTER NONUNIFORMITIES

CHARACTERIZED BY FOUR-POINT CONTOUR MAPPING

ELECTROSTATIC SCANNING
TILTING EFFECTS

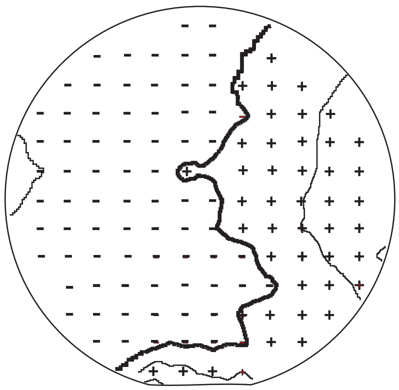


ELECTROSTATIC SCANNING
FAILURE OF THE QUADRAPOLE
LENS POWER SUPPLY

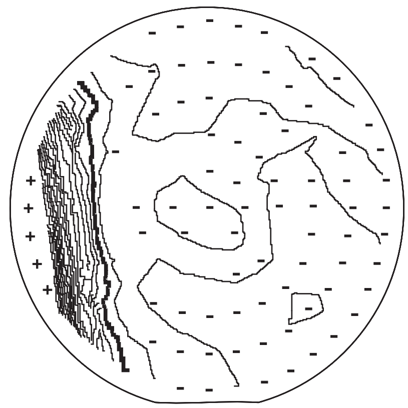


MODERATE X-Y SCAN LOCK-UP

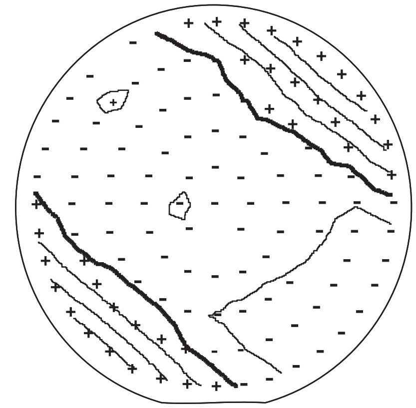
MECHANICAL SCANNING
SPEED VARIATION EFFECTS



SEVERE UNDERSCANNING



MODERATE UNDERSCANNING



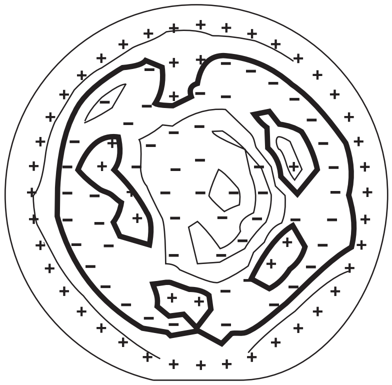
THE ABOVE FOUR-POINT MAPS WERE SUPPLIED COURTESY OF DAVID PERLOFF OF THE PROMETRIX CORPORATION, SANTA CLARA, CALIFORNIA

A COMPARISON OF FOUR-POINT SHEET RESISTIVITY CONTOUR MAPS AND DIAMETER SCANS

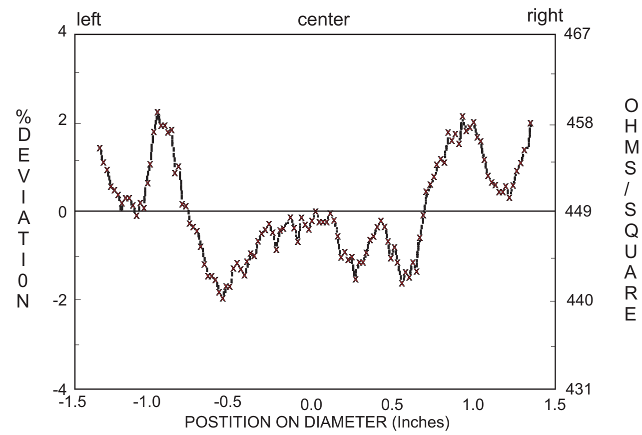
FOUR-POINT CONTOUR MAP The sheet resistivity of the top layer on the wafer is measured at some 120 locations with a special 4-point probe using configuration switching to minimize probe wobble and edge effects. To a first order approximation, sheet resistance varies inversely with the electrically active doping concentration (holes/sq cm or electrons/sq cm). A heavy line is drawn connecting the locations having average resistivity. Additional lines (called contour interval lines) are drawn indicating regions where resistivity is one interval higher (+) or lower (-) than the adjacent contour line. The contour intervals are 1% for the three examples given below.

FOUR-POINT PROBE DIAMETER SCANS While contour maps present an excellent picture of the nonuniformity trends over a wafer, sometimes a more detailed measurement along one dimension is desired. The characterization of x-y scan lock-up (not shown here) provided the initial motivation for using the technique. 121 four-point probe measurements with configuration switching are taken on a given line on the wafer -- usually a diameter and hence the name. The calculated average and standard deviation of the diameter scan are usually different from those for the contour map because the diameter scan gives the central portion of the wafer disproportionately high representation.

N-TYPE WAFER PRIOR TO WAFER FAB PROCESSING

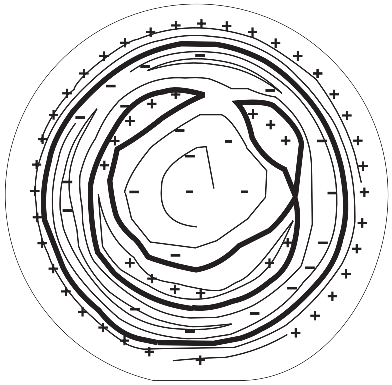


AVE. VALUE 465.3 ohms/sq
STD. DEV. 1.25%
CONT. INT. 1.00%

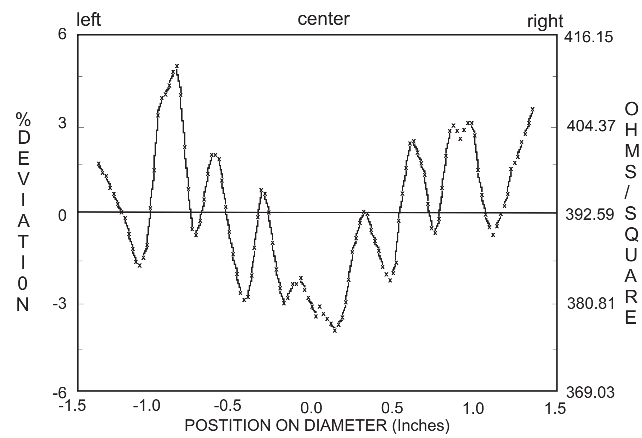


AVE. VALUE: 449.8 ohms/sq
STD. DEV.: 1.08%

P-TYPE WAFER PRIOR TO WAFER FAB PROCESSING

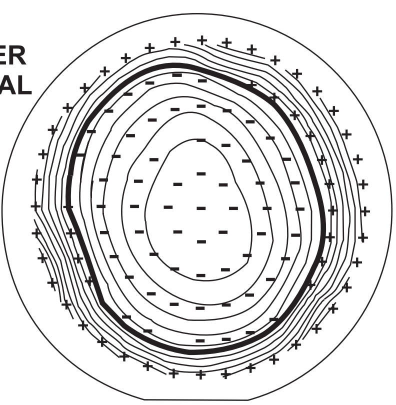


AVE. VALUE 388.1 ohms/sq
STD. DEV. 1.87%
CONT. INT. 1.00%

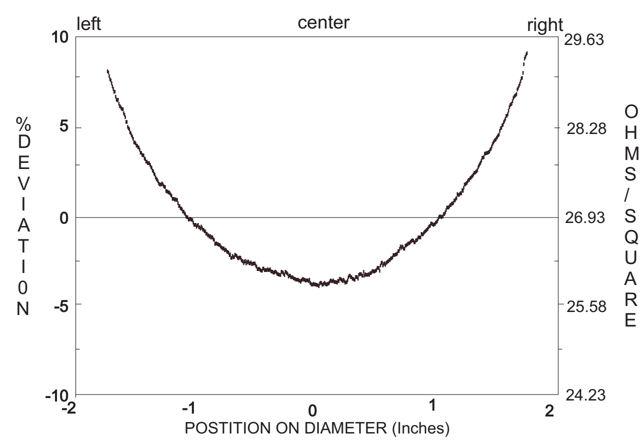


AVE. VALUE: 392.5 ohms/sq
STD. DEV.: 2.17%

ION-IMPLANTED WAFER AFTER A RAPID ANNEAL



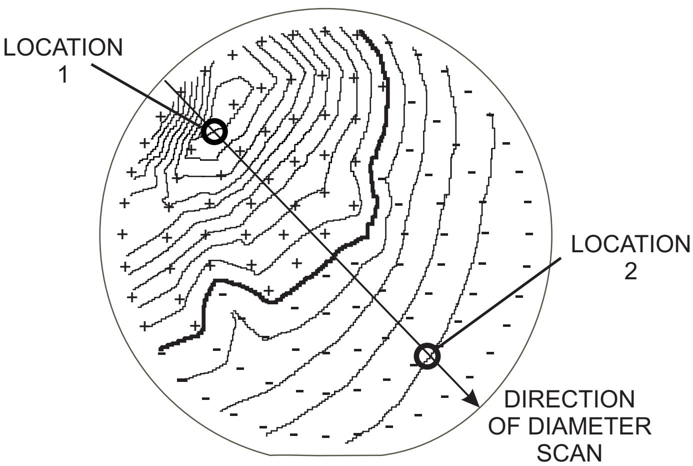
AVE. VALUE 27.60 ohms/sq
STD. DEV. 4.23%
CONT. INT. 1.00%



AVE. VALUE: 26.93 ohms/sq
STD. DEV.: 3.55%

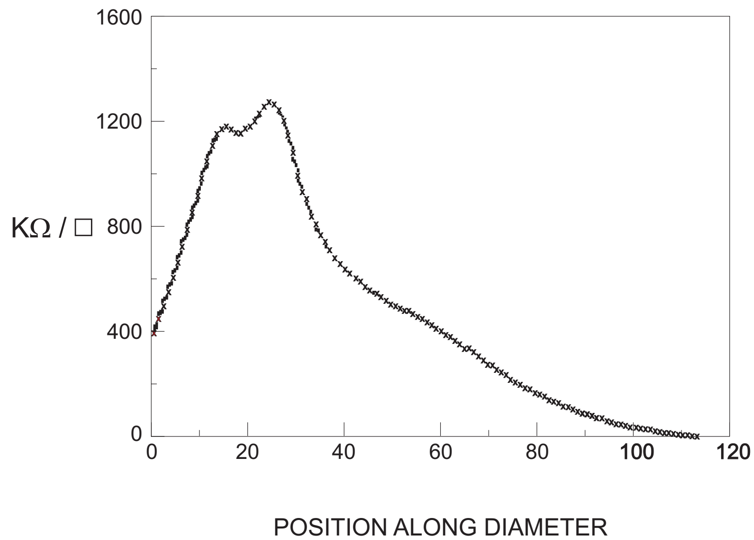
THE CHARACTERIZATION OF A VERY NONUNIFORM EPI WAFER

1) A FOUR-POINT PROBE CONTOUR MAP was produced by Solecon Labs. The sheet resistivity of the epi layer was measured at approximately 121 locations with a special 4-point probe using configuration switching to minimize probe wobble and edge effects. To a first order approximation, sheet resistance varies inversely with the electrically active doping density (holes/sq. cm. or electrons/sq. cm.). A heavy line is drawn connecting the points having average resistivity. Additional lines (called contour interval lines) are drawn indicating regions where the resistivity is one interval higher (+) or one interval lower (-) than the adjacent contour line. In this outrageously non-uniform sample, the contour intervals are 20%. Usually,

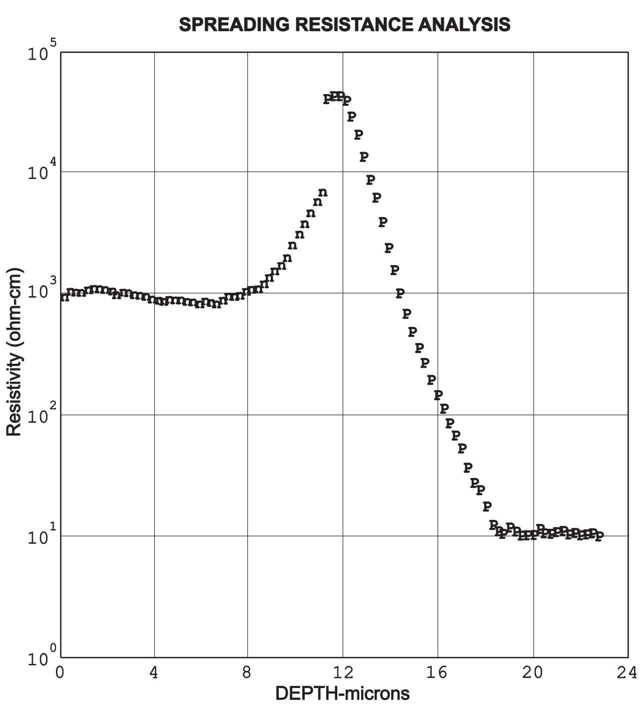


Average Sheet Resistivity = 307 KΩ /□
Contour Interval = 20%
Standard Deviation = 78%

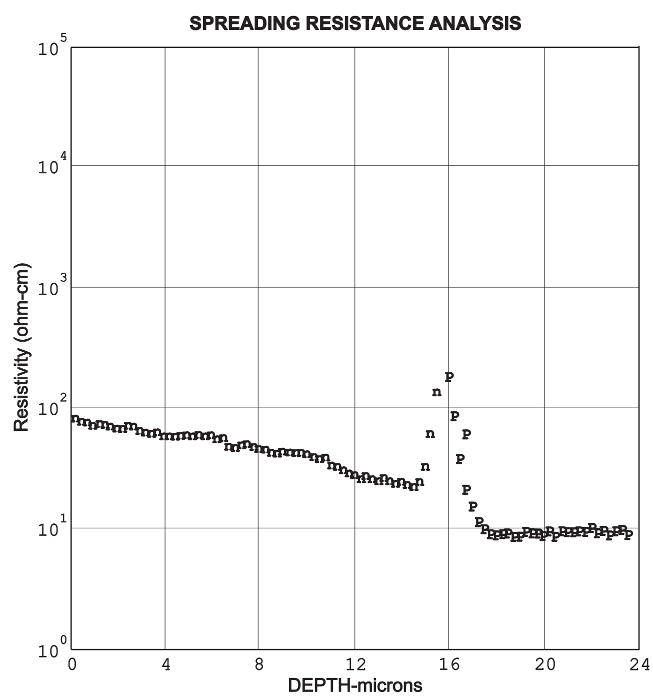
2) A FOUR-POINT PROBE DIAMETER SCAN consisting of 121 probings was run in the direction shown. The diameter scan in this case merely corroborates the contour map. Often, the diameter scan will characterize local variations (such as ion implant scan striping shown on the next page) that the contour map would possibly have missed.



3) A SPREADING RESISTANCE RESISTIVITY PROFILE was done at location 1. The grown epi layer appears to be about 17 microns thick while the N-P junction is less than 12 microns below the surface. Note the epi resistivity is quite high and reasonably flat.

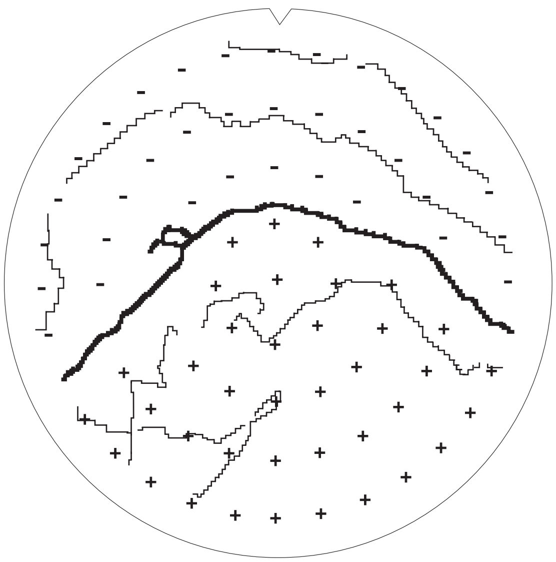


4) A SPREADING RESISTANCE RESISTIVITY PROFILE was done at location 2. Note that the epi resistivity varies a factor of four being highest at the surface and lowest in the vicinity of the N-P junction. Again, the grown epi thickness appears to be 17 microns. The N-P junction, however, is about 16 microns below the surface or four microns deeper than at location 1. This is primarily due to the lower epi resistivity (higher carrier concentration) at location 2.

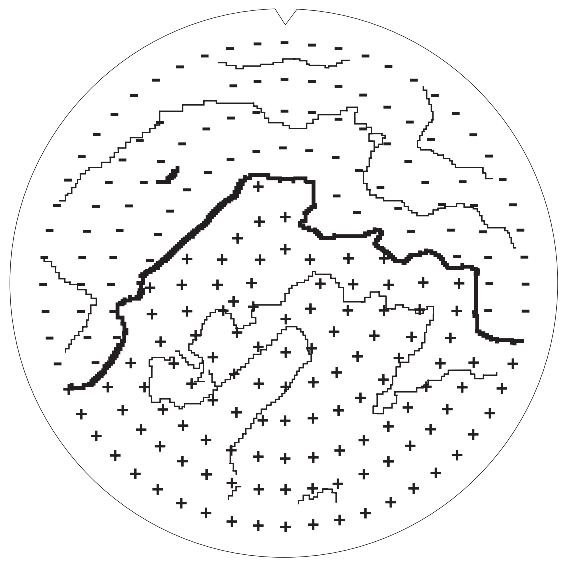


HOW UNIFORM ARE YOUR WAFERS?

Consider this 80 keV Boron 5E14 Implant.

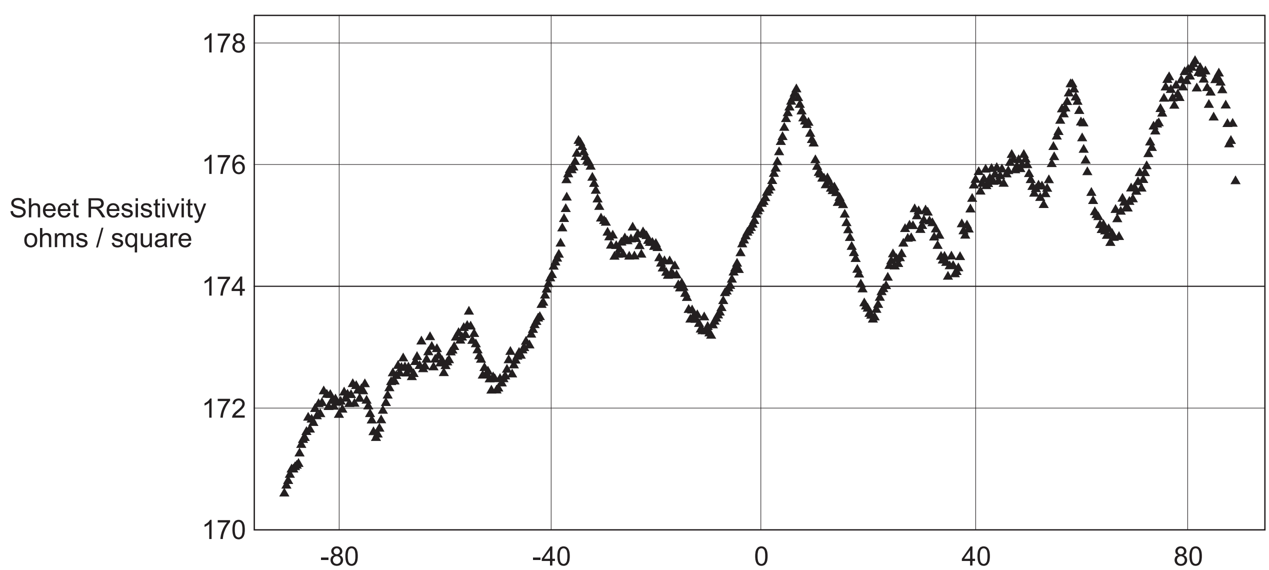


81 Sites, 6 mm Edge Exclusion
Standard Deviation = 0.95%



225 Sites, 6 mm Edge Exclusion
Standard Deviation = 0.91%

NOT TOO BAD AT ALL
BUT SEE THE DIAMETER SCAN!



0.2mm STEP DIAMETER SCAN INDICATES A STRIPING PROBLEM