SOLECON
LABORATORIES
INCORPORATED

An Introduction to Spreading Resistance Analysis and its Application in the Semiconductor Industry

Sheila Loftis
Dan Dickey
Solecon Labs
770 Trademark Dr
Reno, NV 89521
(775) 853-5900
www.solecon.com

SPREADING RESISTANCE ANALYSIS REQUEST FORM

Date

Priority: High ☐ (surcharge) Normal ☐

Purchase Order #

Company

Mailing Address
(Mail Stop too, please)

Engineer

Tel #

Message #
(please!)

Fax #

email

Number of Samples _______________

Total Number of Profiles _______________

Sample #	Approximate structure expected from surface down: Type Depth Type Depth Type Depth Type Depth	Maximum Depth of Interest	Circle Substrate Type	Circle Crystal Orientation
			P N	<111> <100>
			P N	<111> <100>
			P N	<111> <100>
			P N	<111> <100>
			P N	<111> <100>
			P N	<111> <100>
			P N	<111> <100>
			P N	<111> <100>

Hard copy carrier concentration plots are supplied automatically. Also available are…

Hard Copy: ☐ Resistivity Plot, ☐ Resistance Plot, ☐ Data Table
Soft Copy: ☐ Text File(s), ☐ Image File(s) -via:- ☐ 3½" DOS, ☐ E-mail

Reference Job # (if any):

Special Instructions: (Any specific region of the profile of greater importance than the rest?)

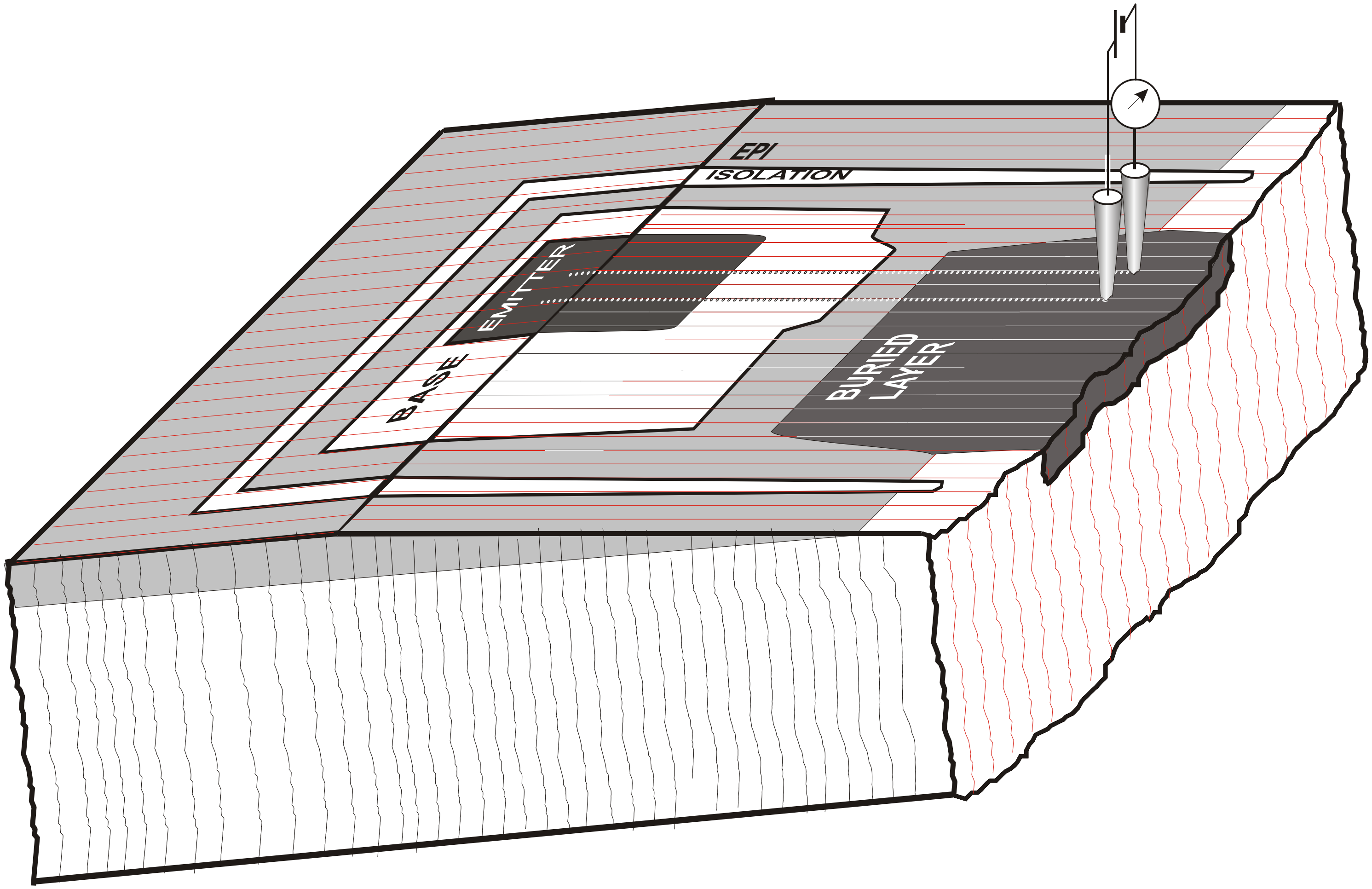
If device wafer, please indicate locations required by a sketch below or by attaching a photo or drawing .

Sketch:

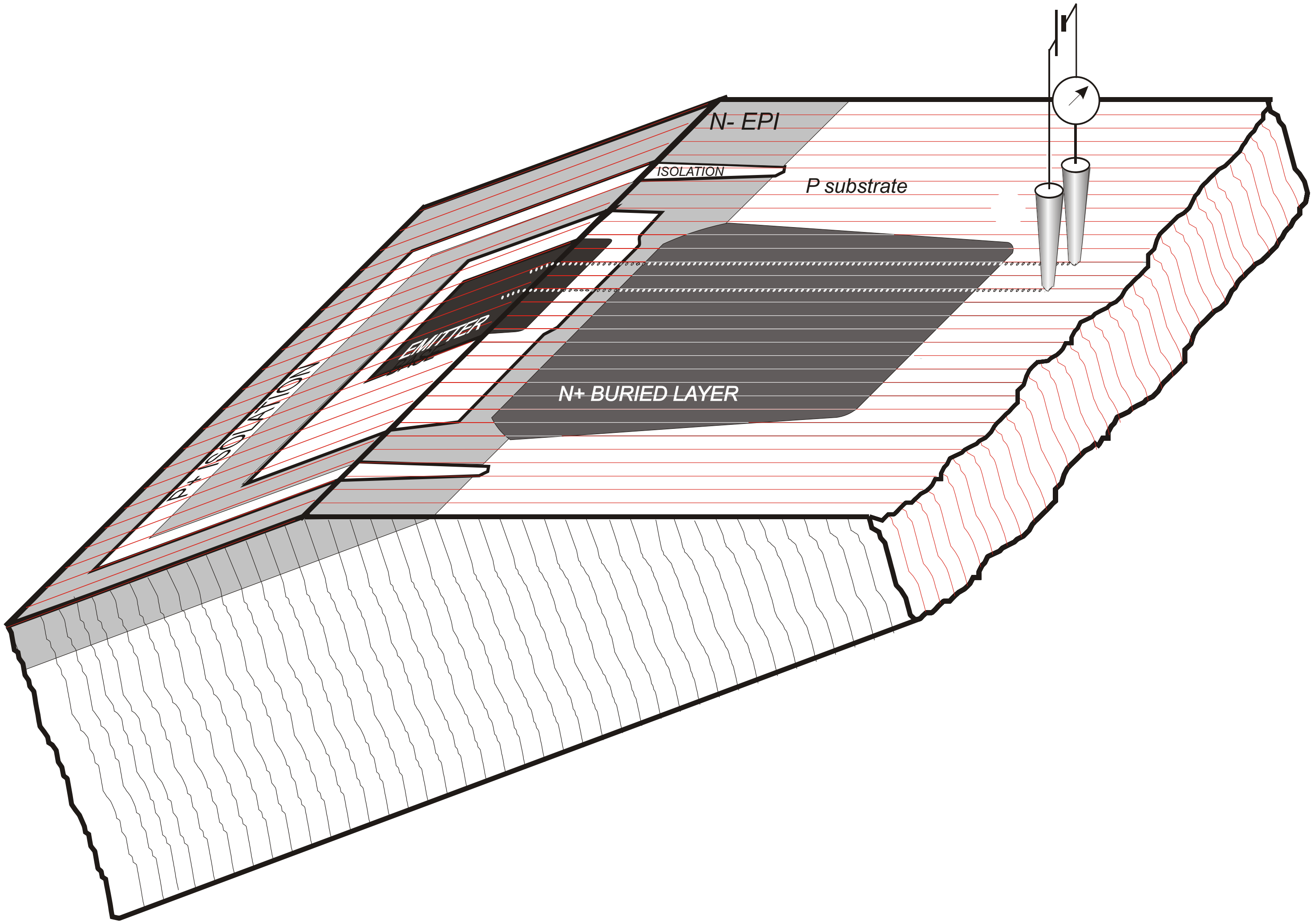
Filling out our request form:

1. Solecon Labs privacy policy.
2. Provide us with as much information as possible.
3. An appropriate bevel angle is needed.
4. Solecon strives for over 20 data points per layer.
5. A shallow emitter at .2µm on base at .4µm on epi/buried layer at 5.5µm on p-type substrate. What are you really interested in?

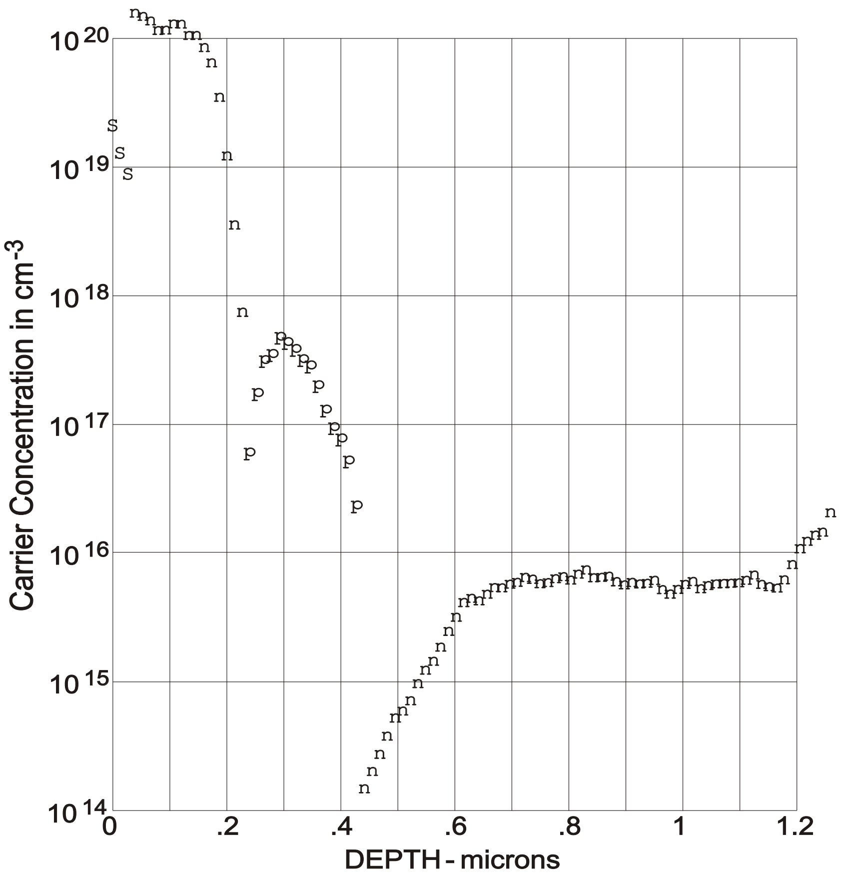
Shallow Profile of the Bipolar Structure

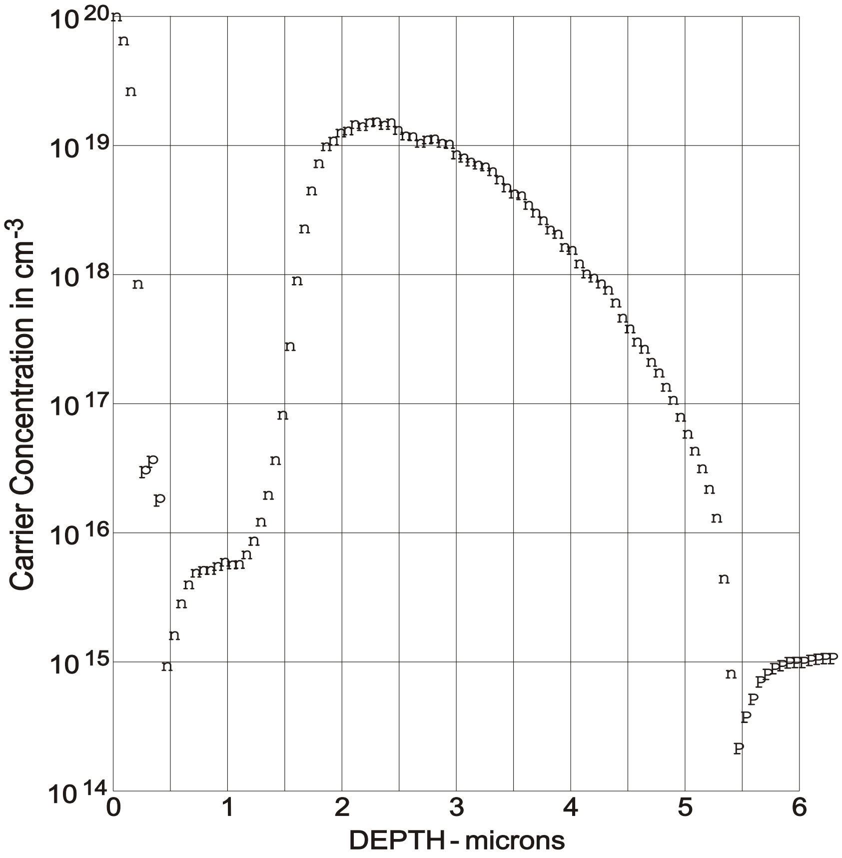


Deep Profile of the Bipolar Structure



Bipolar Transistor





How much of the sample do we need?

1. We measure from full wafers to a millimeter square.
2. Pattern wafers and backups.

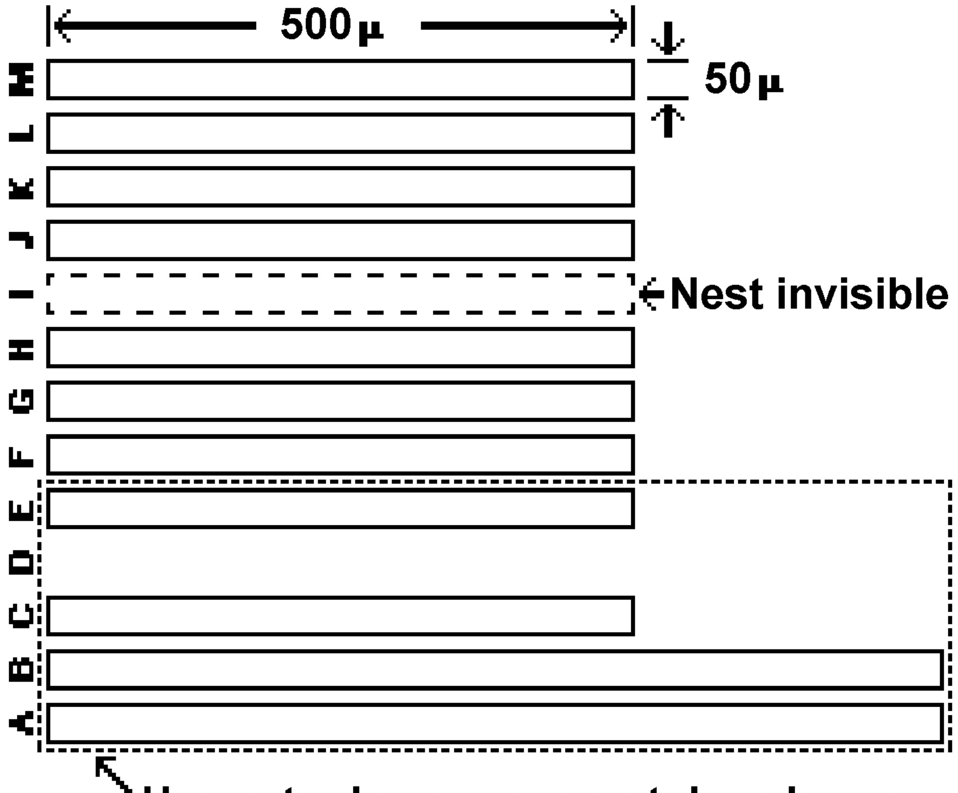
Beveling:

1. Your samples are mounted on angled beveling blocks.
2. Samples should be beveled immediately before probing, to avoid interference from native oxide.

Size of pattern:

1. Our minimum requirements are 20µm wide x 100µm long.
2. The smaller the pattern size the greater the compromise.
3. For this reason we suggest dedicated spreading resistance test patterns which are 50 x 500µm.

Dedicated SRA Test Patterns

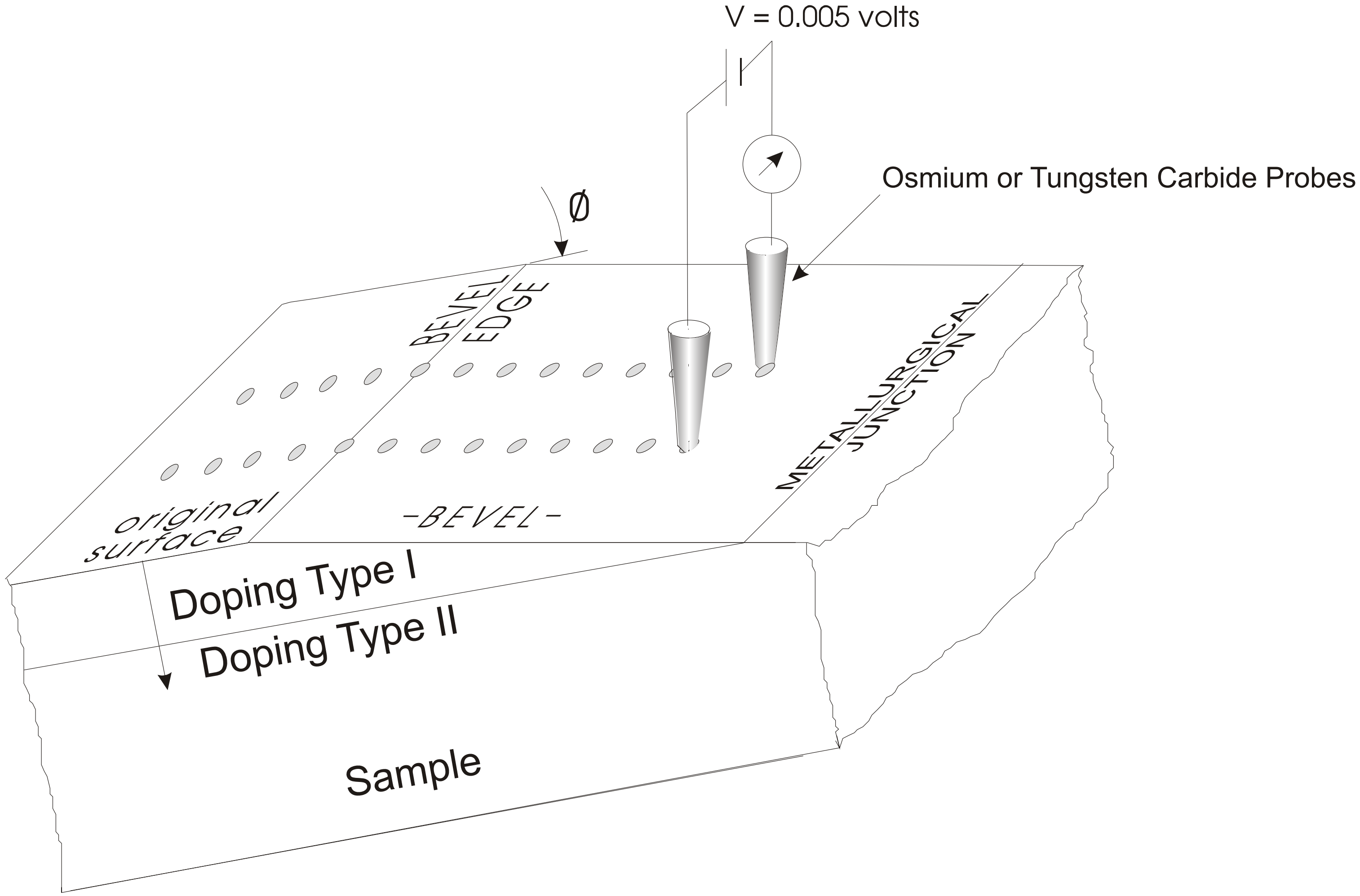


Nest invisible bars

Use extra long common tubs when possible

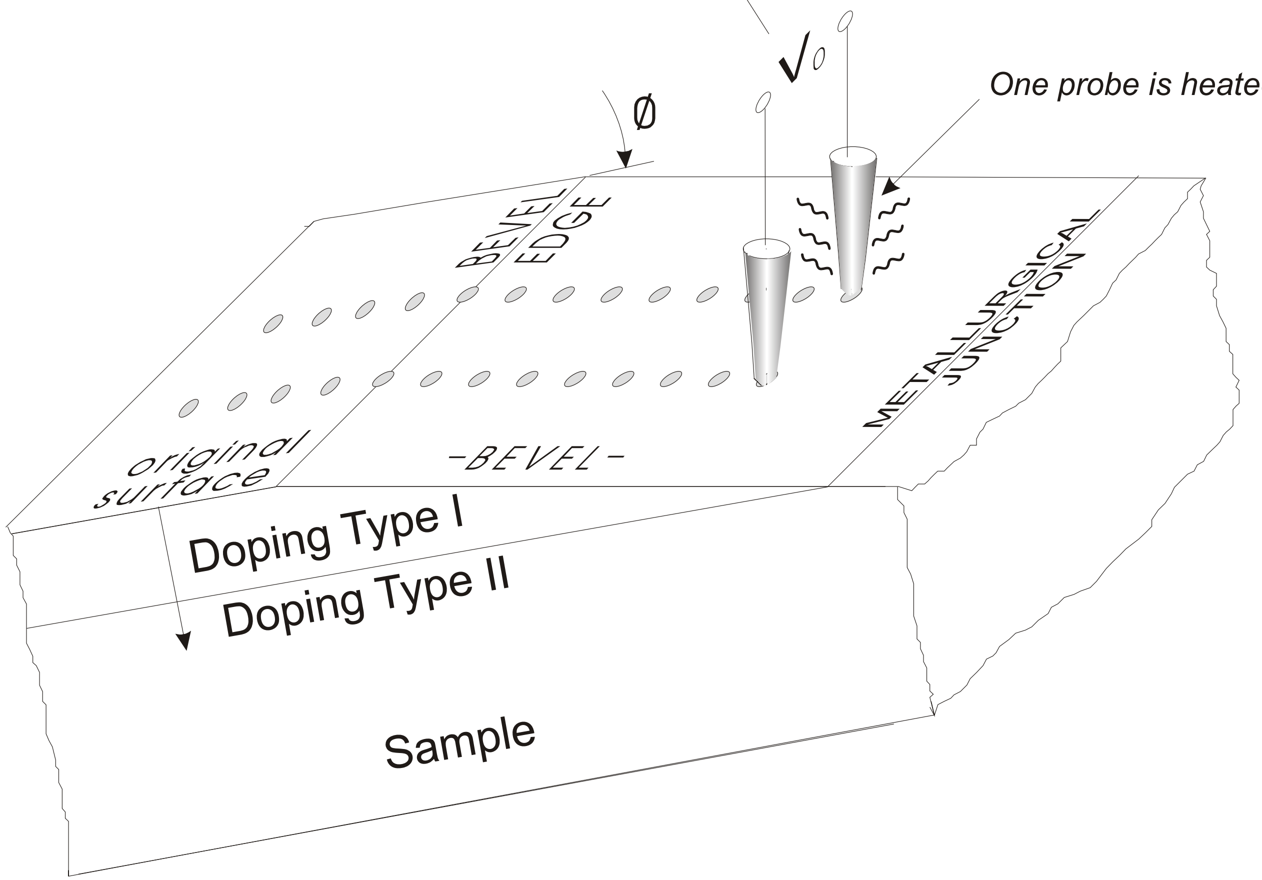
Recommended for Scribeline use Only

Schematic diagram of a spreading resistance measurement on a beveled sample



Carrier Type Determination

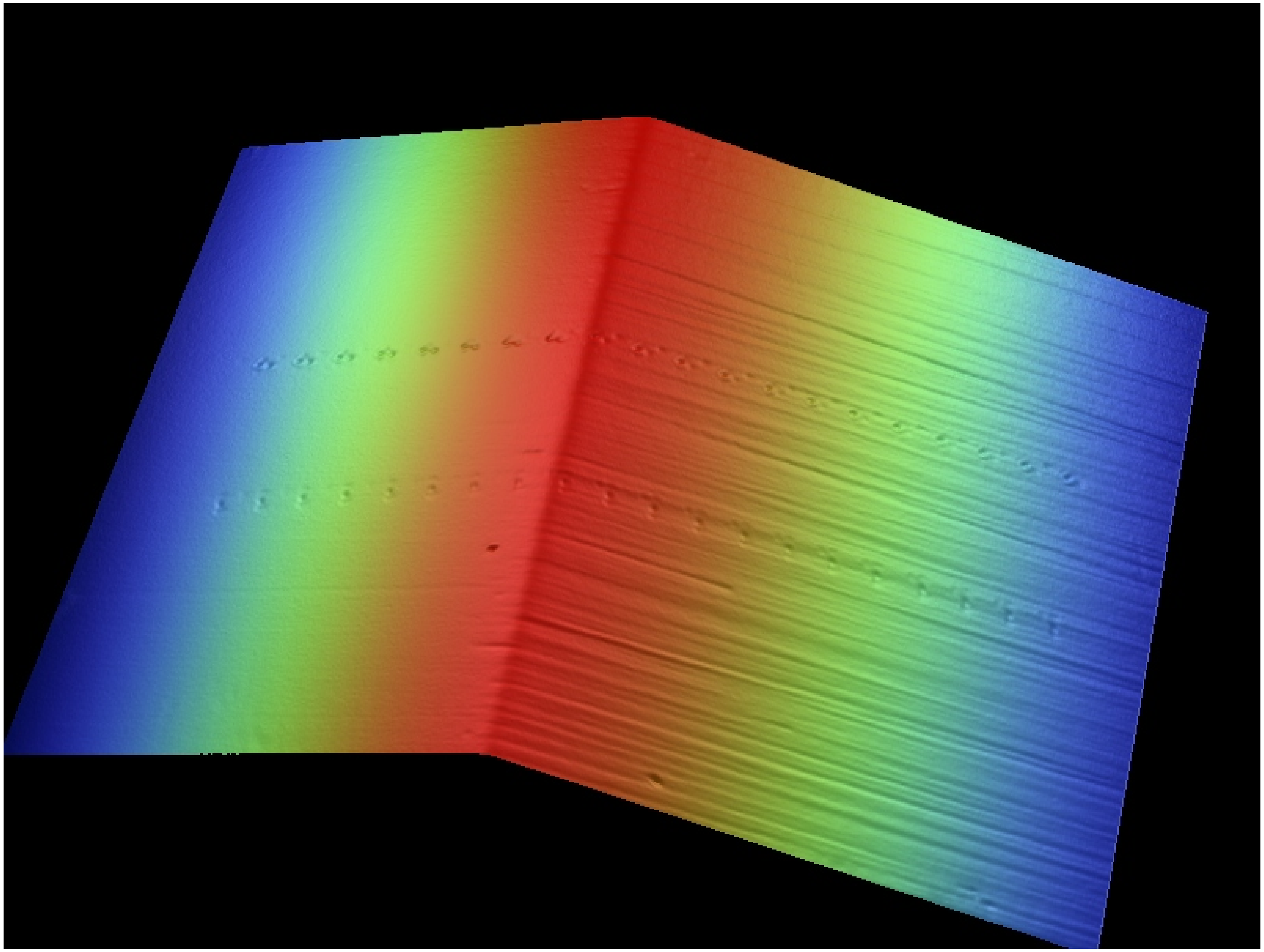
With a Few Modifications, the Spreading Resistance Set-Up Can Determine “N” or “P”.



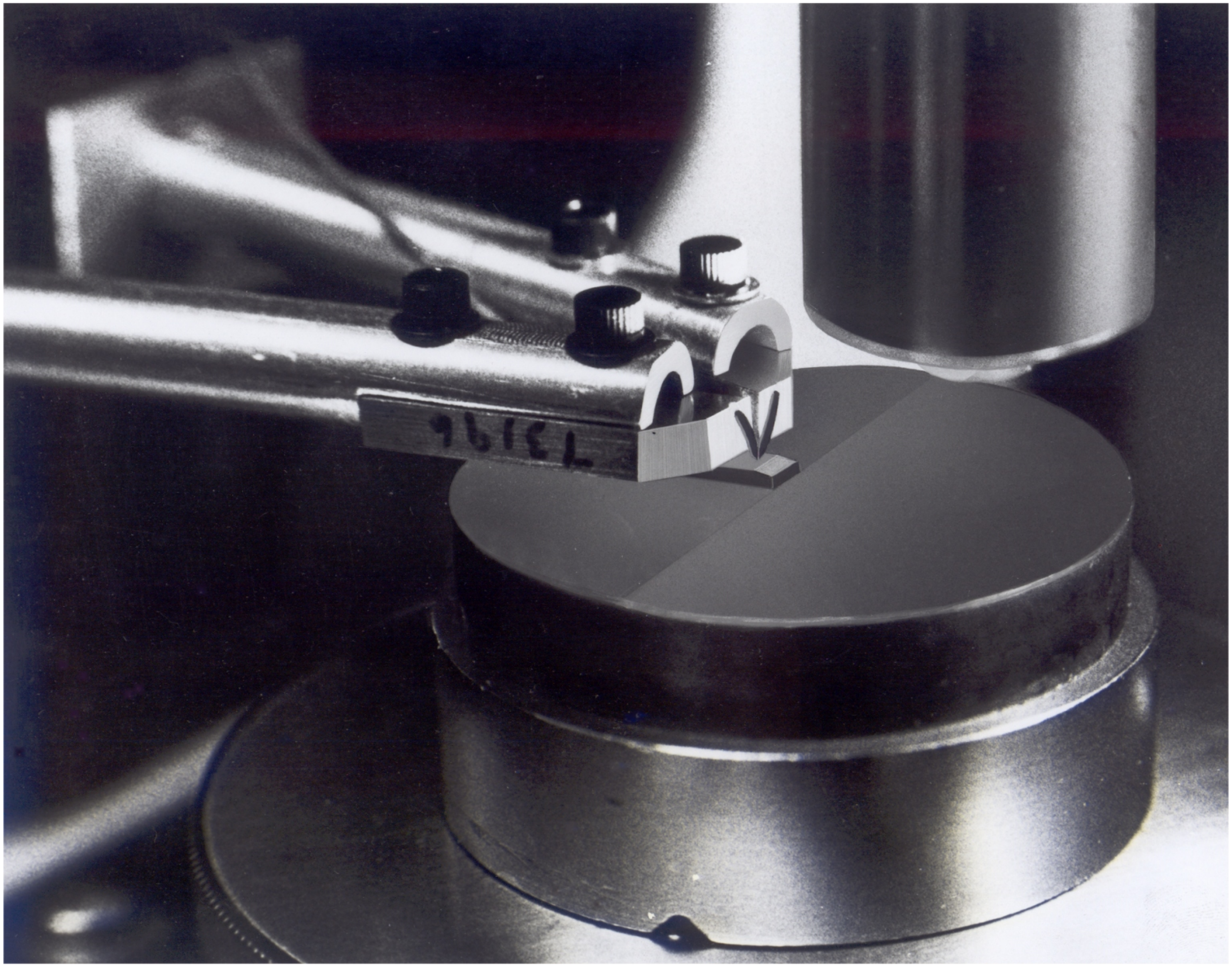
Polarity and magnitude of the open circuit (Seebeck) voltage determined

One probe is heated.

Optical Profilometer view of a spreading resistance measurement on a beveled sample



Birds Eye View of SRA Sample and Probes

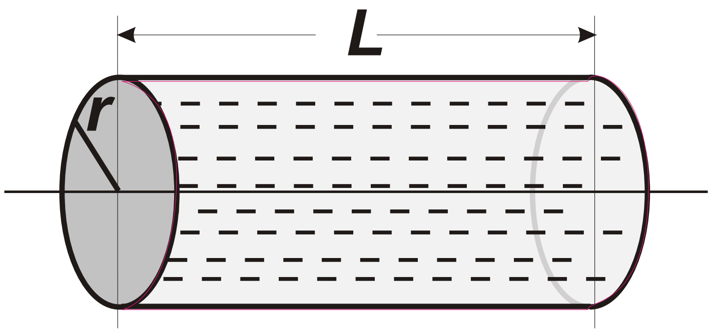


Probing

1. 2 probe tips made of tungsten carbide are used.
2. The probe tips are shaped so that they can be positioned within 20um of each other.
3. Each probe tip is mounted on the end of a separate arm.
4. Each arm pivots on a kinematic bearing system that eliminates lateral motion or "scrubbing" as it contacts the sample.
5. Probe tips are lowered gently onto the sample.
6. Because of the small contact area, pressure is in excess of a million pounds per square inch.
7. 5 millivolts are applied across the probes and the resistance is measured.

LINEAR CURRENT FLOW

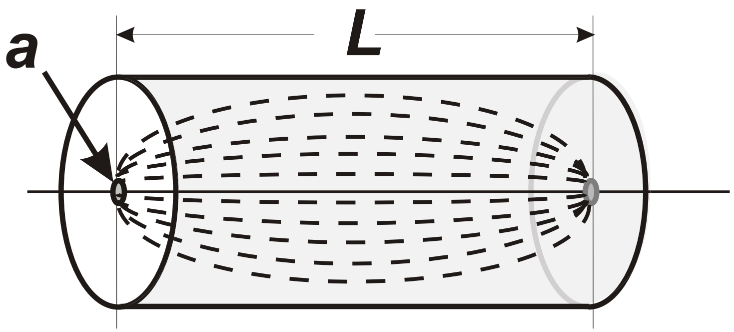
$$R = \frac{L}{r^2}$$



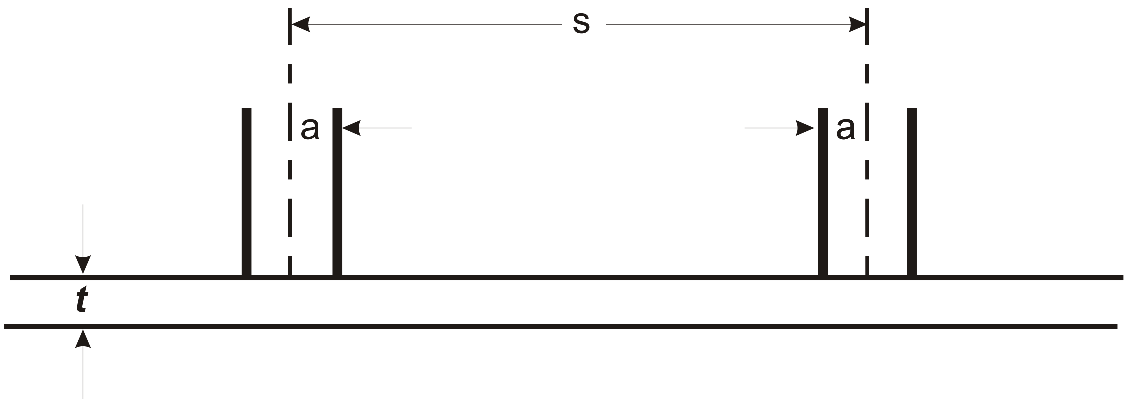
where is the bulk resistivity in ohm-cm

SPREADING RESISTANCE

$$R = \frac{}{2a}$$



Two Probes on a Thin Layer (t<a):



$$R = \frac{}{t} \; ln\frac{s}{a}$$

D. H. Dickey, **NBS SP 400-48**

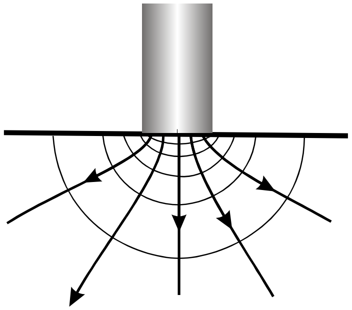
What is the significance of resistivity? In a semiconductor it is related to the concentration of electrons and holes:

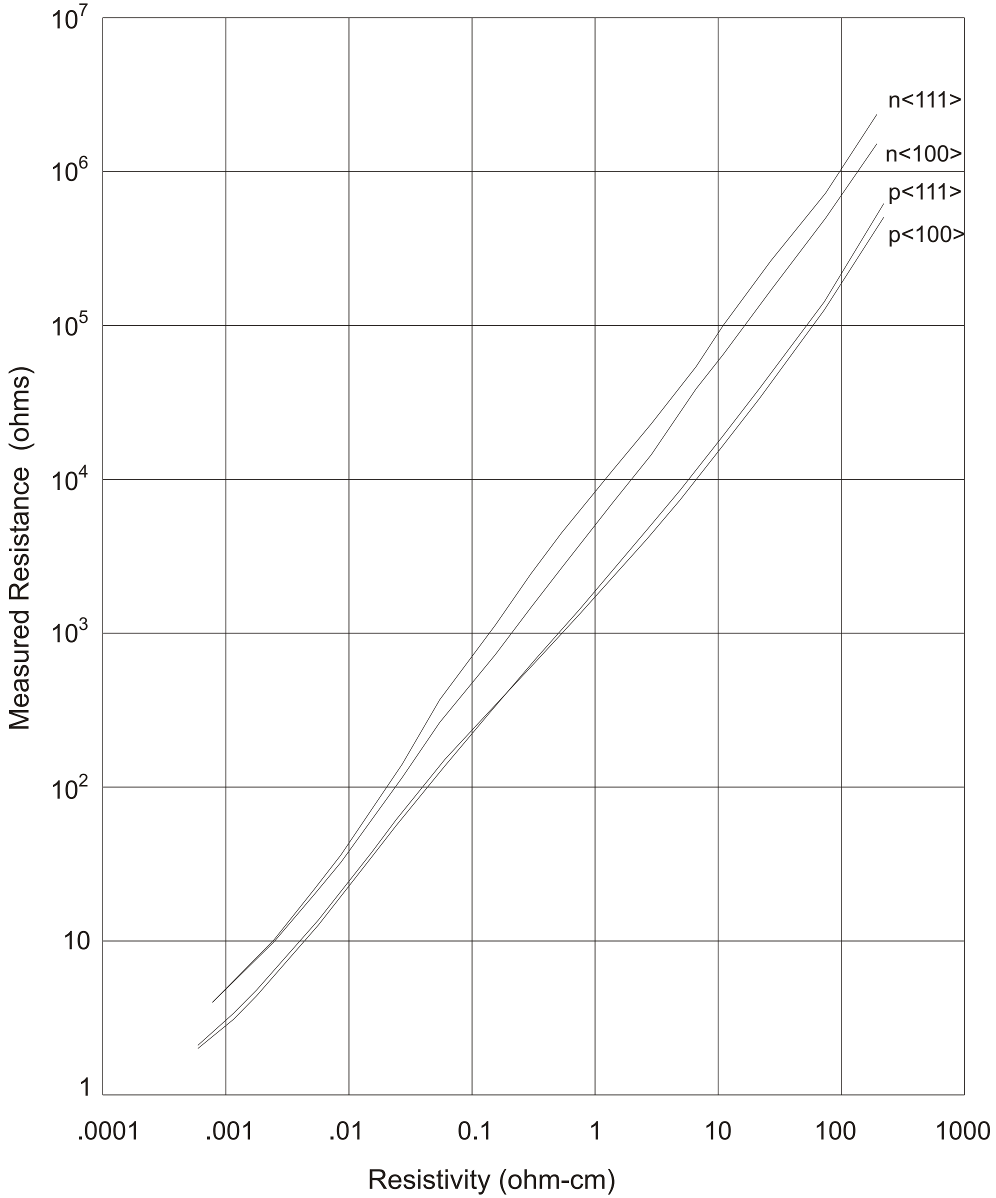
$$= \frac{1}{\quad} = nq \quad {}_e + pq \quad {}_p$$

And from that, the dopant concentration can be approximated.

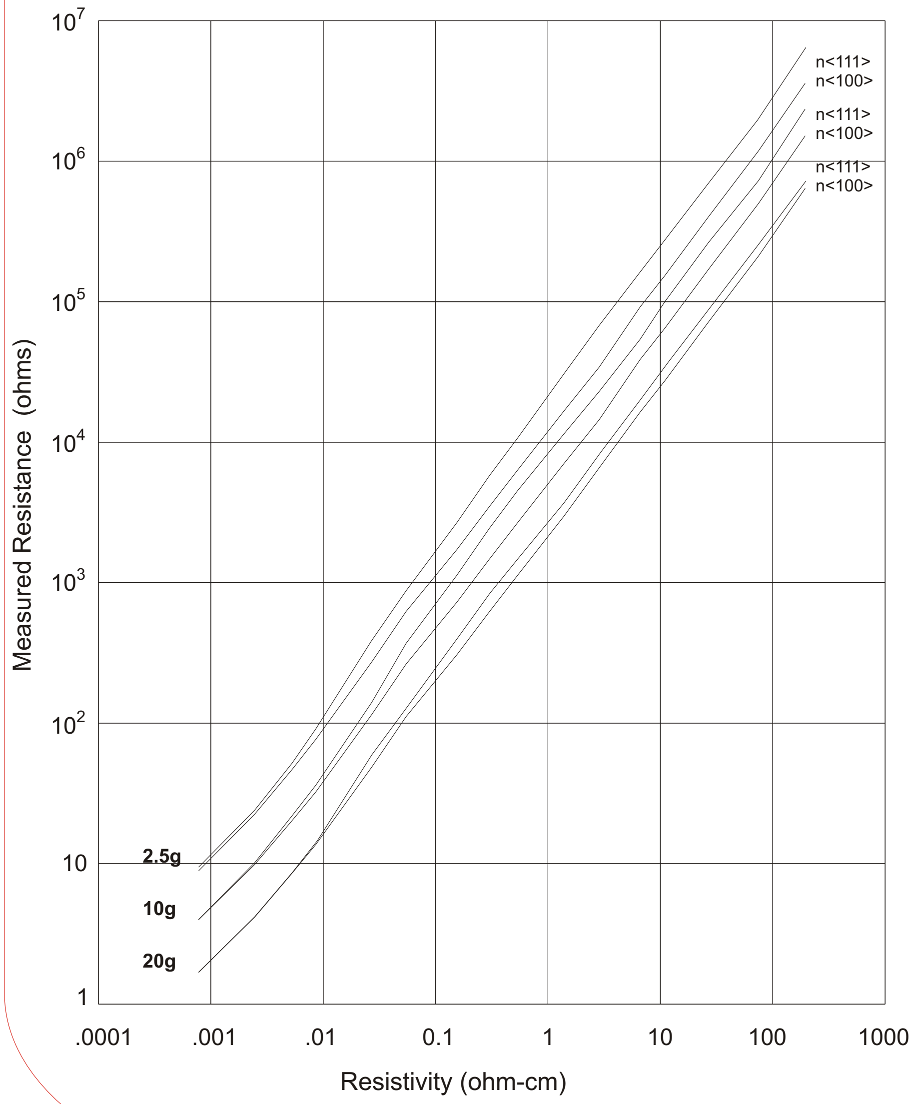
$$N \quad n \quad \frac{1}{q \quad {}_e}$$

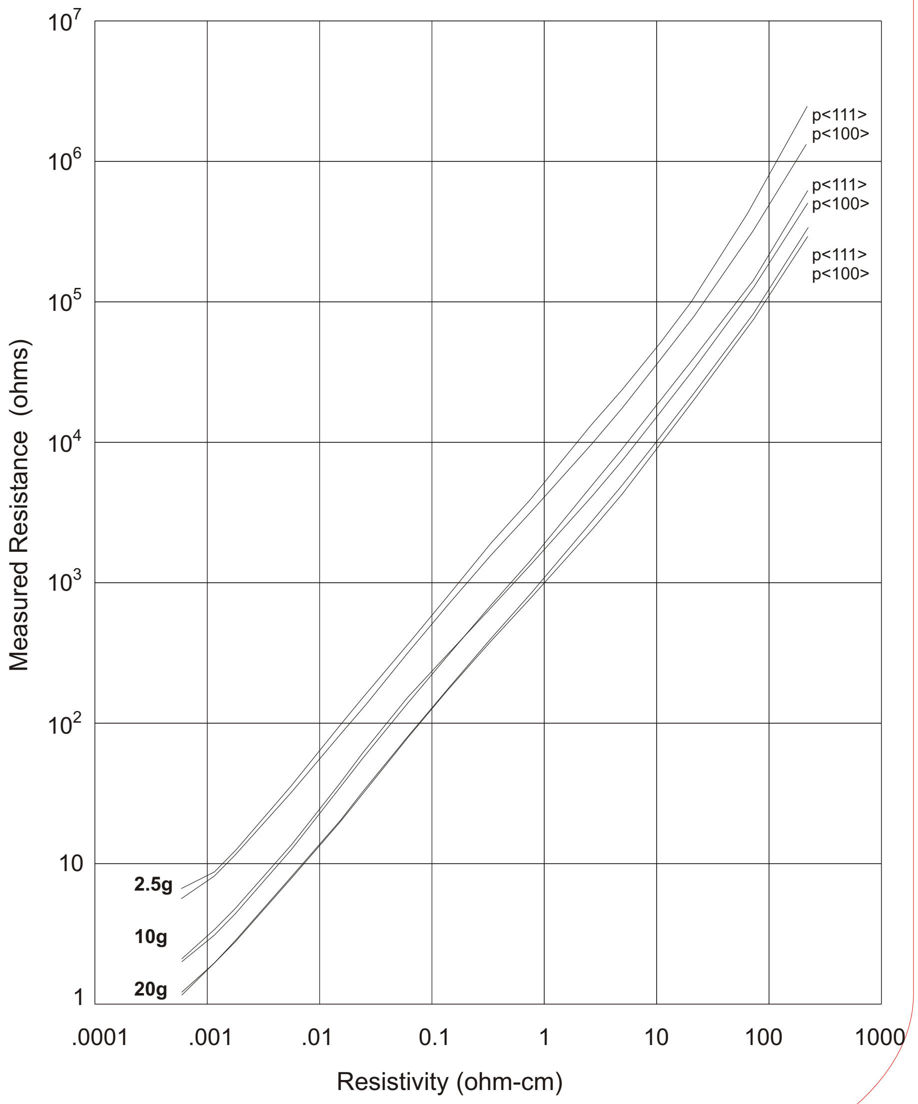
Calibration Chart
Spreading Resistance
vs. Resistivity
(NIST Traceable Si Bulk Standards)





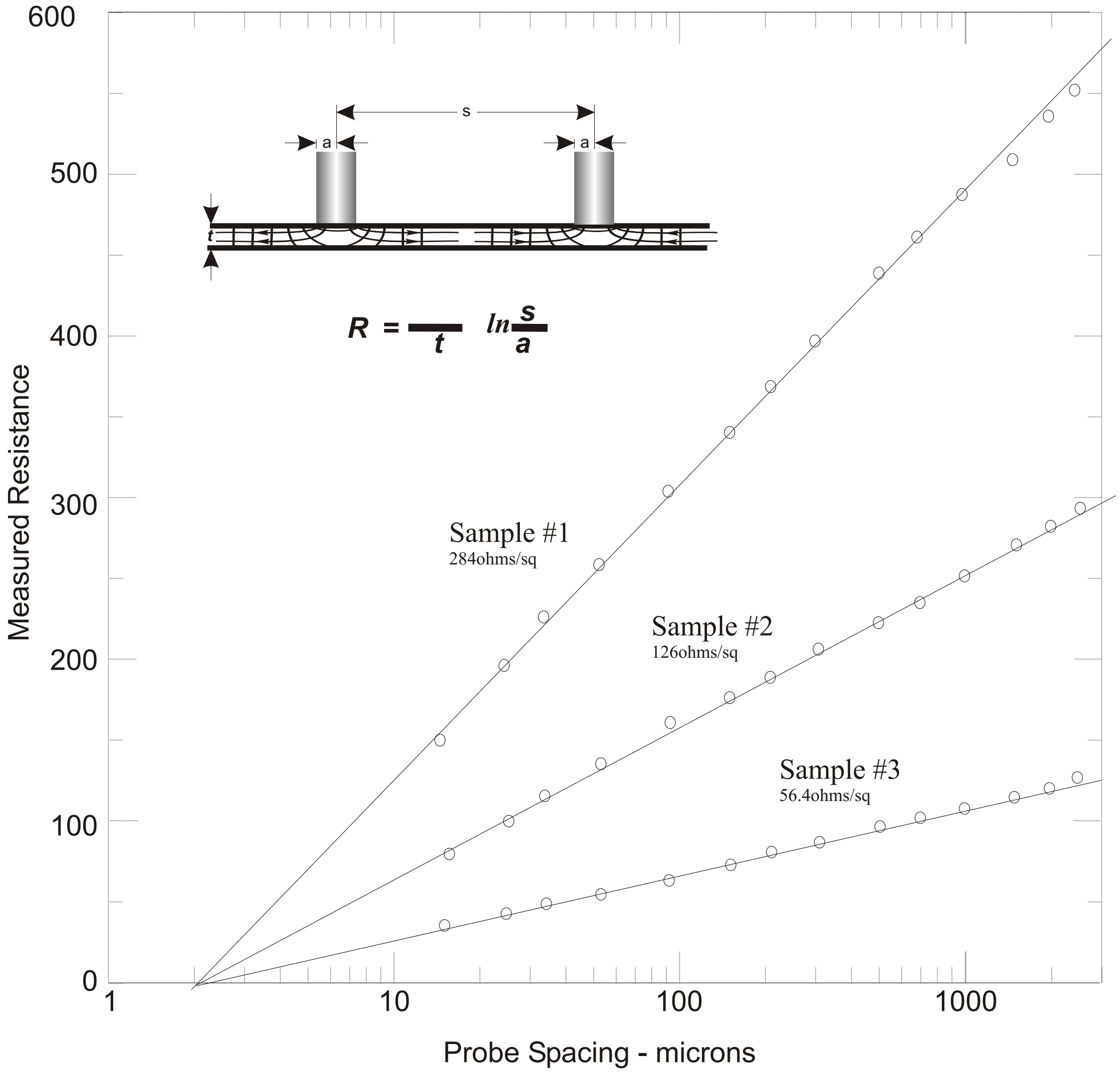
Calibration Data for Three Probe Loads





Probe Spacing Experiment on Relatively Thin Layers

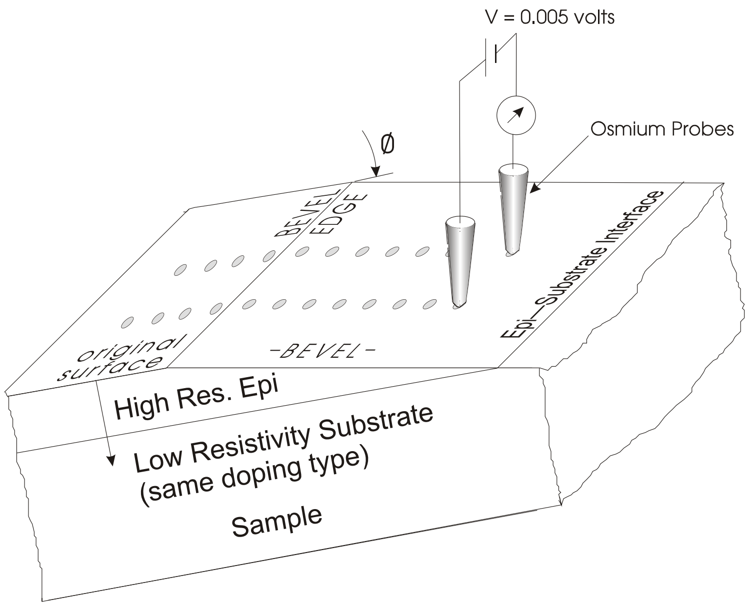
(Measured resistance is dominated by the lateral current flow)

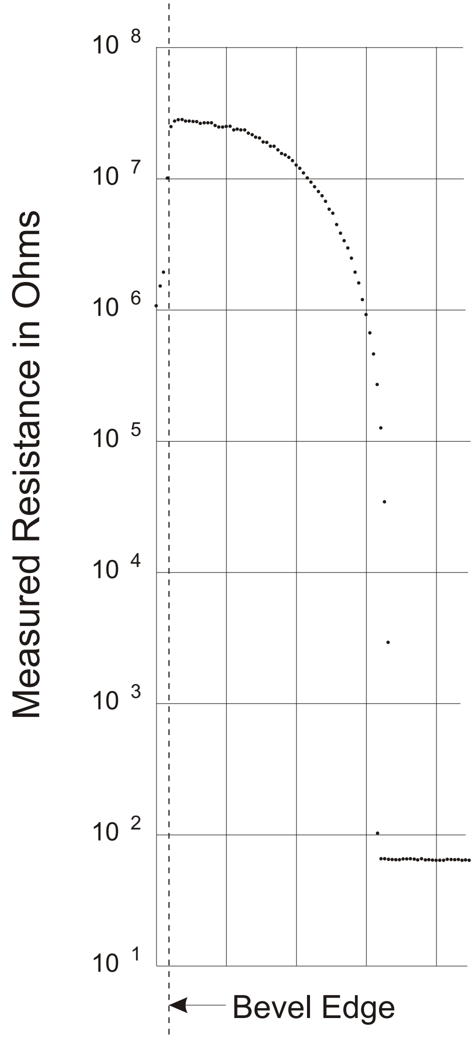


$$R = \frac{}{t} \ln\frac{s}{a}$$

After: Dickey, **NBS SP 400-48 p16**

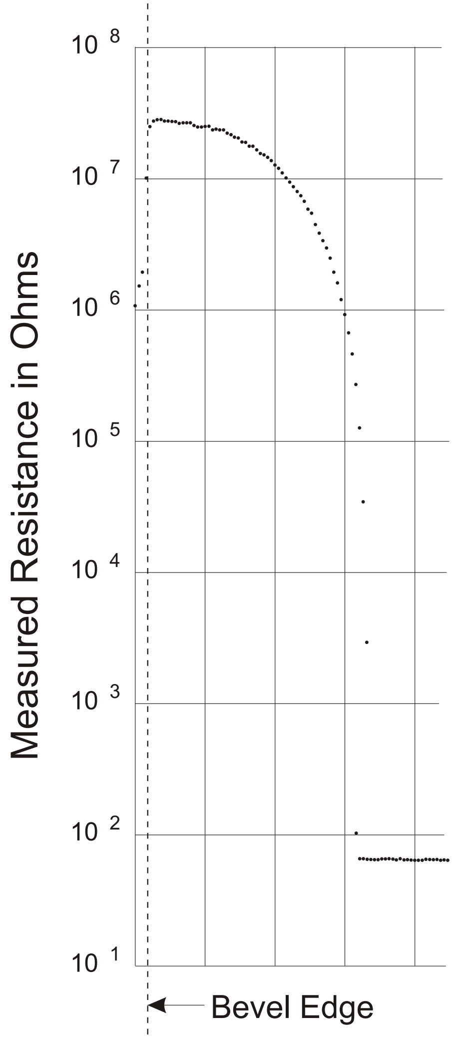
High Resisitivity Epi



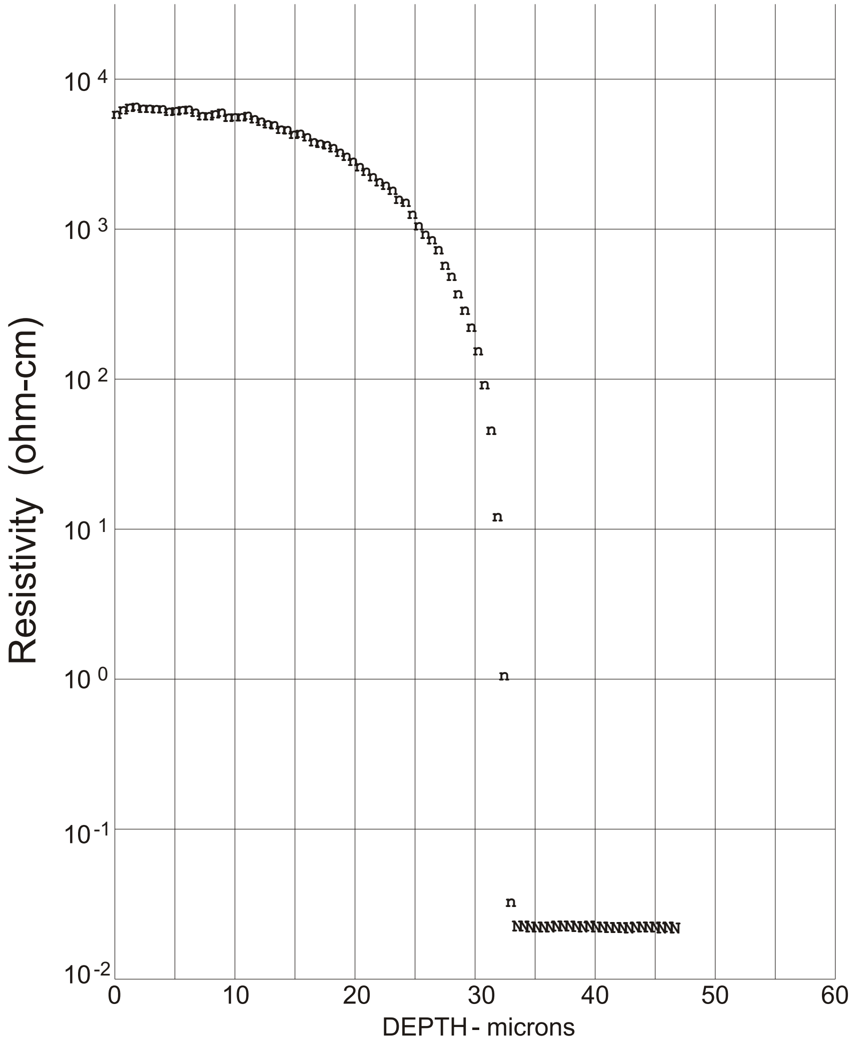


Probing → “Raw Data”

High Resisitivity Epi (continued)

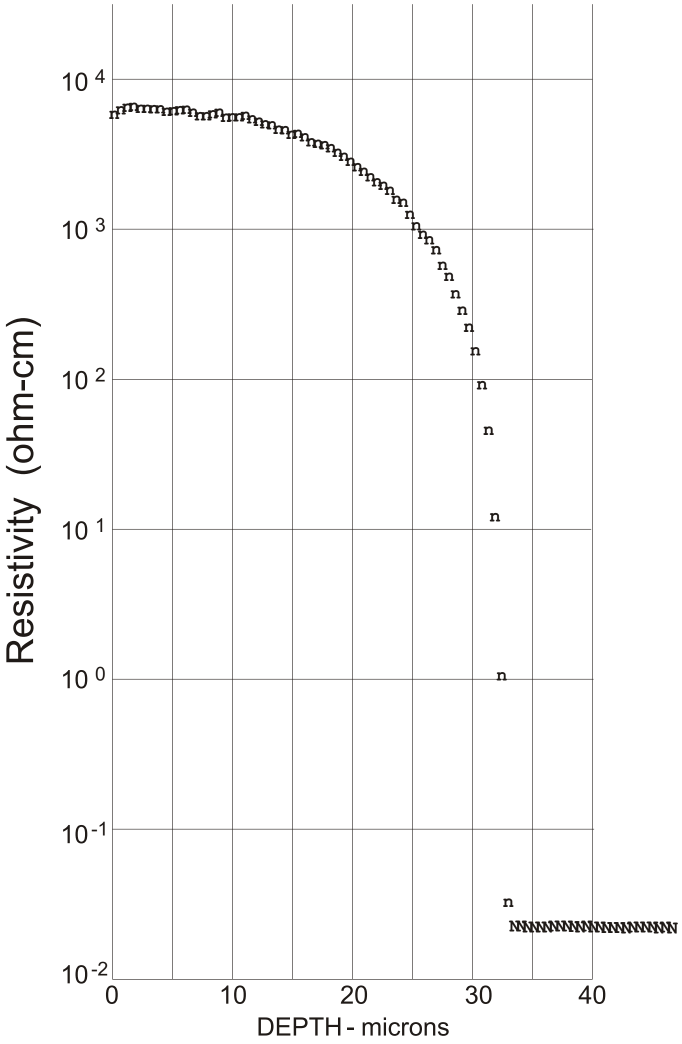


Data Reduction →

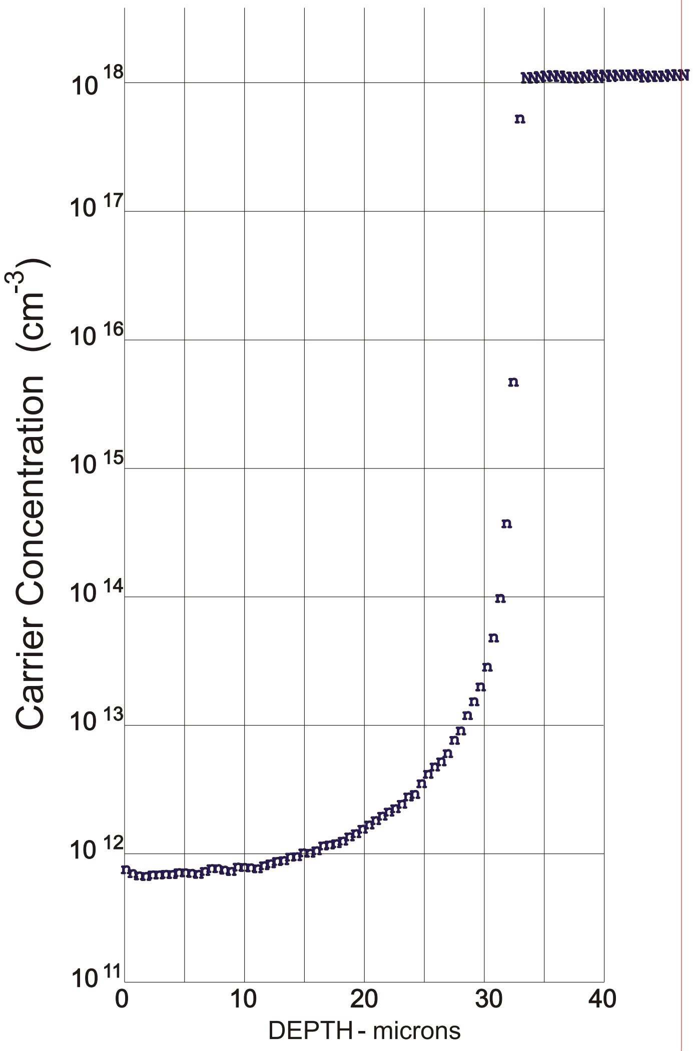


“Raw Data” → Resistivity Plot

High Resisitivity Epi (continued)

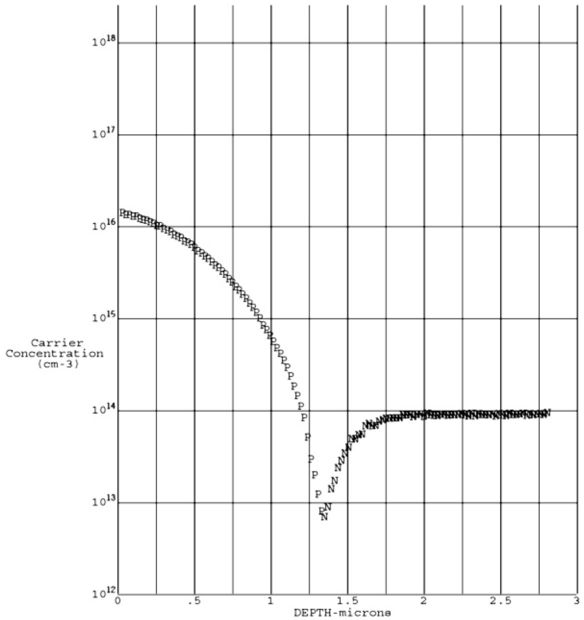


Carrier Concentration Calculated Using Published Carrier Mobility Values

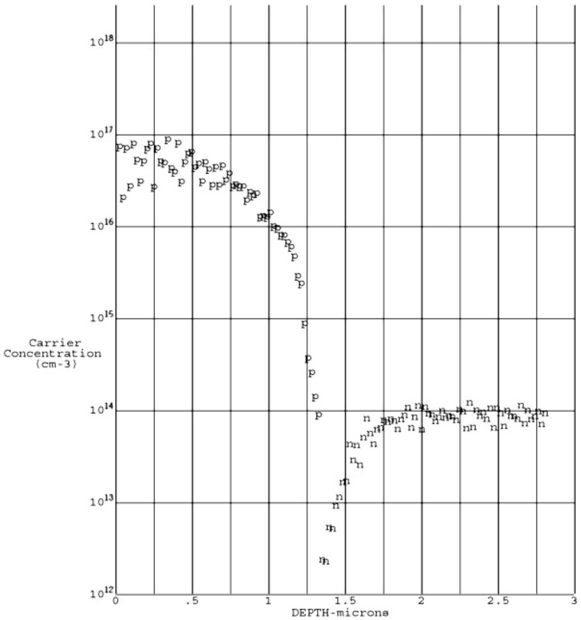


Resistivity → Carrier Concentration

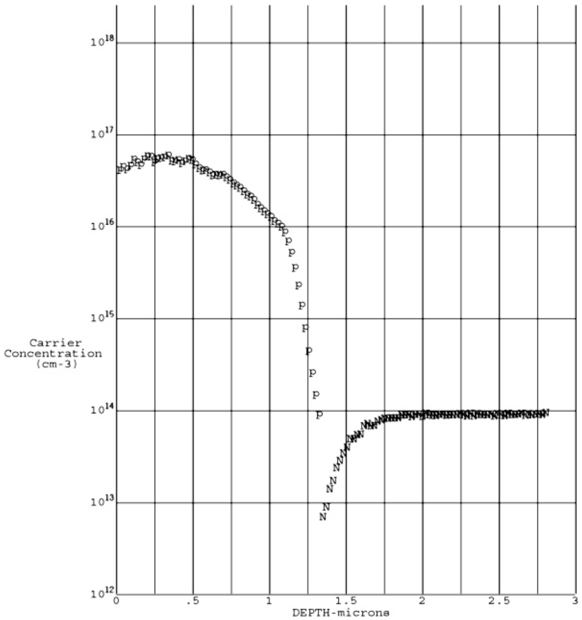
Sampling Volume Correction



Uncorrected layers
(Unsmoothed data)



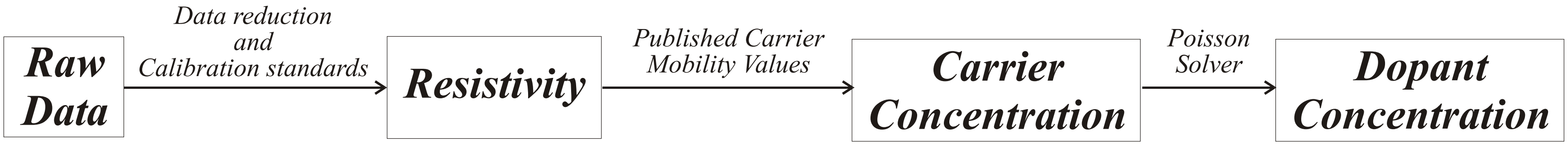
Both layers corrected
(Unsmoothed data)



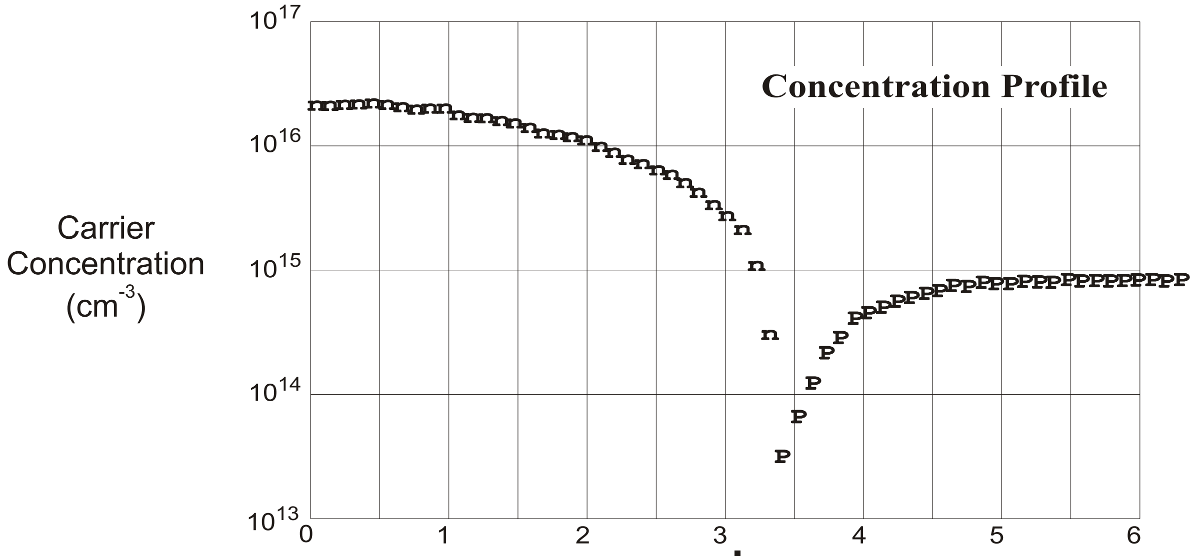
Top layer corrected and smoothed
(Uncorrected/unsmoothed substrate)

Our correction algorithms account for the sampling volume on non-uniformly doped layers. In regions with slight to no resistivity gradient, the algorithms tend to magnify the mechanical noise. But without correction the graded layer's values can be very wrong! We have various levels of smoothing which we can use to reduce the scatter in your profiles.

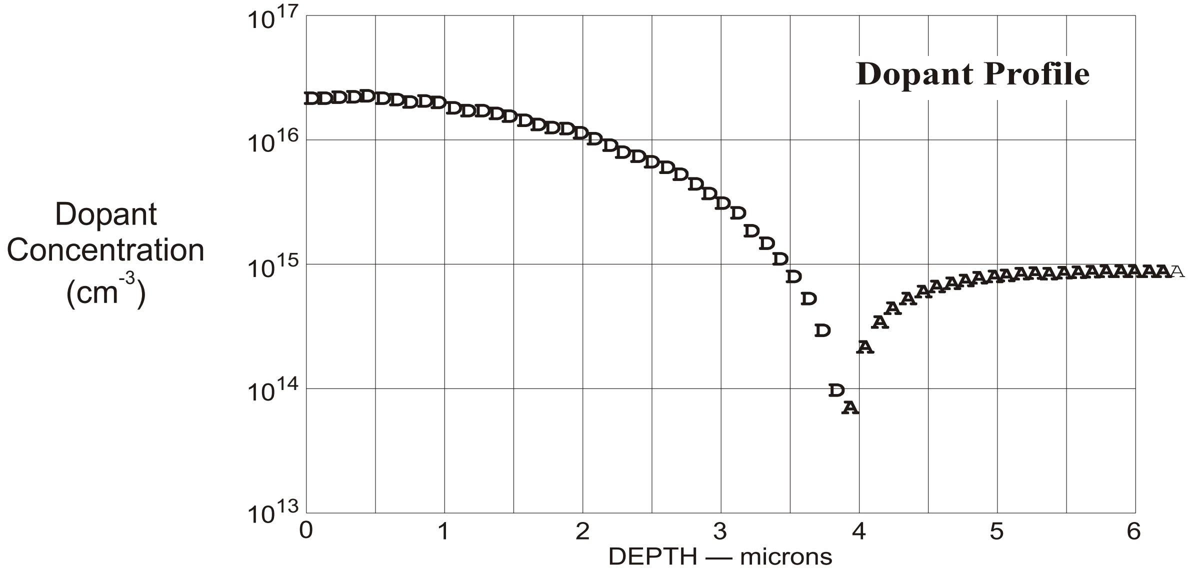
SIMPLE CARRIER CONCENTRATION PROFILES CAN BE CONVERTED TO DOPANT PROFILES USING OUR POISSON SOLVER



Simple Carrier Concentration Profiles Can Easily Be Converted to Dopant Profiles using Our Poisson Solver

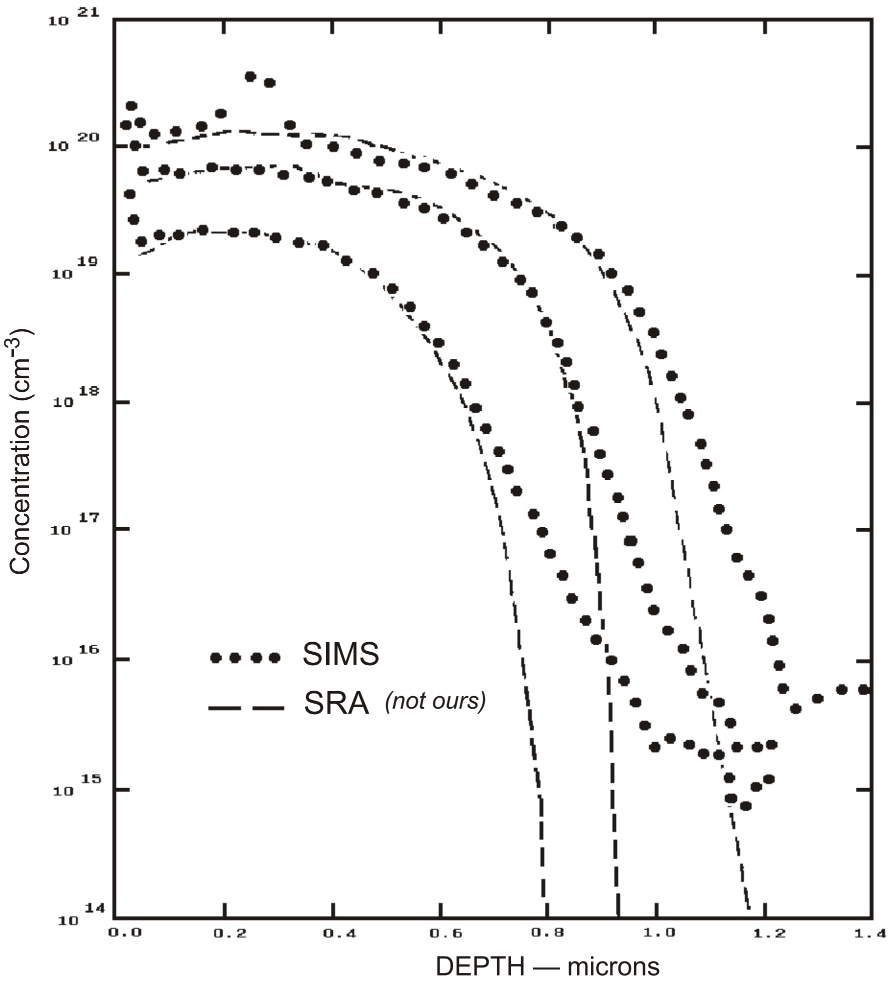


Poisson Solver



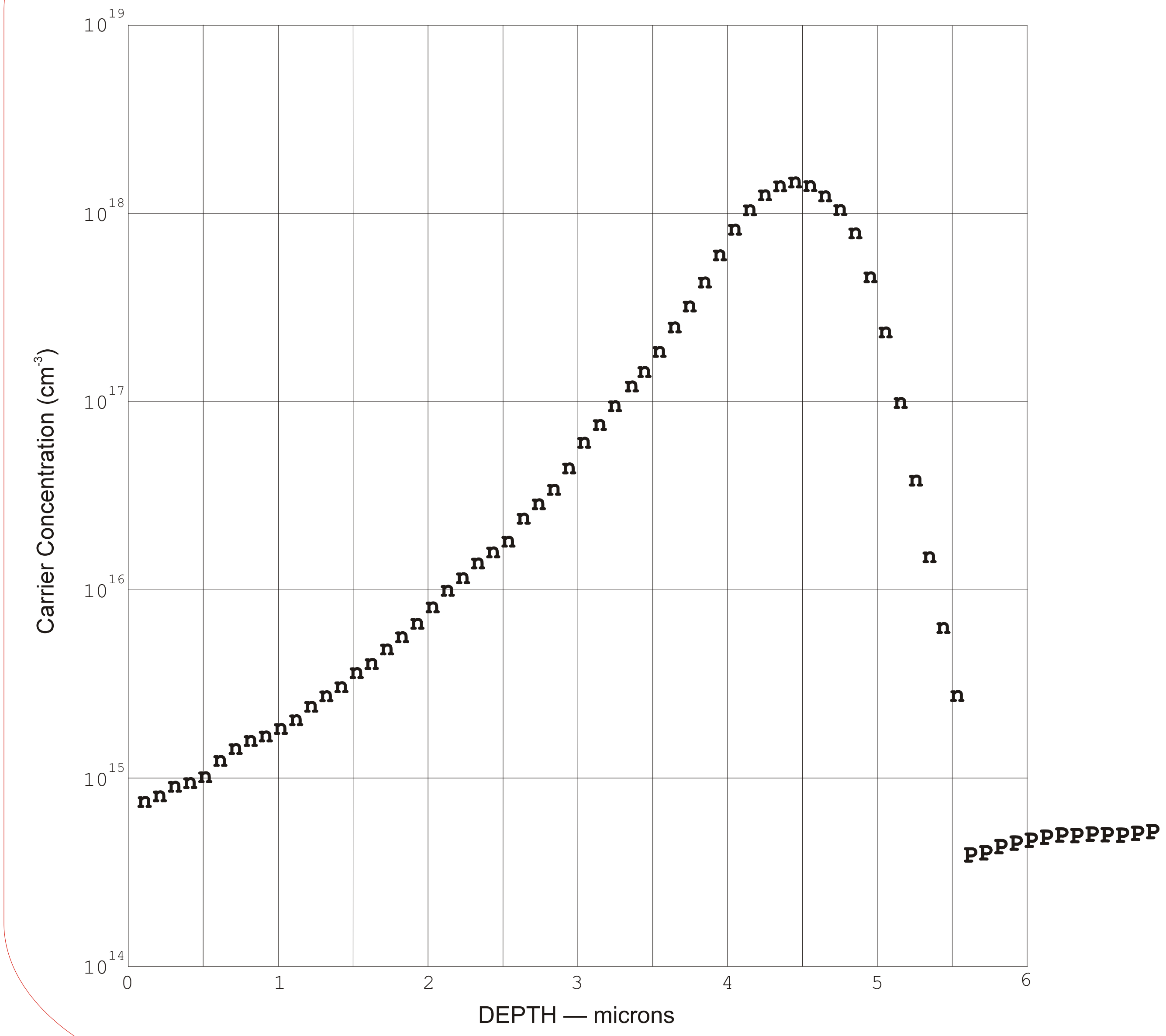
SIMS Typically Reports Greater Depth in the Tail Region of B Diffusions. In the Following Example, Boron was Implanted into Single-crystal Si.

70 keV 1e15, 4e15,1e16 10B into Silicon (circa 1983)



From : James Ehrstein *et al*, ASTM Special Technical Publication **850**, D. C. Gupta, editor, p. 415.

11 MeV Arsenic Implant

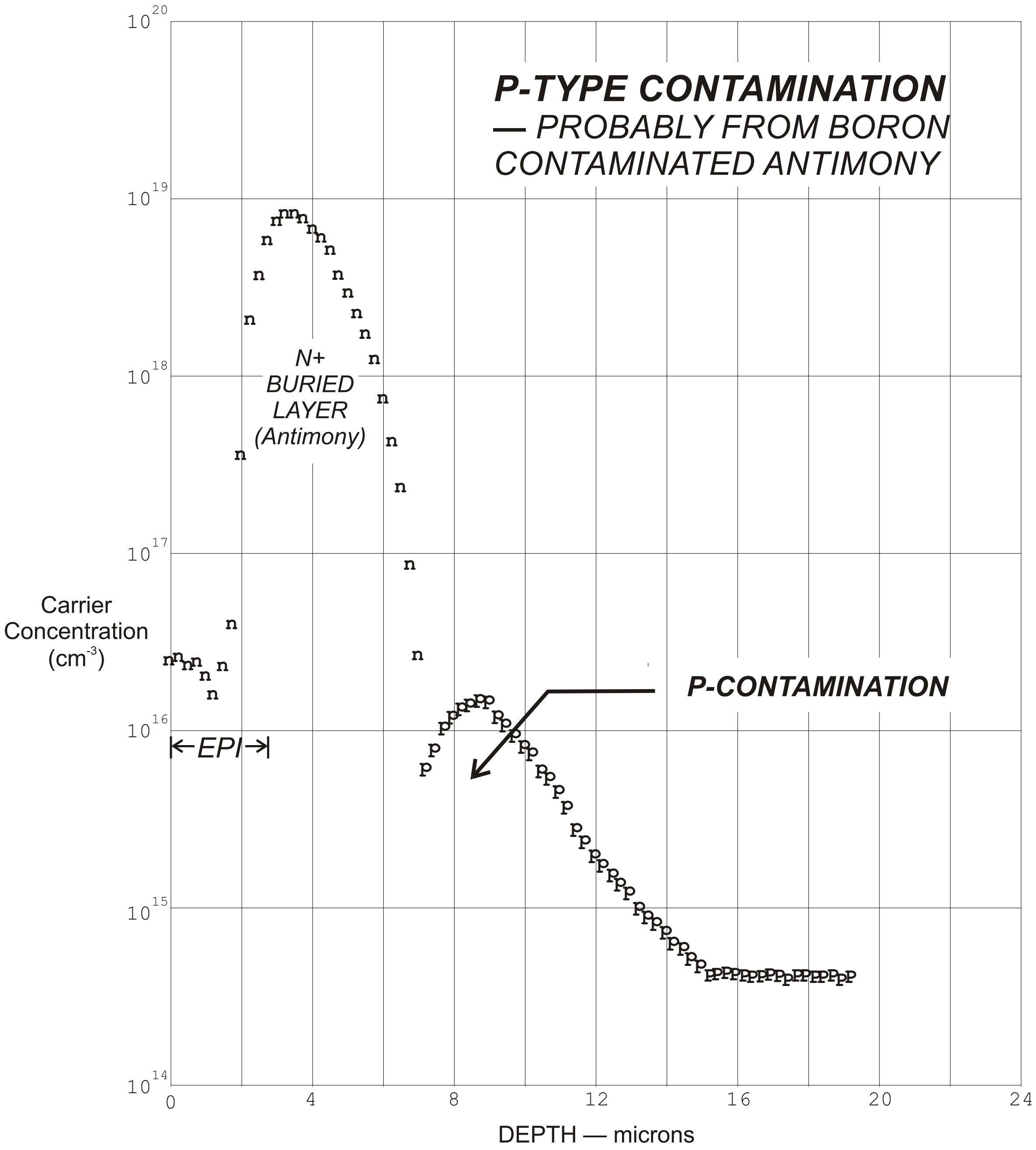


> “The implantations were carried out using the facilities of the Lawrence Berkeley Laboratory. 11 MeV beams were obtained from a dynamatron with a 2.2 megavolt terminal. The ion source is a conducting crystal of gallium arsenide from which arsenic ions in the 5+ charge state were sputtered and extracted into the accelerator column.”

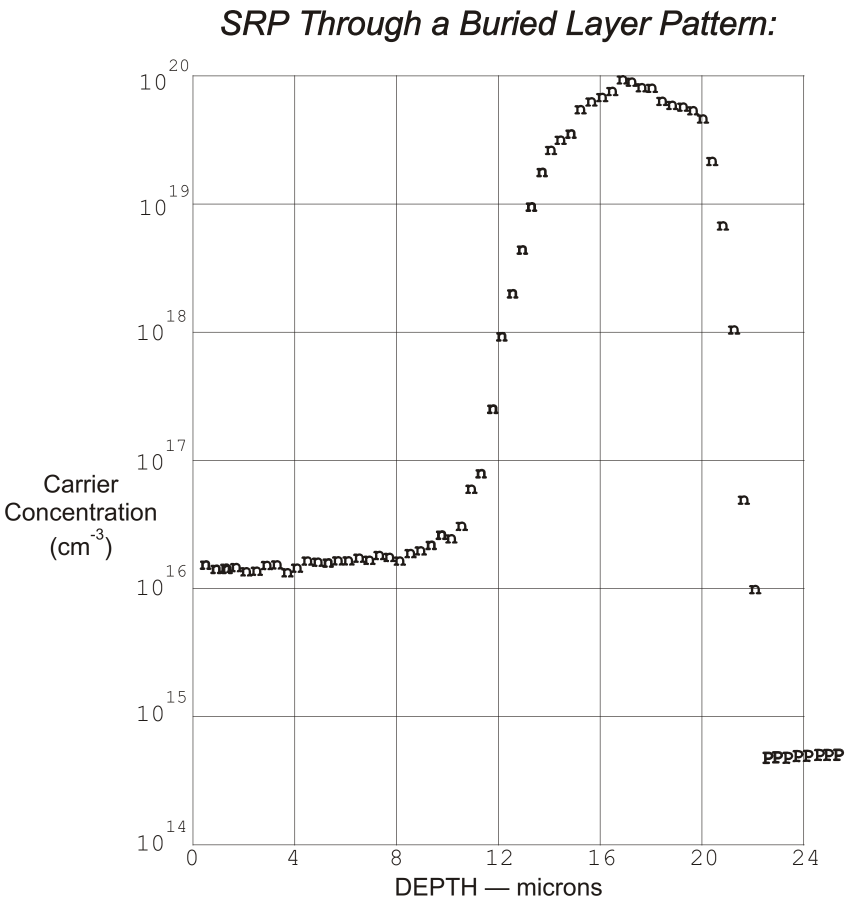
From *Megavolt Arsenic Implantation into Silicon,* a paper presented at the 1982 International Conference on Metallurgical Coatings and Process Technology by P.F. Byrne, N. W. Cheung, and D.K. Sadana, University of California, Berkeley.

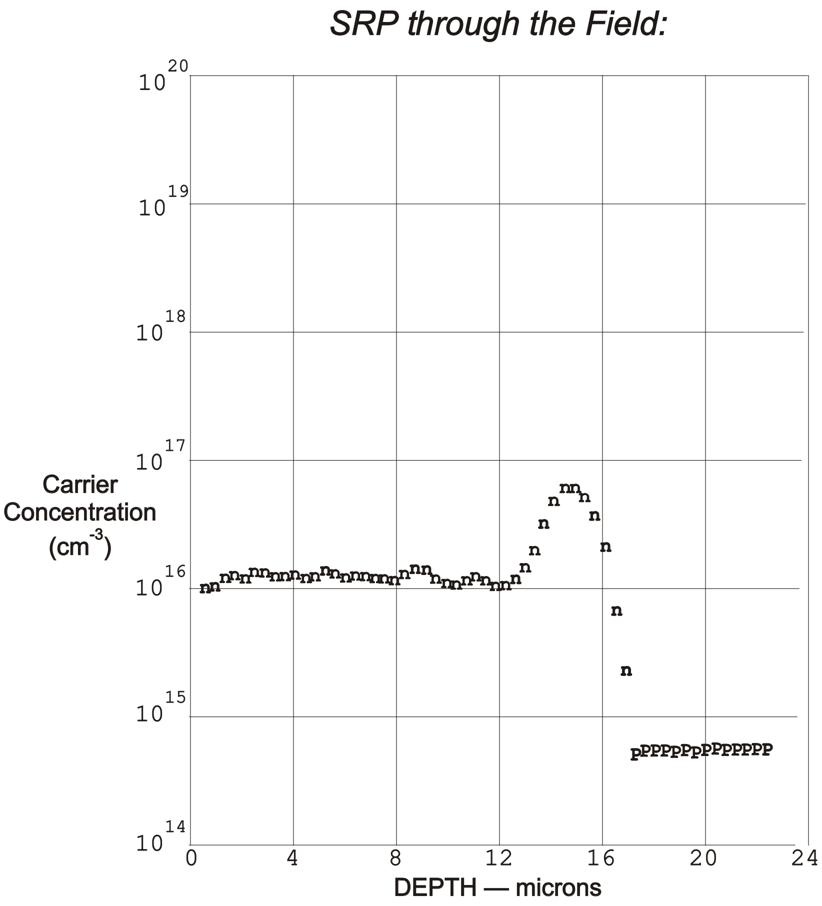
Many thanks to Peter Byrne for permission to reproduce and disseminate this very impressive profile.

P-TYPE CONTAMINATION
— PROBABLY FROM BORON CONTAMINATED ANTIMONY

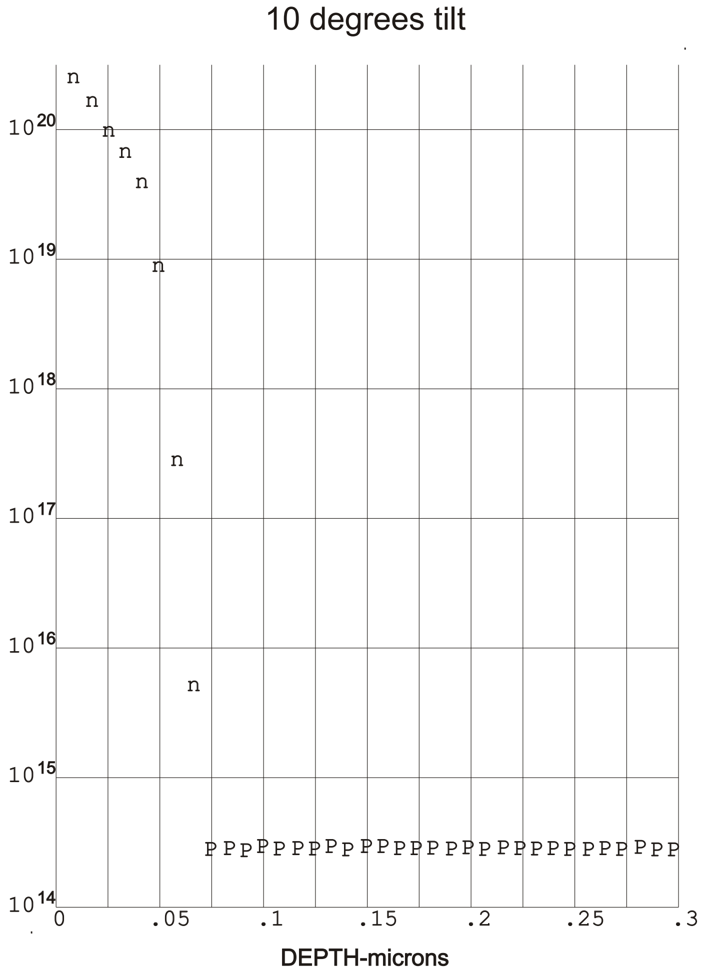


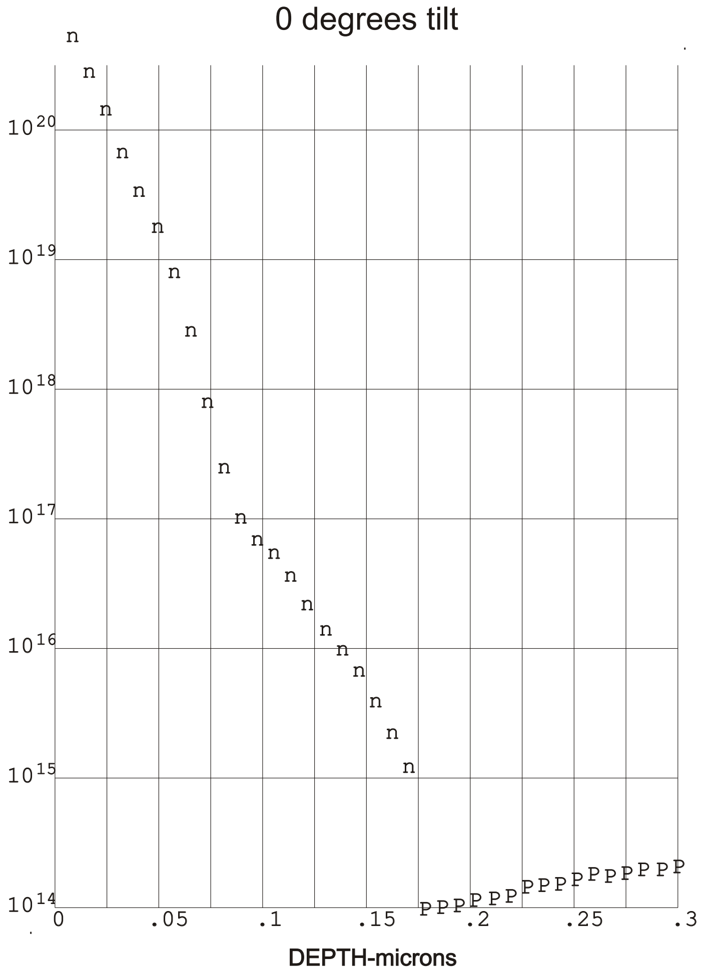
Arsenic Autodoping During Epitaxial Deposition





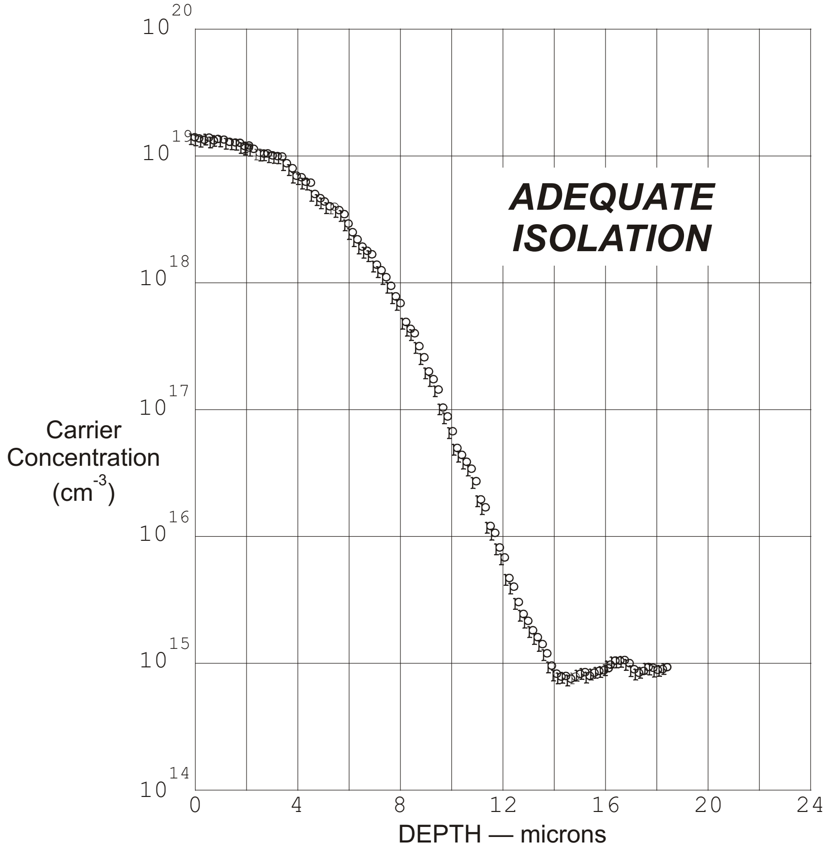
Ion Implant Channeling



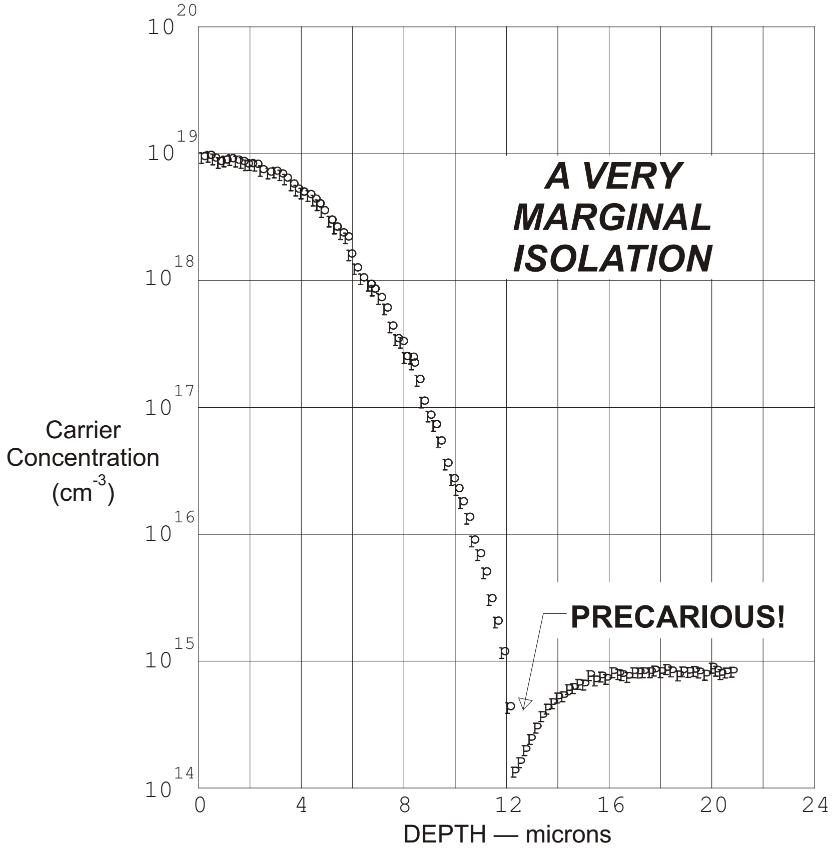


P+ Isolation Diffusion into N-Epi

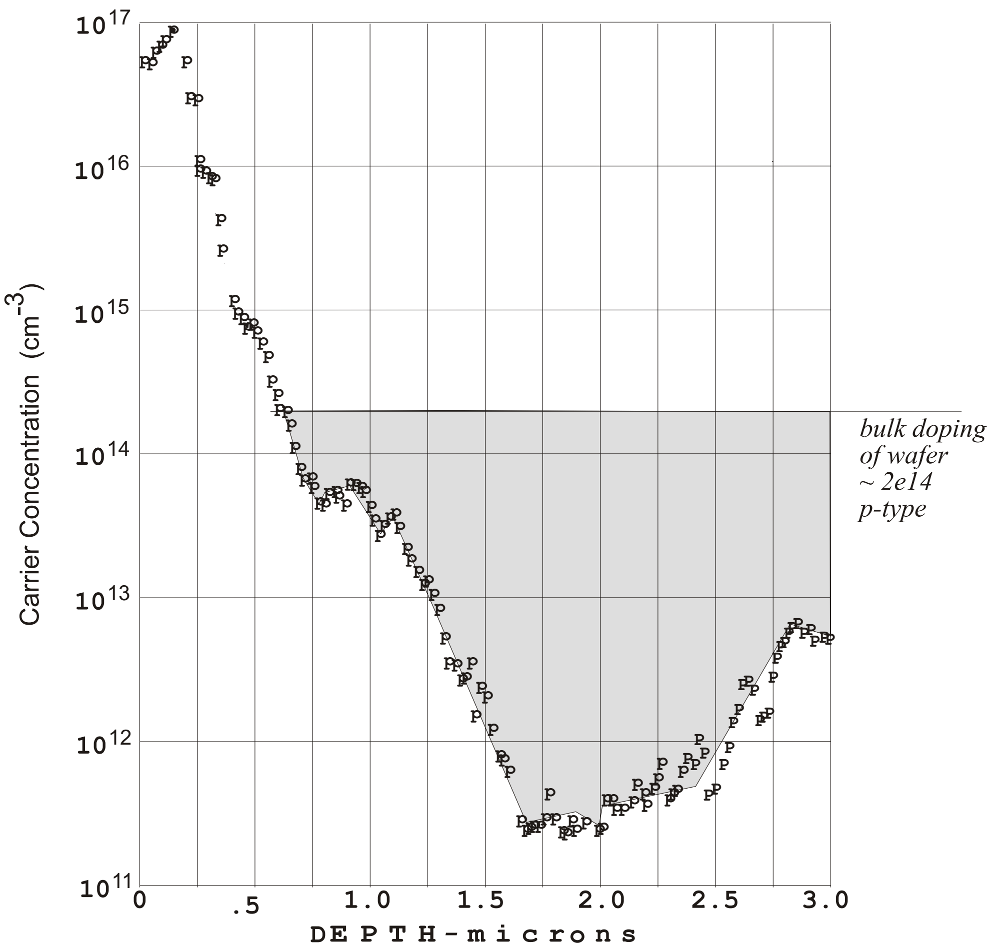
Wafer A



Wafer B

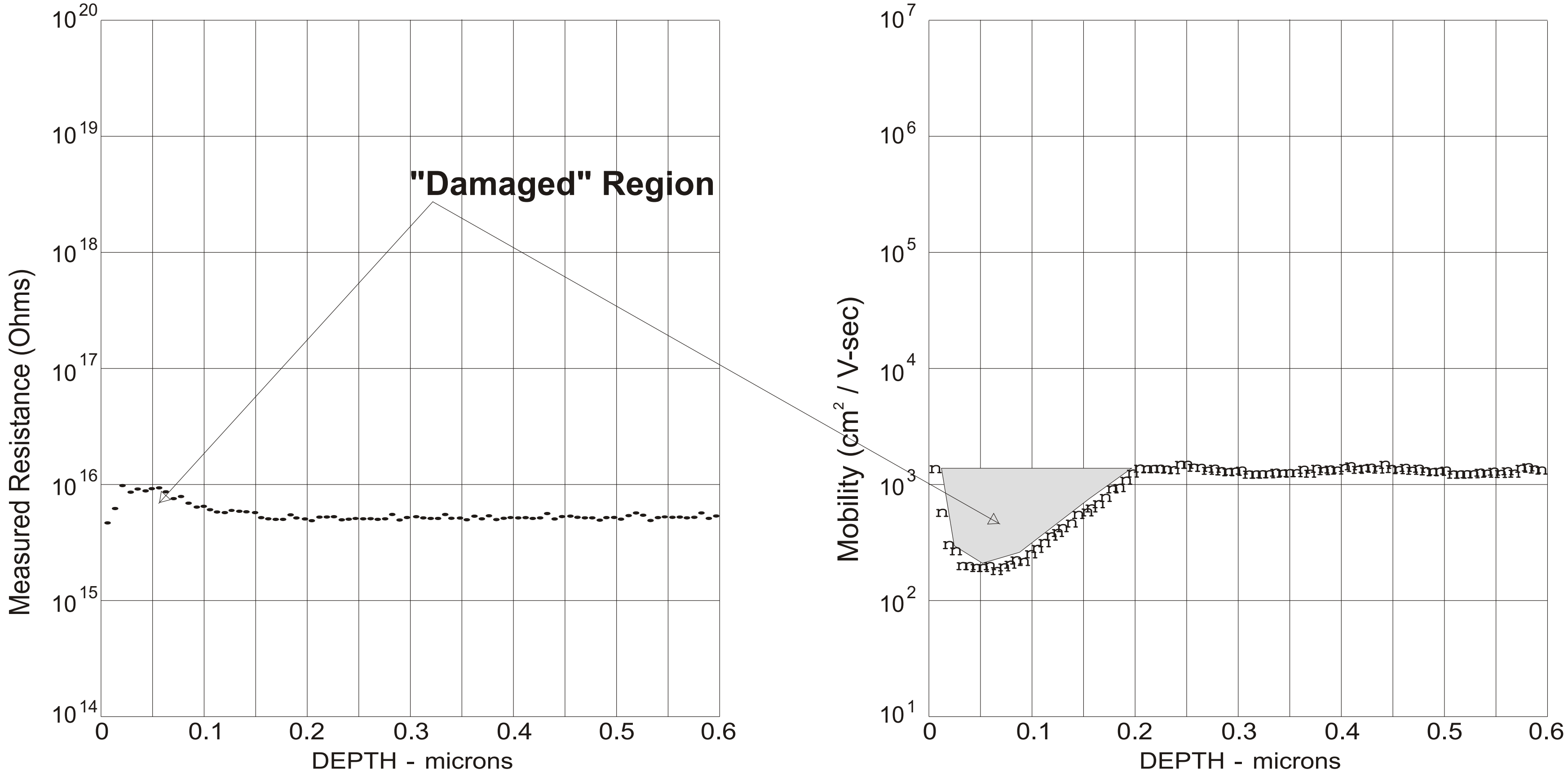


Thermal Donors — A Severe Case



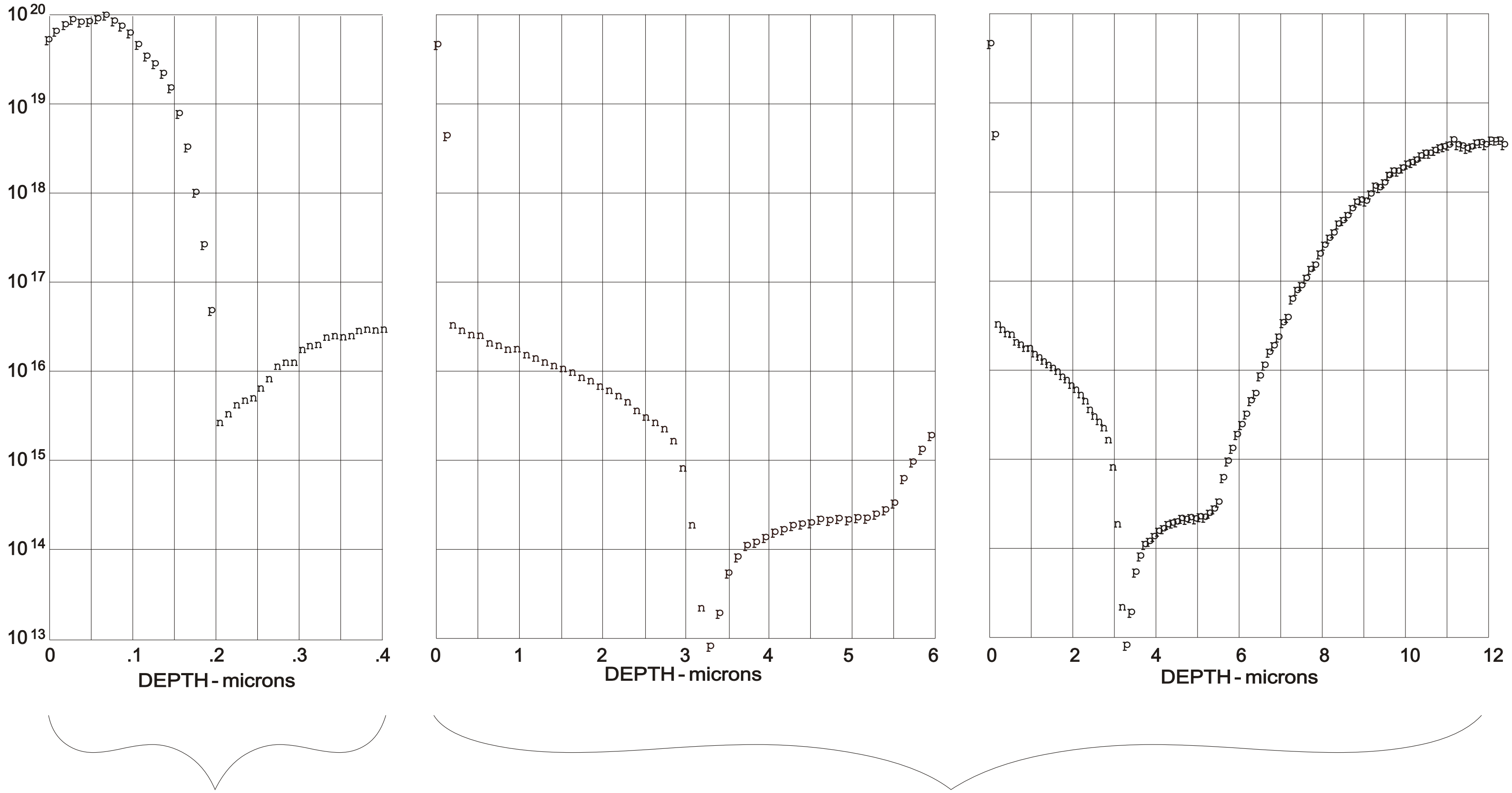
Unannealed Implant

N-type implant into 1e16 cm^{-3} N-type background. Since the implant wasn't activated, SRA senses the mobility change in the damaged area.



"Damaged" Region

CMOS (P-channel Source-Drain)



Shallow Profile to
Characterize the Source-Drain

Steeper Profile (Plotted on 2 Depth Scales)
to Characterize the
N-Well, Epi, and Substrate

Factors influencing SRP measurements (X$_j$, Shape, Carrier Concentration)

1) **Bevel edge: Clear edge is required to identify fringes from different films near the active area, starting points and footprints. We use high quality optical microscope with dark field illumination to identify this**

2) **Bevel angle: Bevel angle multiplied by step increments influence the depth. Can influence shape, X$_j$, Base width measurements, etc. particularly in shallow SRPs**

3) **Step increments**

4) **Location of interest: Falling out of pattern and probing adjacent structures can lead to distorted profiles**

5) **Probe tip condition: Probe penetration, Calibration, Data Smoothing: While smoothing data, it is necessary to follow data trends, visually examine and suppress concavity or convexity and not allow data to follow random noise by choosing best fits and appropriate correction factors**

Common Structures of Interest For SRA

CMOS STRUCTURES

- Epi/Substrate
- P-Well/Epi
- N-Well/Epi
- Poly/Gate Ox/Epi
- Poly/Gate Ox/N-Channel
- Poly/Gate Ox/P-Channel
- P+/Epi
- P+/NWell
- N+/Epi
- N+/PWell
- NLDD
- PLDD
- Under field Ox with implant
- Under field Ox without implant

BIPOLAR STRUCTURES

- Epi/Substrate
- Epi/Buried Layer/Substrate
- Base/Epi
- Base/Epi/Buried layer/Sub
- Base/Isolation/Epi/Sub
- Emitter/Base/Epi
- Emitter/Base/Epi/Buried layer
- Sinker/Epi/Sub
- Sinker/Epi/Buried layer
- Isolation/Epi/Sub

QA Checklist

1. Was the profile run in the location specified by the requester?
2. Were the final profiles shown to lab supervisor?
3. Are the profiles plotted with correct crystal orientation?
4. Was the customer contacted for information regarding orientation or a break test done?
5. Are the step increments optimal?
6. Do the job numbers match those of customer copy?
7. Do the sample numbers match those of customer copy?
8. Are there different profiles for the same file numbers and sample numbers?
9. Are the file numbers matching with customer copy?
10. Was Calibration Check done for epi samples?
11. Are the correction factors, smoothing factors optimal?
12. Was hot probe done on all samples where this was necessary? Hot probes wires not reversed?
13. Do scalings (y axis) match so customer can overlay with reference jobs and supreme 4?
14. Has frsp been tried for p to p+ and n to n+ layers and for dips at epi to n+ junctions?
15. Were the bevel angle scales chosen on the full axis according to information posted at profilometer?
16. Was there a close correlation between the 4 point probe and SRA data sheet rho on bare silicon/test samples?
17. Check customer satisfaction to see if profiles are in line with his expectations.

Quality Systems In Line With ISO 9001/17025

- **Management responsibility**
- **Quality manual**
- **Business planning**
- **Contract review**
- **Written procedures on critical operations**
- **Purchasing**
- **Control of customer supplied samples**
- **Sample identification and traceability via job tracking system**
- **Statistical techniques**
- **Measurement and inspections**
- **Control of measurement and test equipment**
- **Control of non conforming profiles**
- **Corrective and preventive actions**
- **ESD control**
- **Internal and external quality control audits**
- **Control of quality records**
- **Customer training records**
- **Shipping of profiles**
- **Customer satisfaction records**
- **Inter lab comparisons, round robin records**

Why Solecon Labs and SRA

1. Over 25 years of experience and continuous improvement in the art and science of beveling and probing with best known method on profiling carrier concentration.
2. High spatial resolution of dopant and depth profiles.
3. Low cost operation and high return on investment for customers, easily affordable.
4. Turnover within 24 hours available.
5. Fast and accurate feedback to fab and foundries.
6. Over 300 satisfied customers.
7. Both SRA and process expertise available at Solecon Labs.
8. Edge over competitors as far as reproducibility goes.