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

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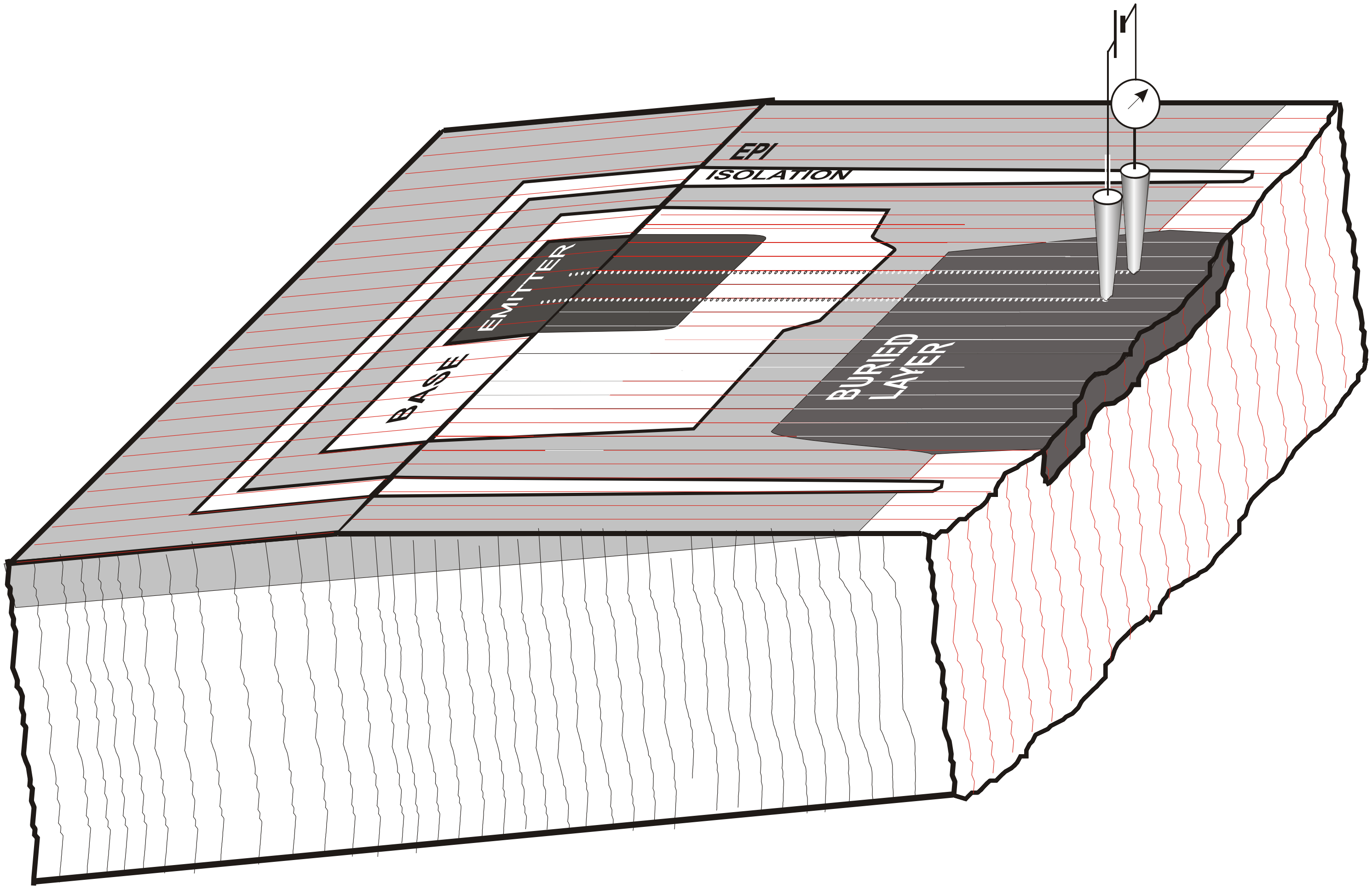
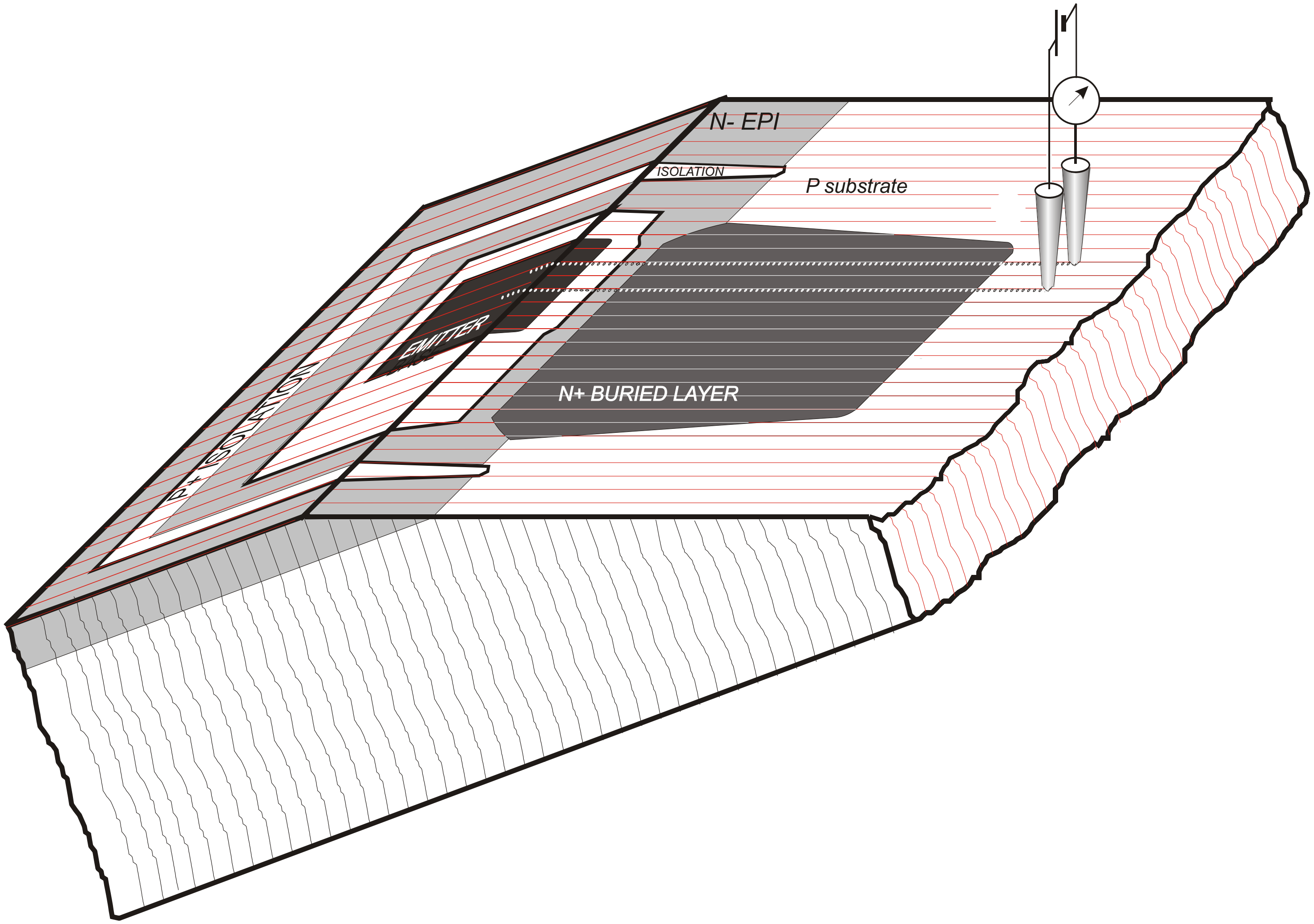
Filling out our request form:

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?

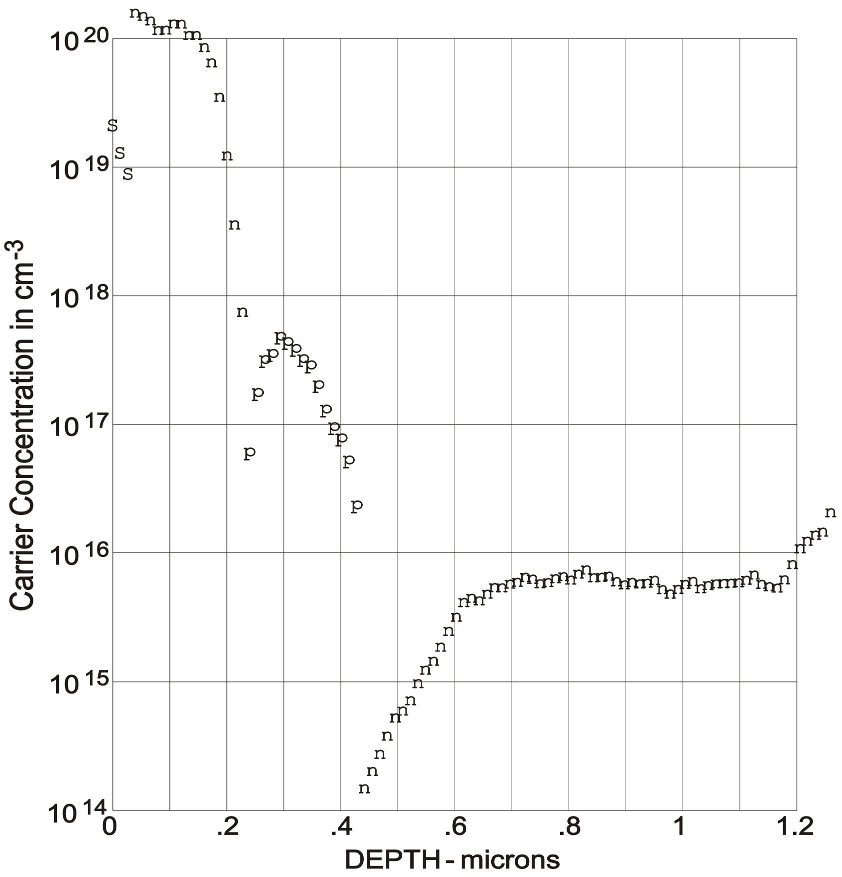
Shallow Profile of the Bipolar Structure

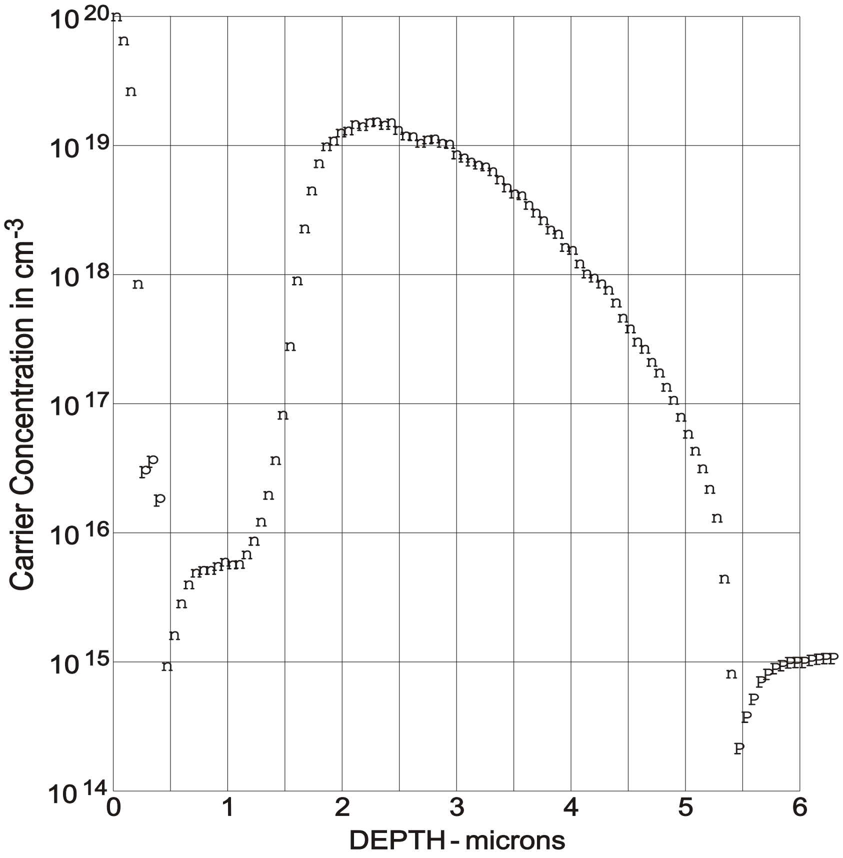


Deep Profile of the Bipolar Structure



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.

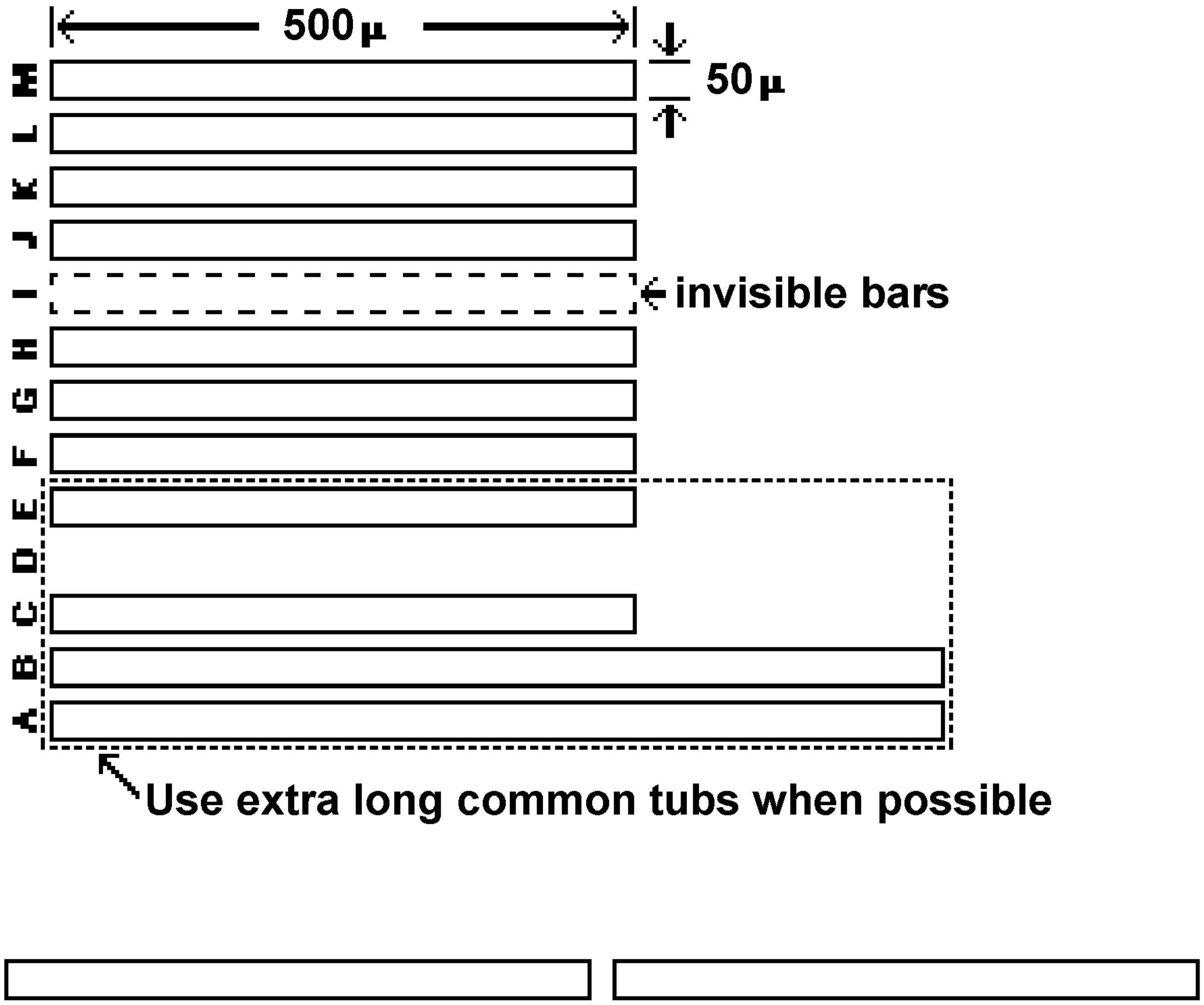
Size of pattern:

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

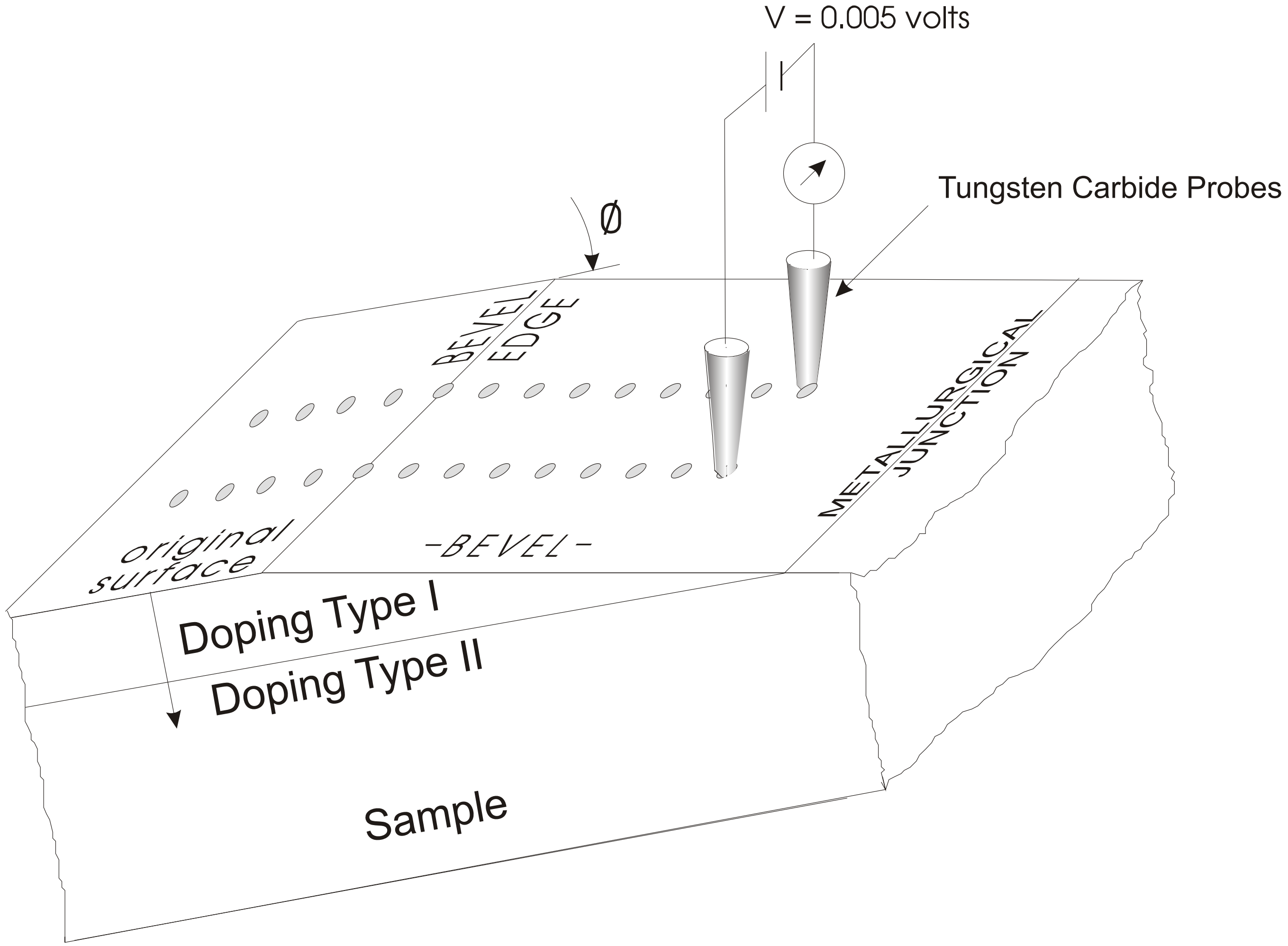


invisible bars

Use extra long common tubs when possible

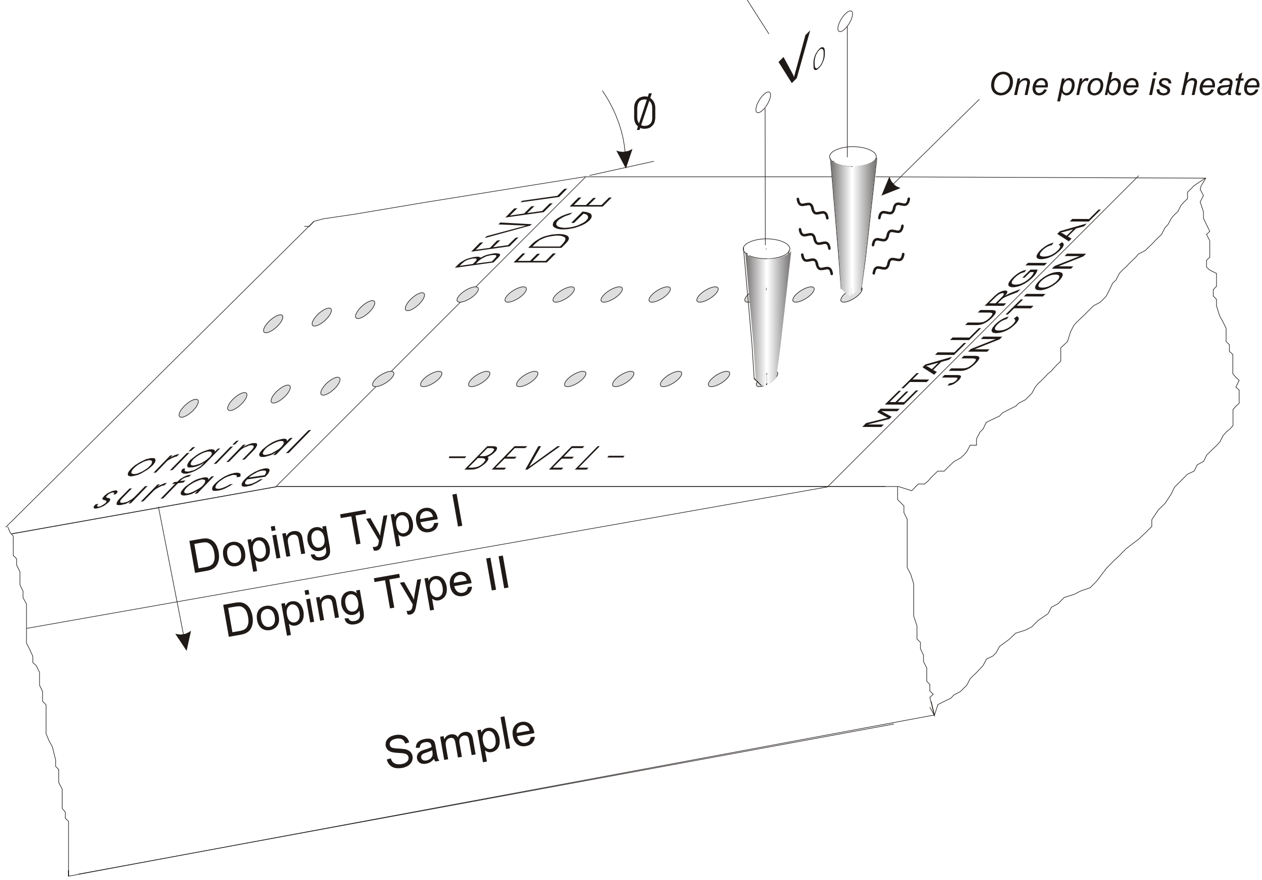
Recommended for Scribeline use Only

Schematic diagram of a spreading resistance measurement on a beveled sample



Carrier Type Determination

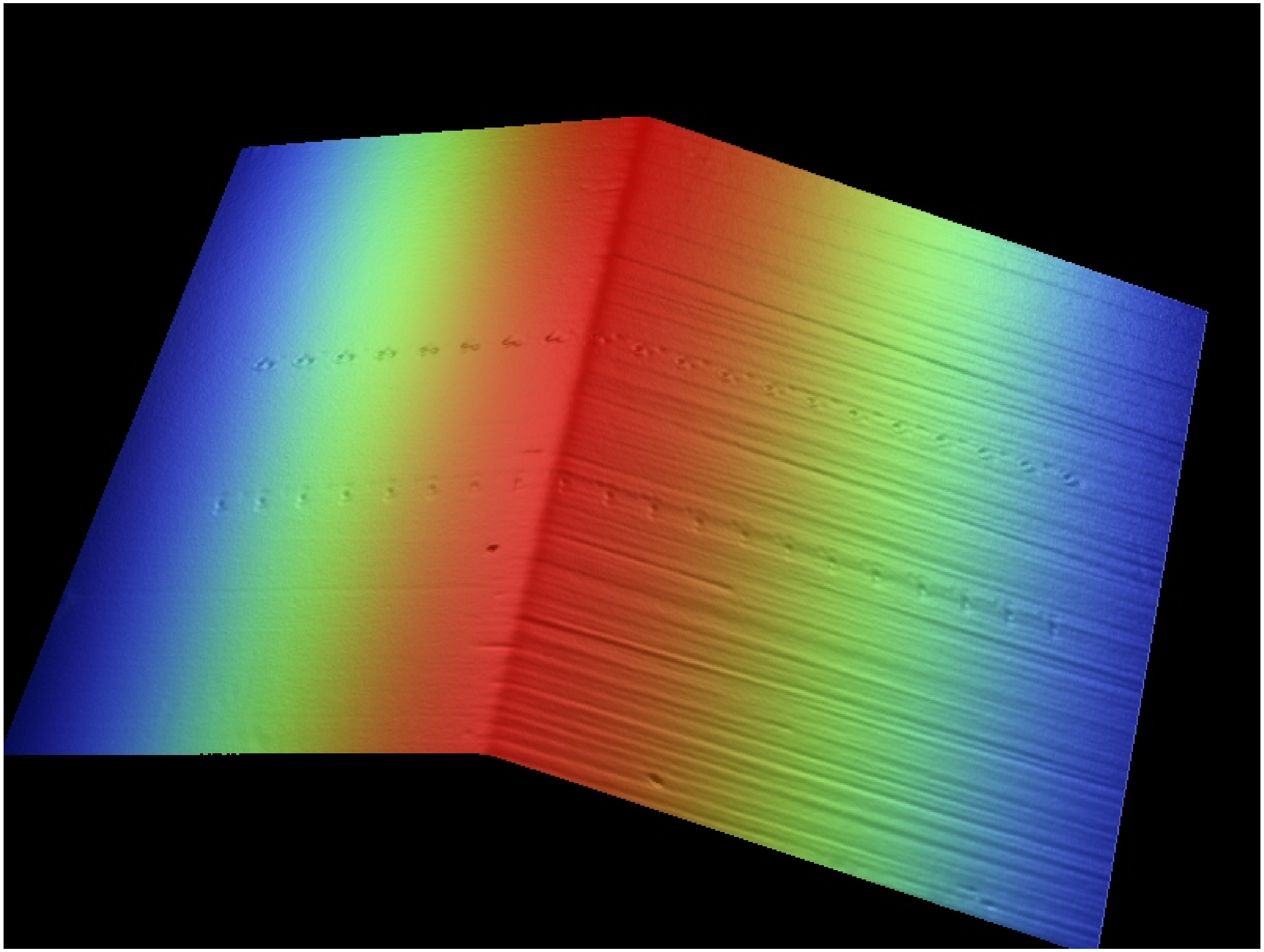
With a Few Modifications, the Spreading Resistance Set-Up Can Determine “N” or “P”.



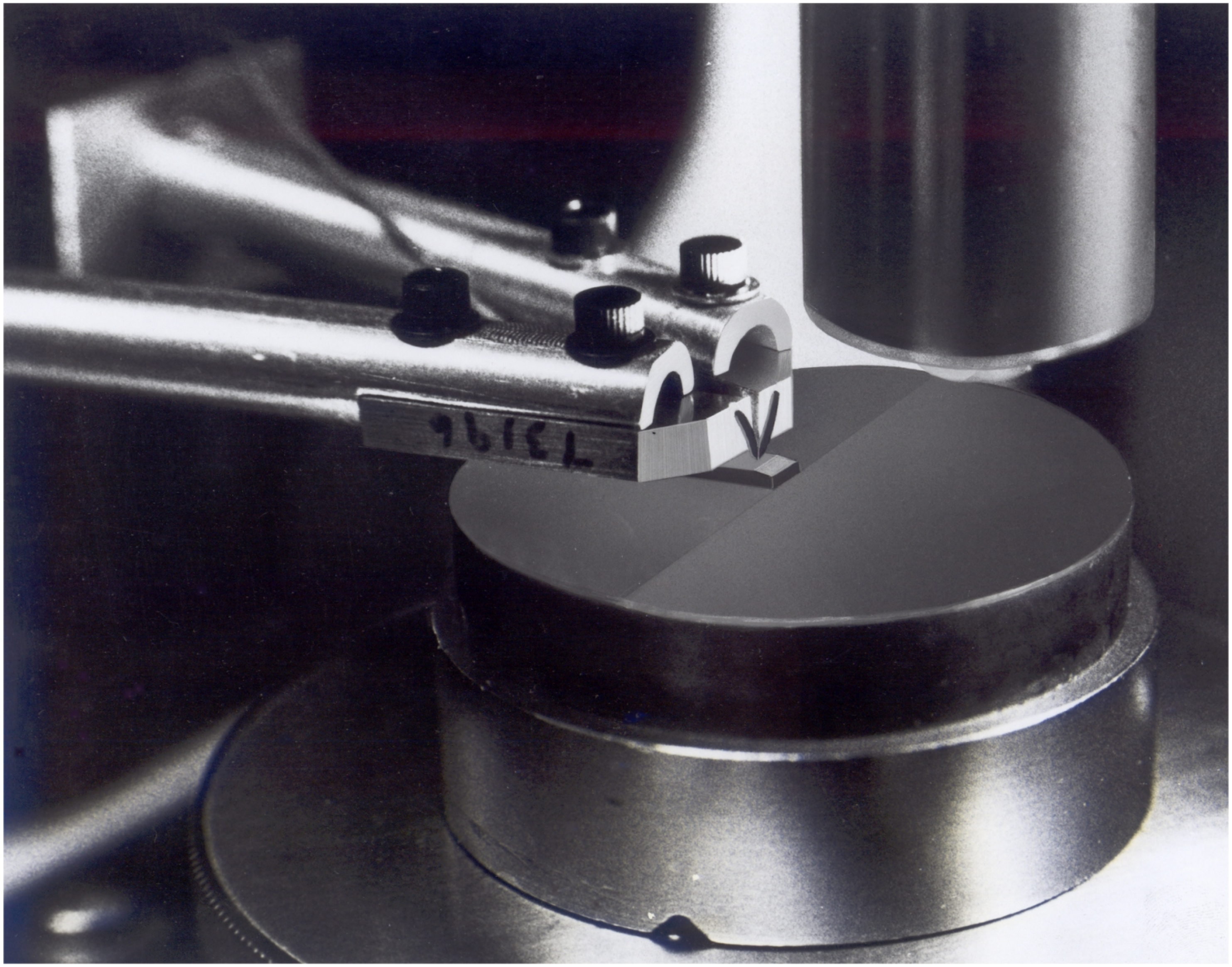
Polarity and magnitude of the open circuit (Seebeck) voltage determined

One probe is heated.

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



Birds Eye View of SRA Sample and Probes

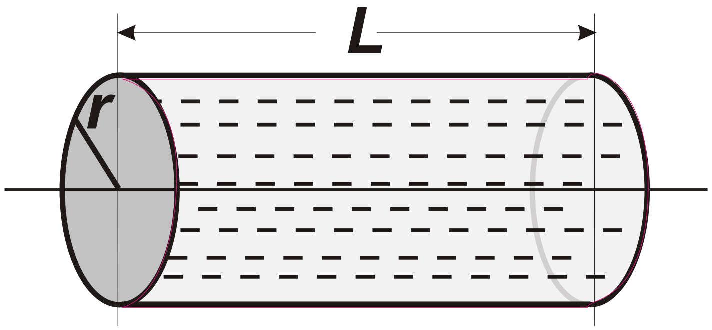


Probing

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

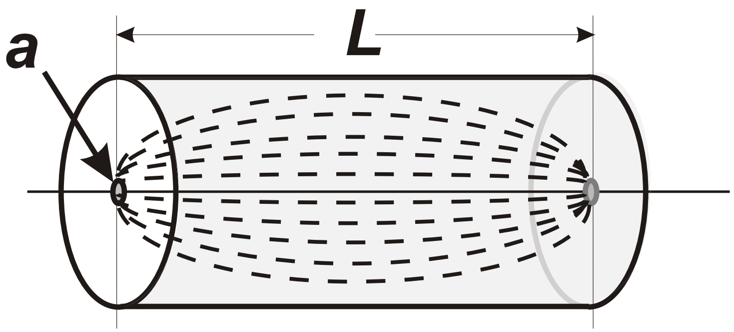
$$R = \frac{L}{r^2}$$



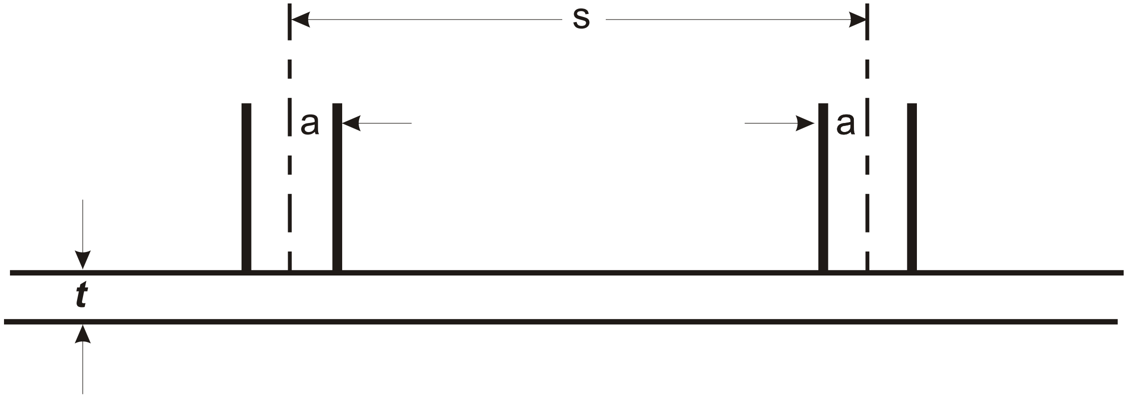
where is the bulk resistivity in ohm-cm

SPREADING RESISTANCE

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



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



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

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.

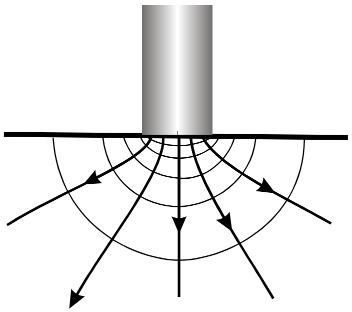
$$N \quad n \quad \frac{1}{q \quad _{e}}$$

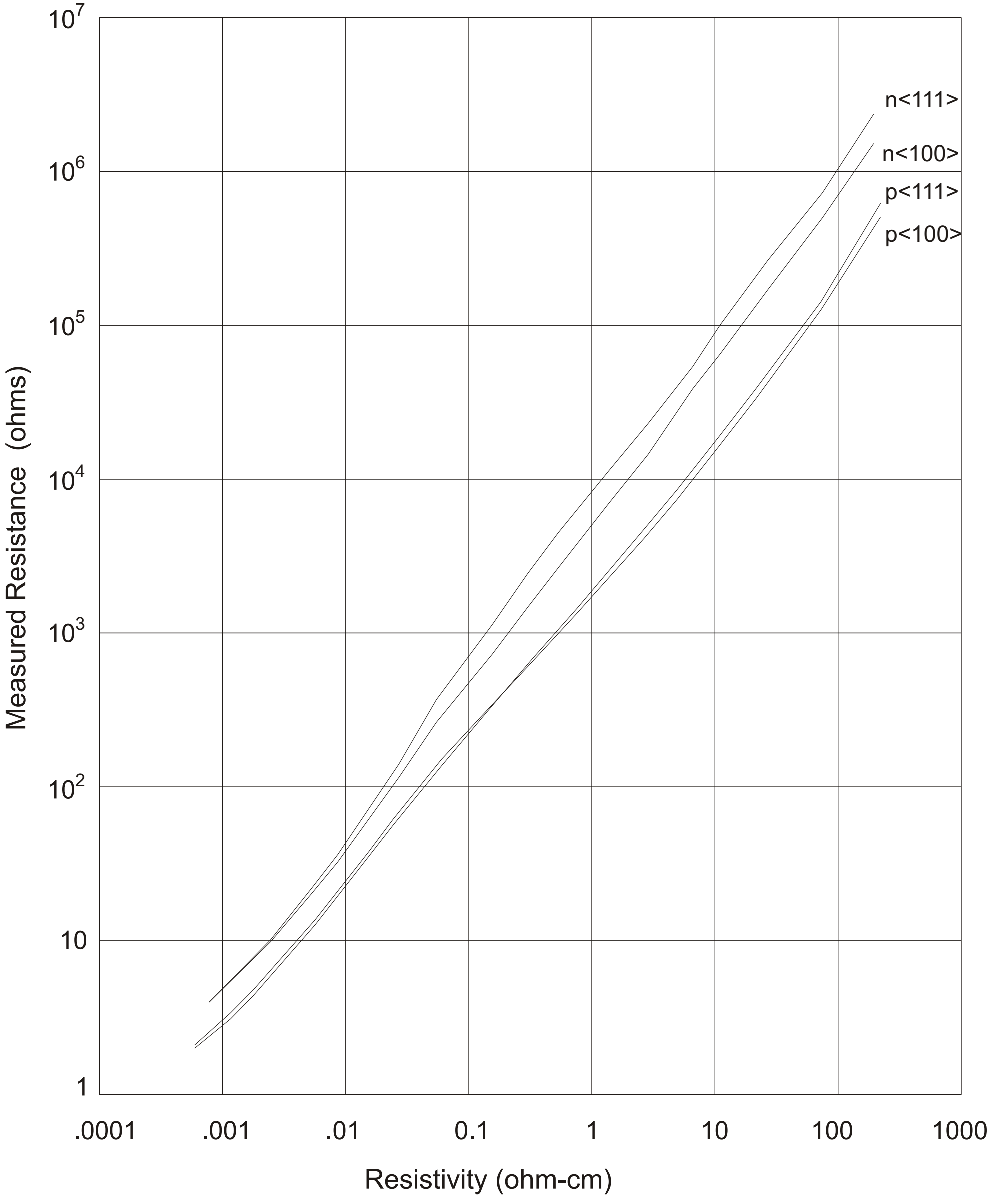
Calibration Chart

Spreading Resistance

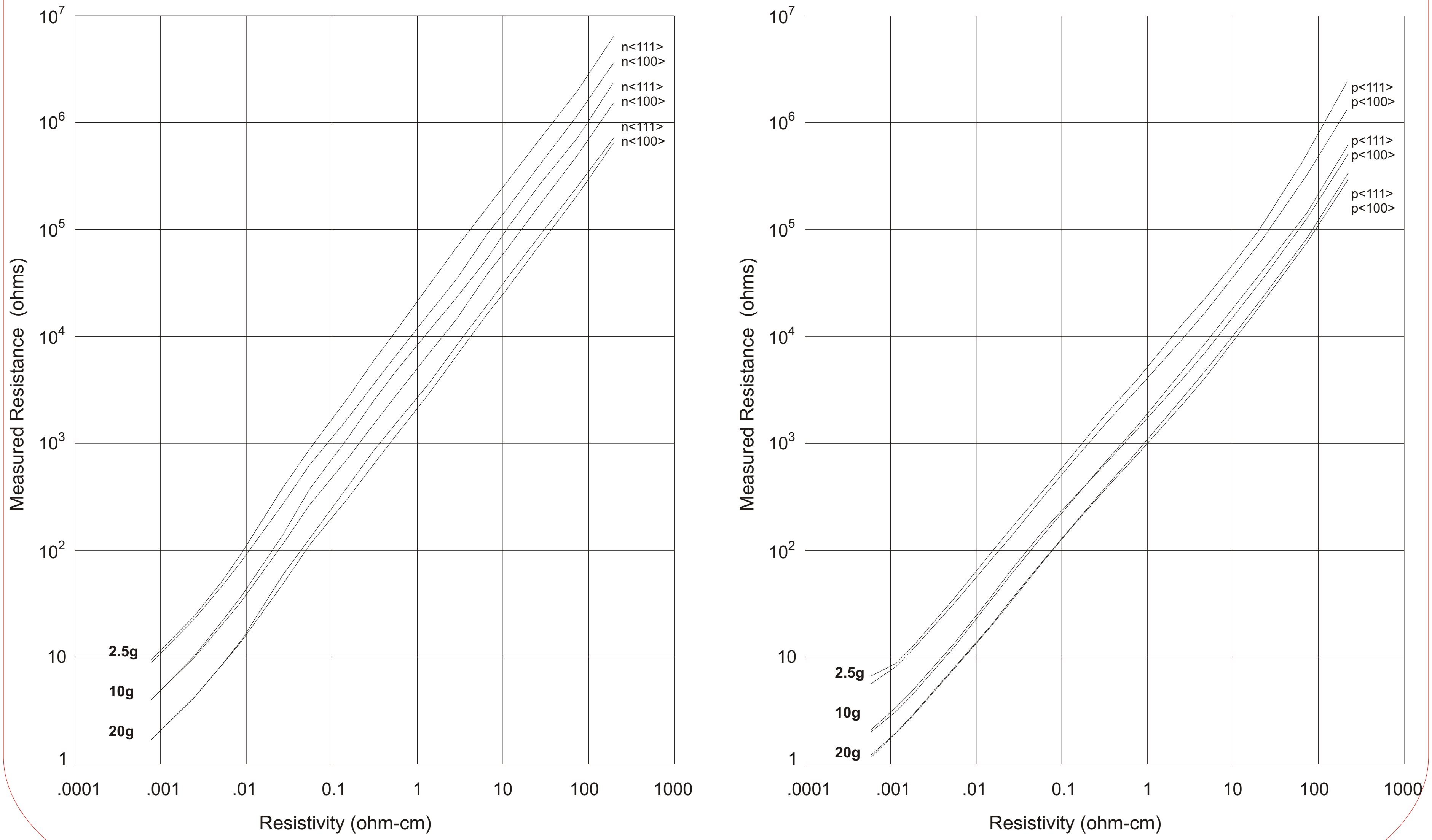
vs. Resistivity

(NIST Traceable Si Bulk Standards)



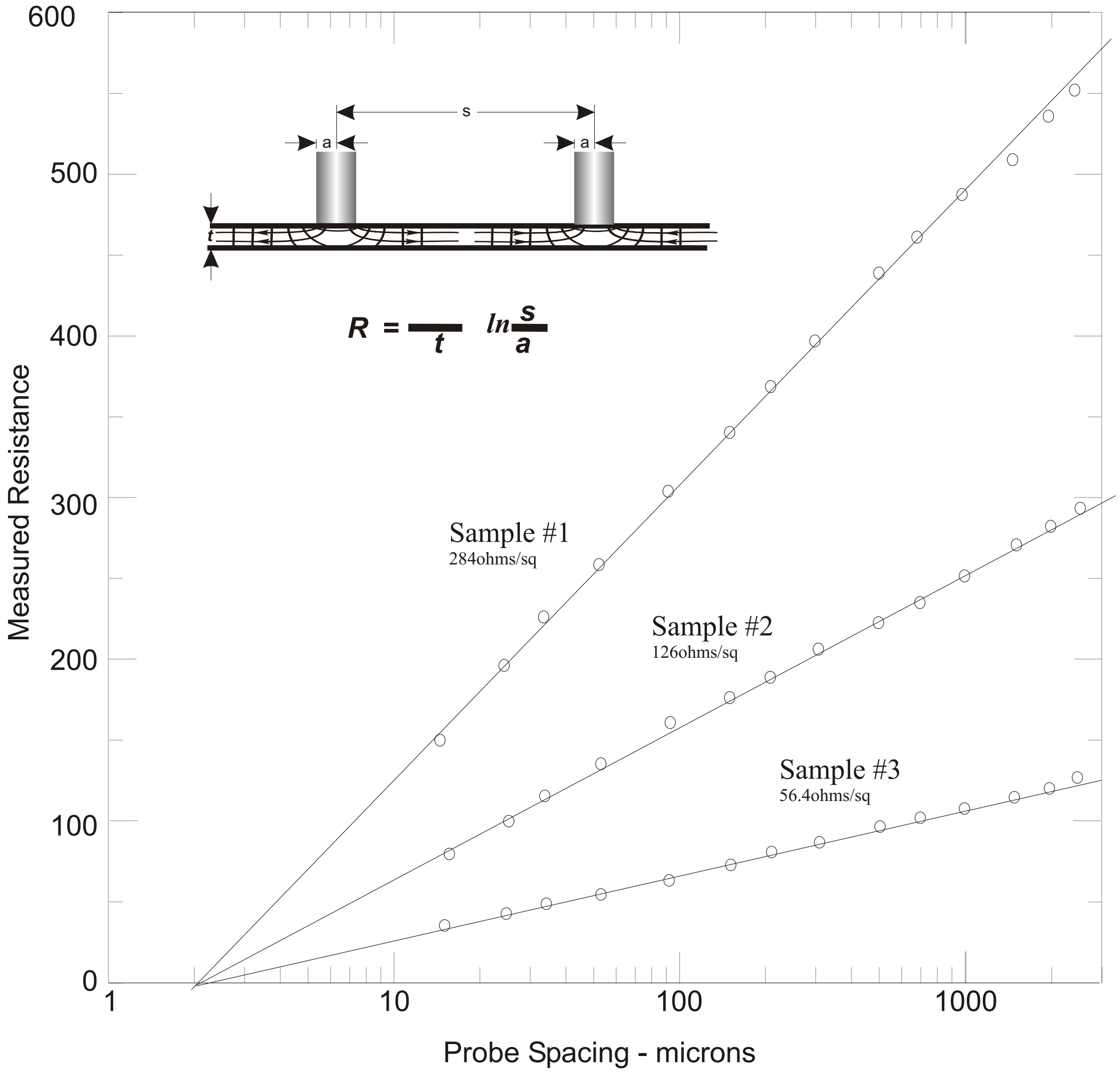


Calibration Data for Three Probe Loads



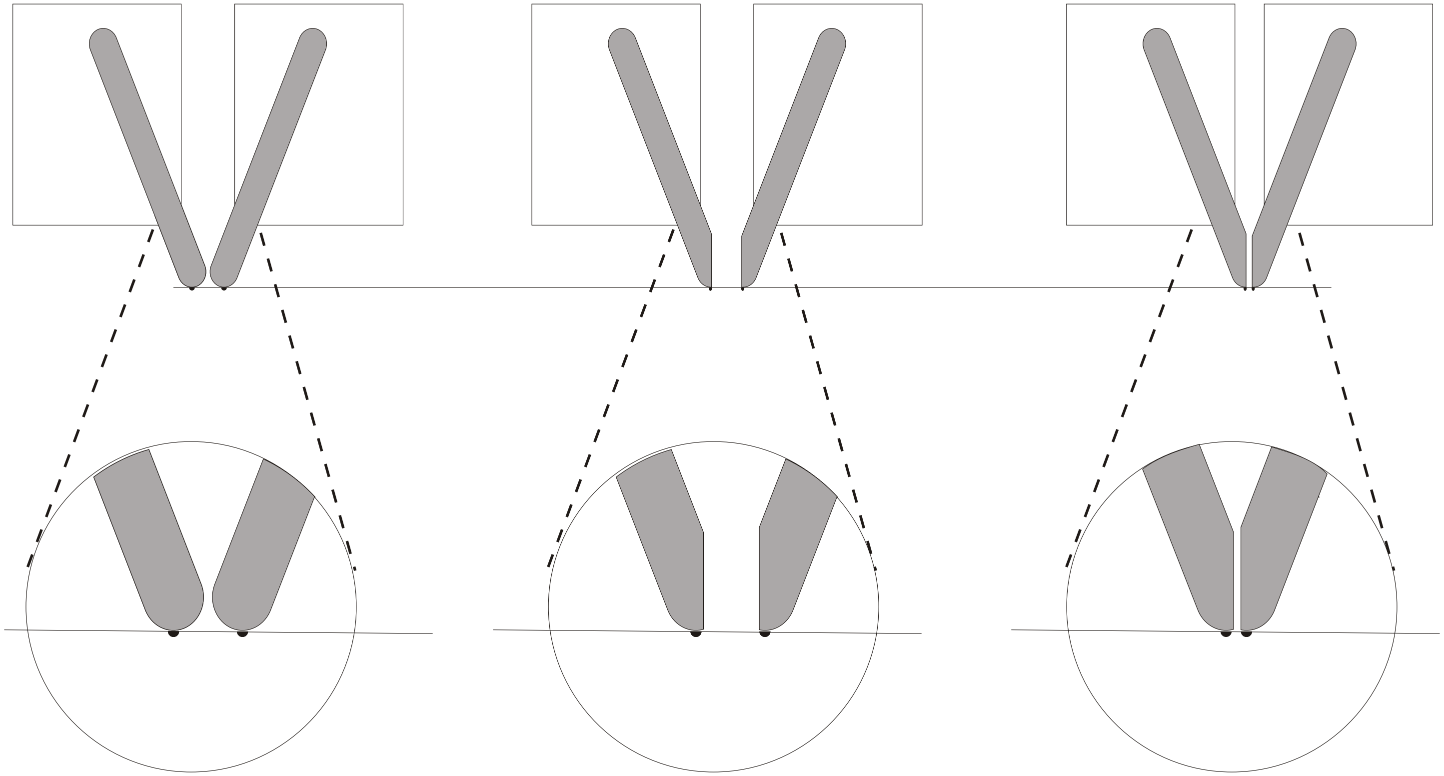
Probe Spacing Experiment on Relatively Thin Layers

(Measured resistance is dominated by the lateral current flow)

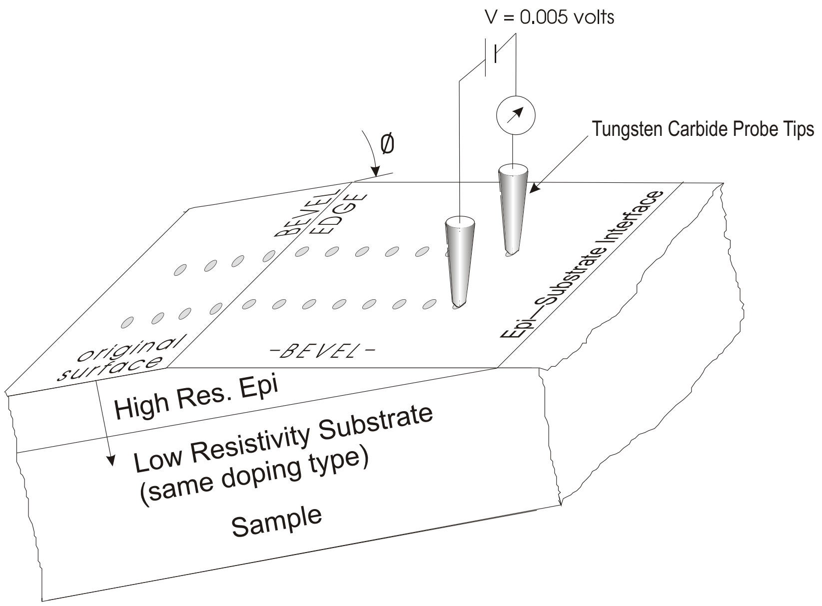


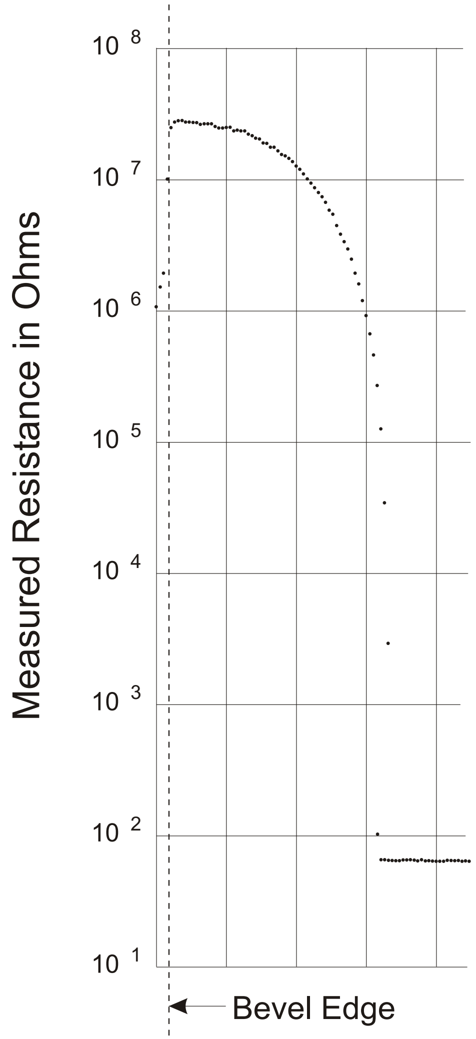
After: Dickey, **NBS SP 400-48 p16**

Simple diagram showing probe shaping to minimize probe separation



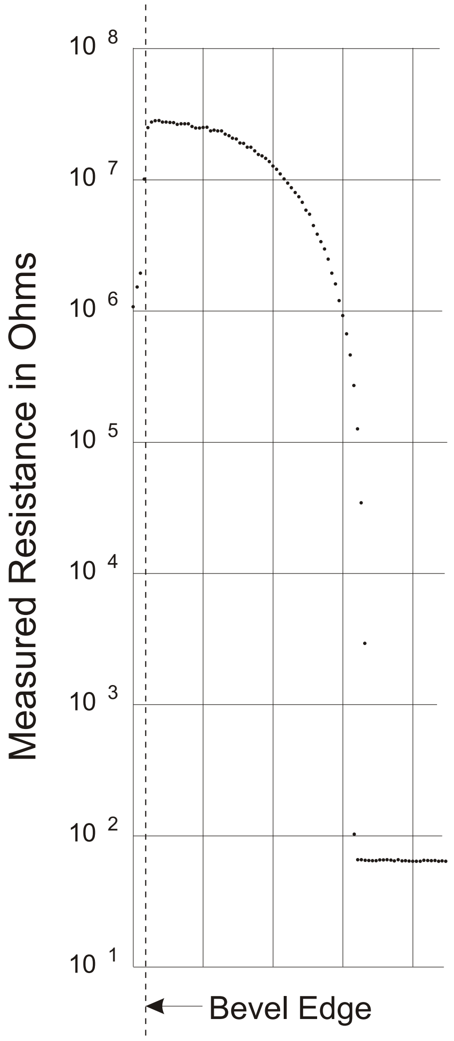
High Resisitivity Epi



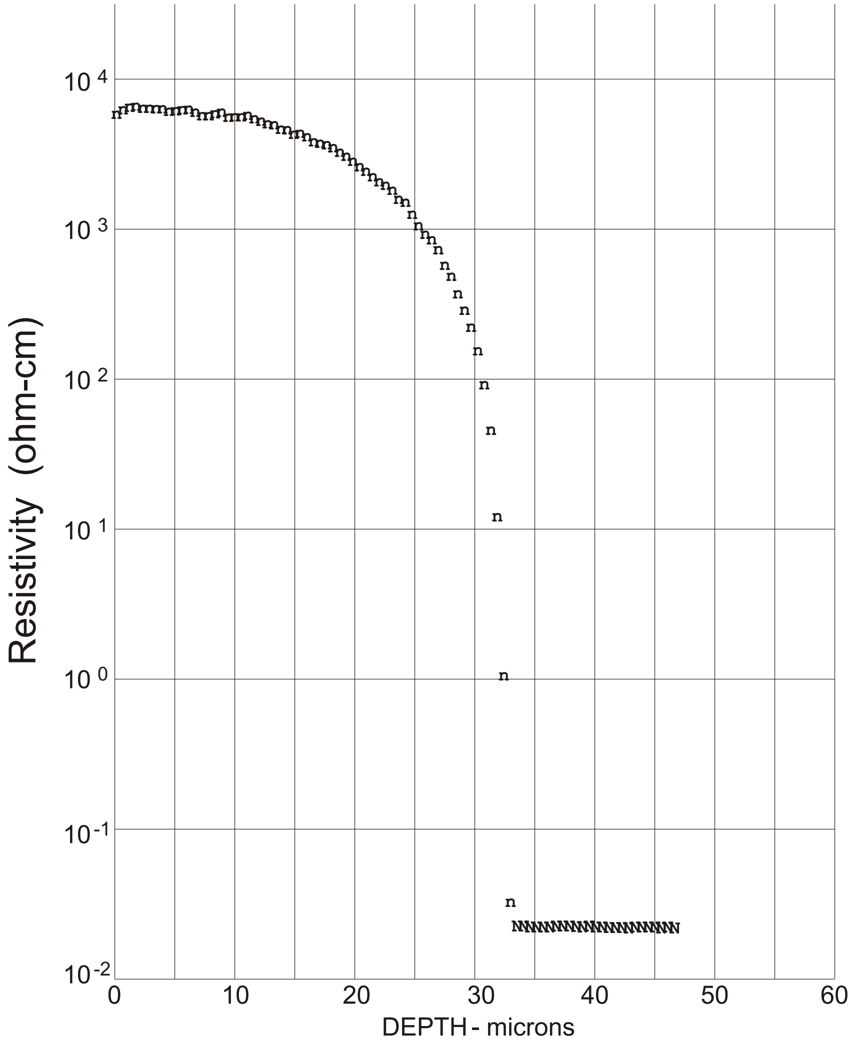


Probing → “Raw Data”

High Resisitivity Epi (continued)

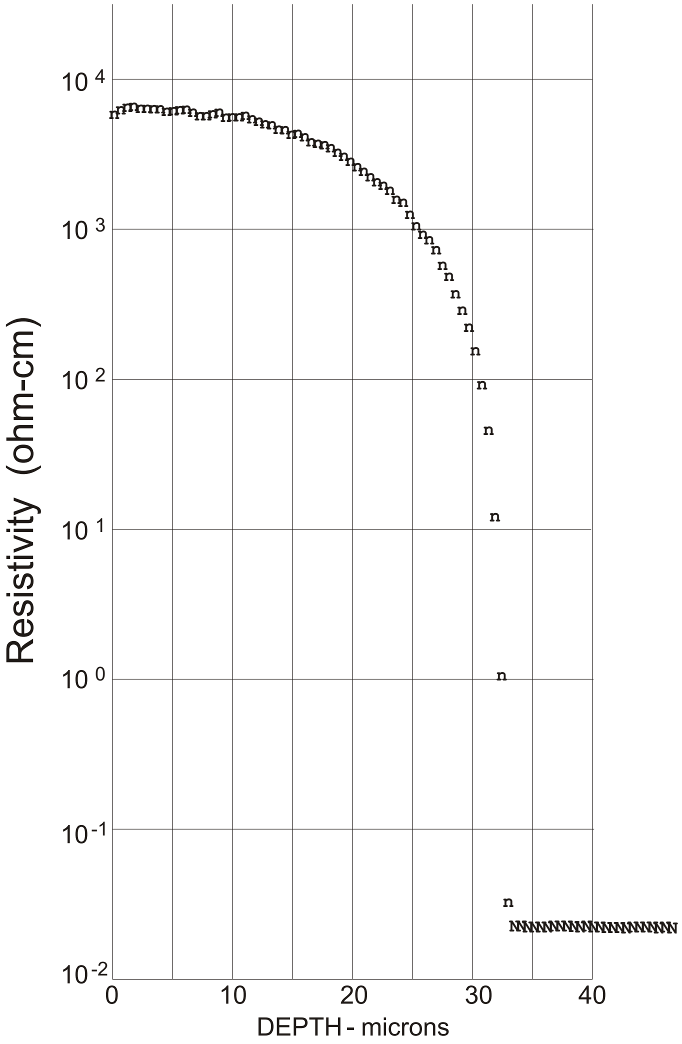


Data Reduction

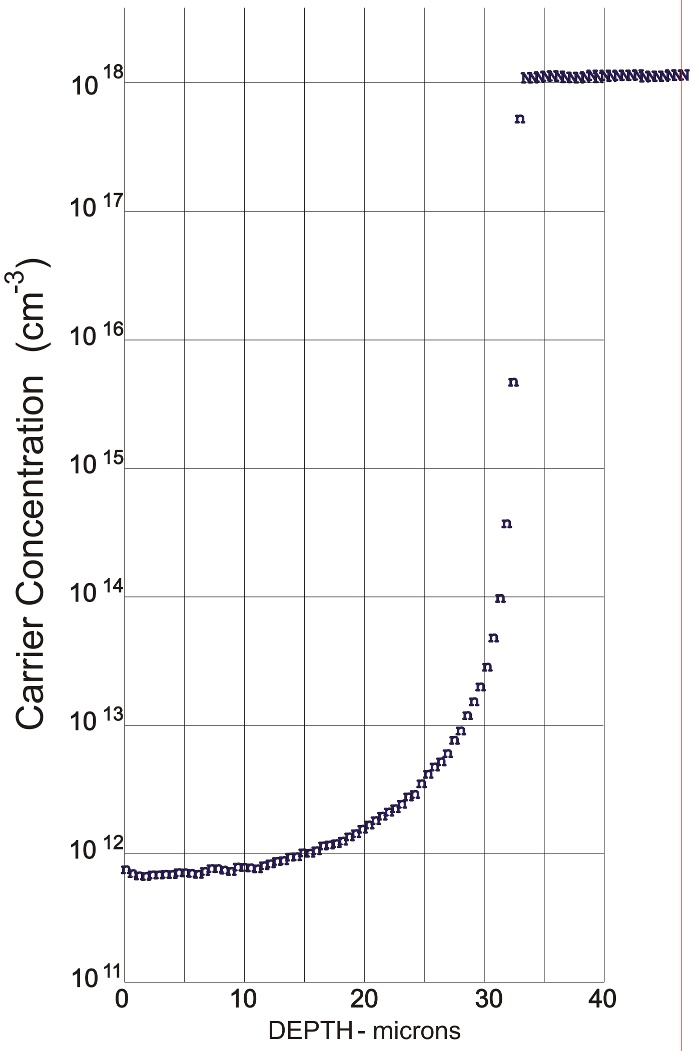


"Raw Data" → Resistivity Plot

High Resisitivity Epi (continued)

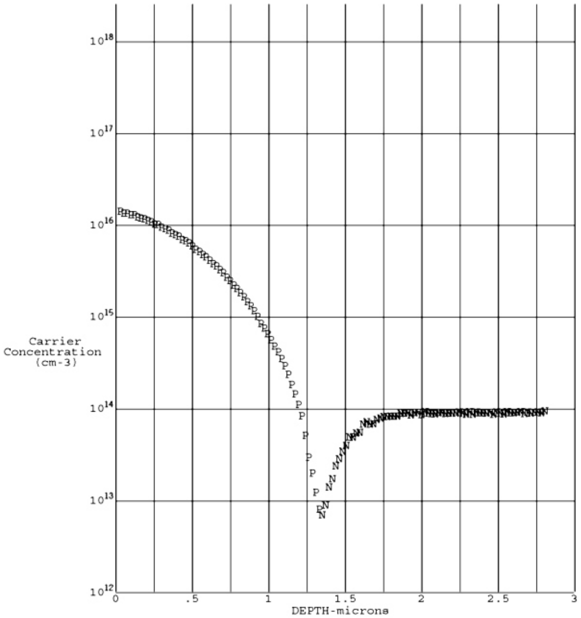


Carrier Concentration Calculated Using Published Carrier Mobility Values

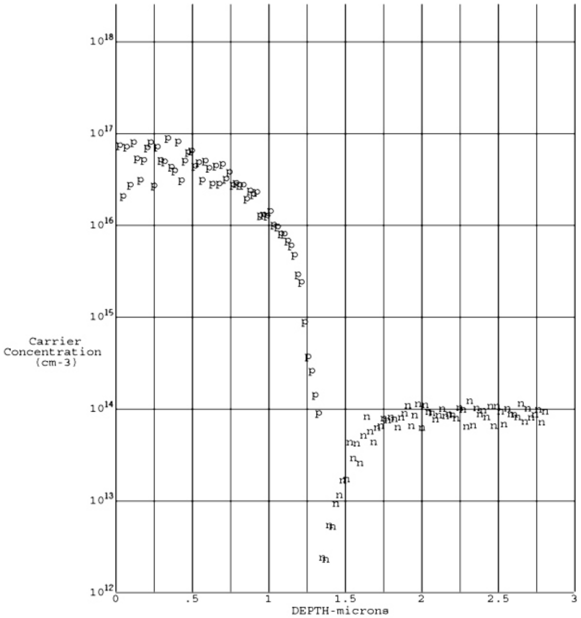


Resistivity → Carrier Concentration

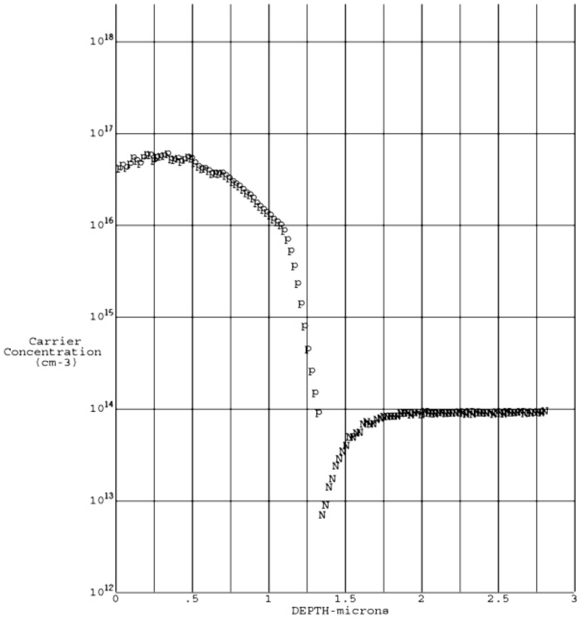
Sampling Volume Correction



Uncorrected layers
(Unsmoothed data)



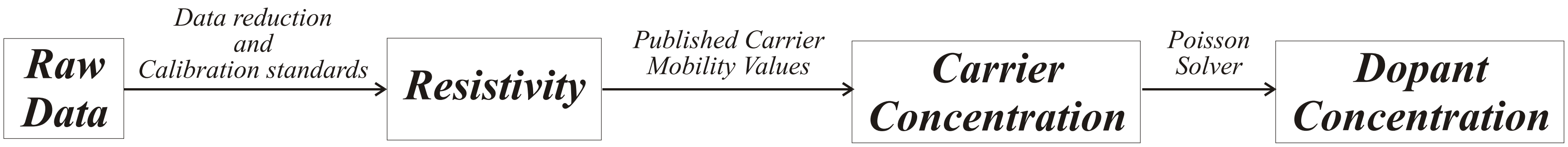
Both layers corrected
(Unsmoothed data)



Top layer corrected and smoothed
(Uncorrected/unsmoothed substrate)

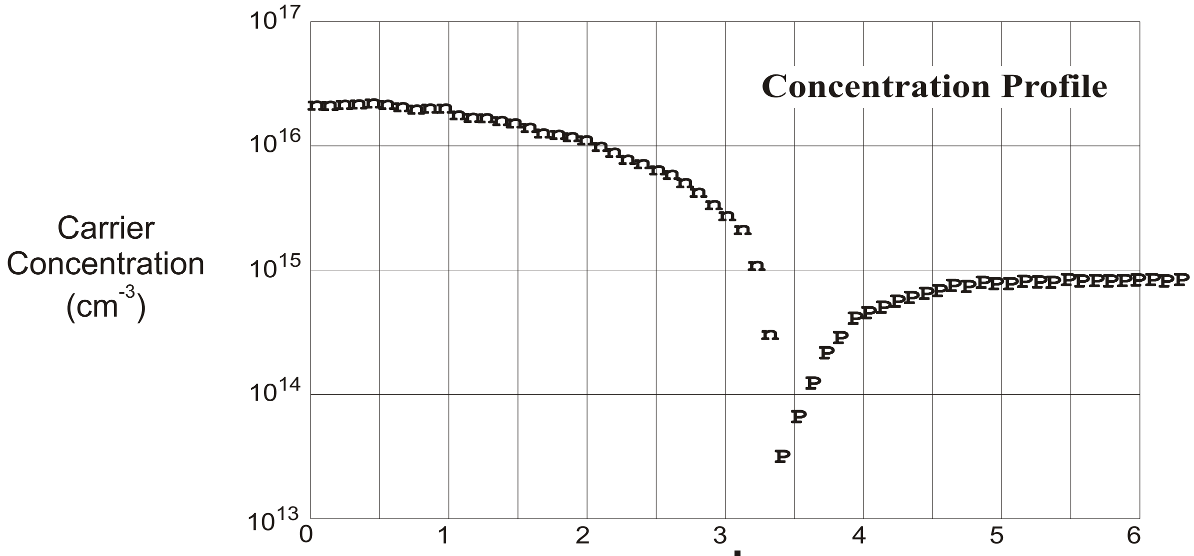
Our correction algorithms account for the sampling volume on non-uniformly doped layers. In regions with slight to no resistivity gradient, the algorithms tend to magnify the mechanical noise. But without correction the graded layer's values can be very wrong! We have various levels of smoothing which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

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

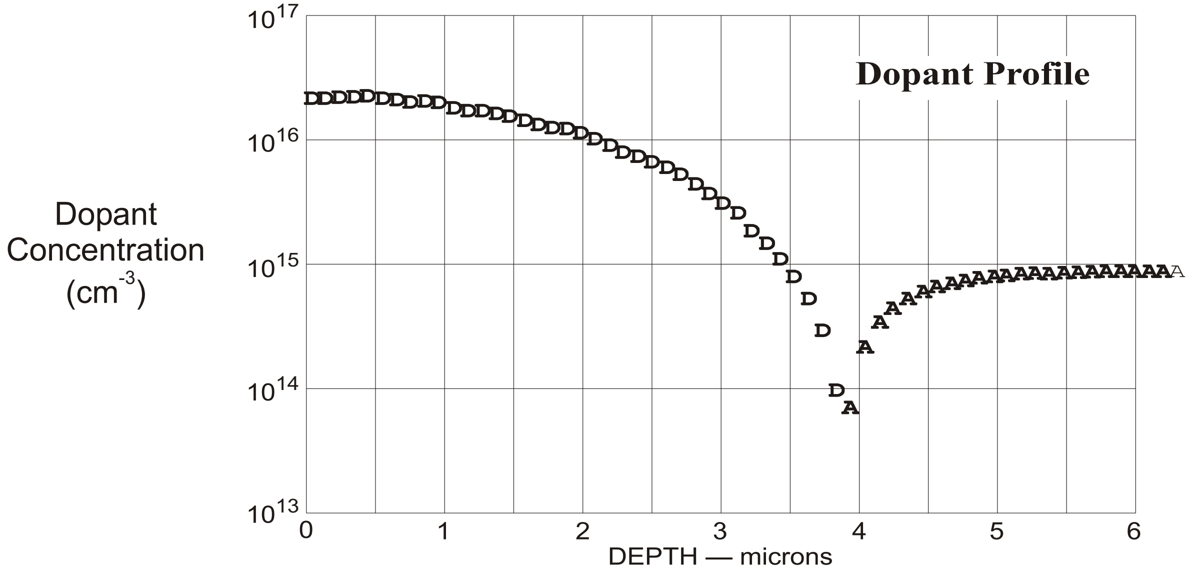


Raw Data → *Data reduction and Calibration standards* → **Resistivity** → *Published Carrier Mobility Values* → **Carrier Concentration** → *Poisson Solver* → **Dopant Concentration**

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

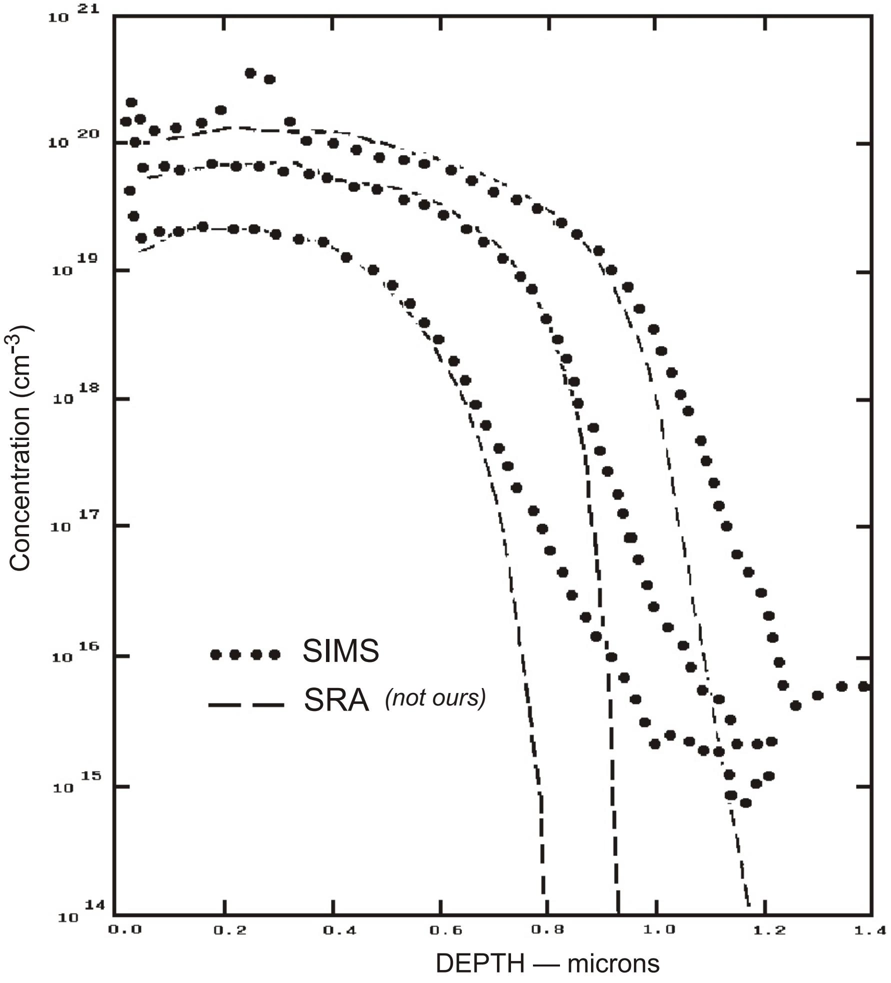


Poisson Solver



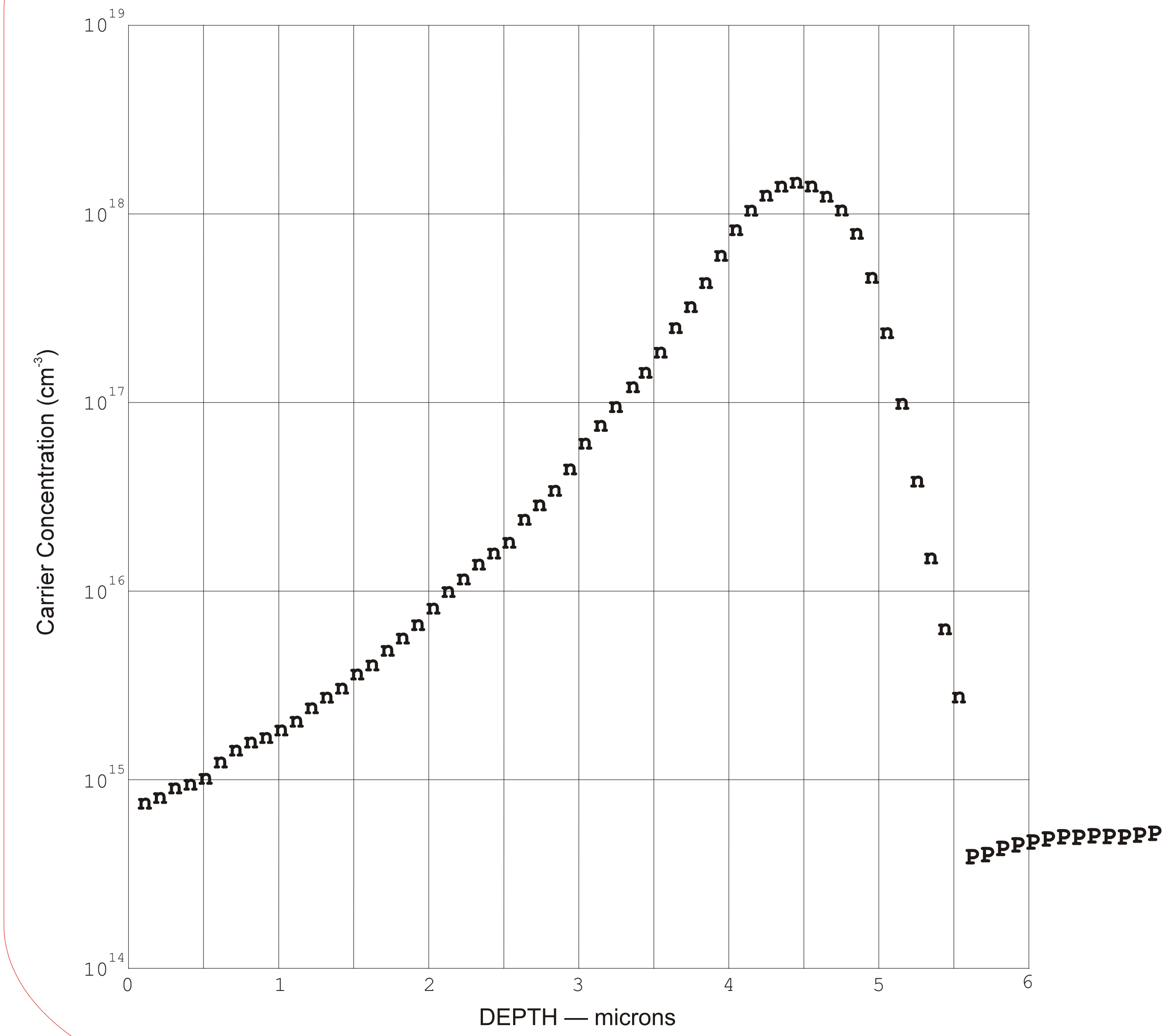
SIMS Typically Reports Greater Depth in the Tail Region of B Diffusions. In the Following Example, Boron was Implanted into Single-crystal Si.

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

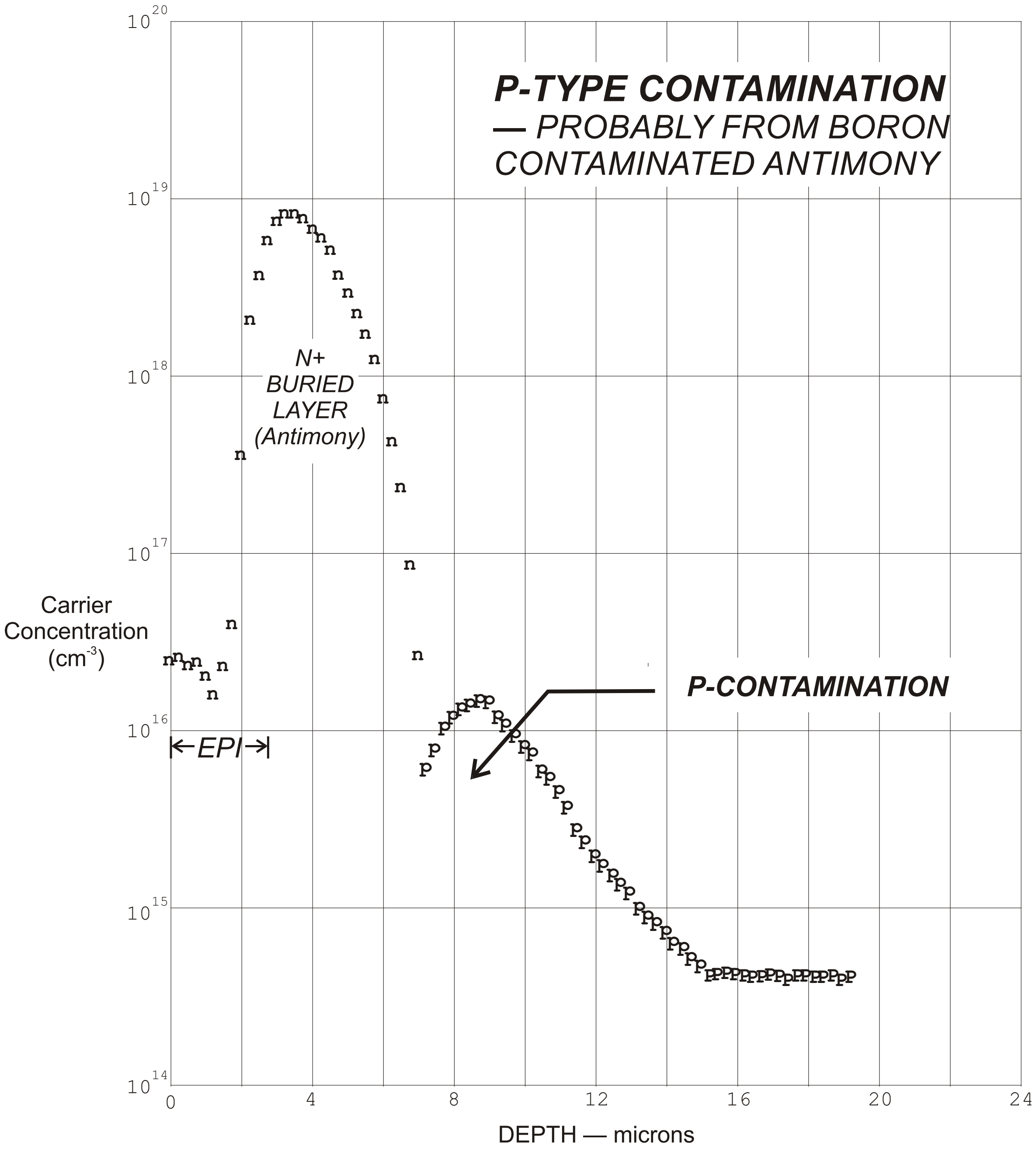


"The implantations were carried out using the facilities of the Lawrence Berkeley Laboratory. 11 MeV beams were obtained from a dynamatron with a 2.2 megavolt terminal. The ion source is a conducting crystal of gallium arsenide from which arsenic ions in the 5+ charge state were sputtered and extracted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

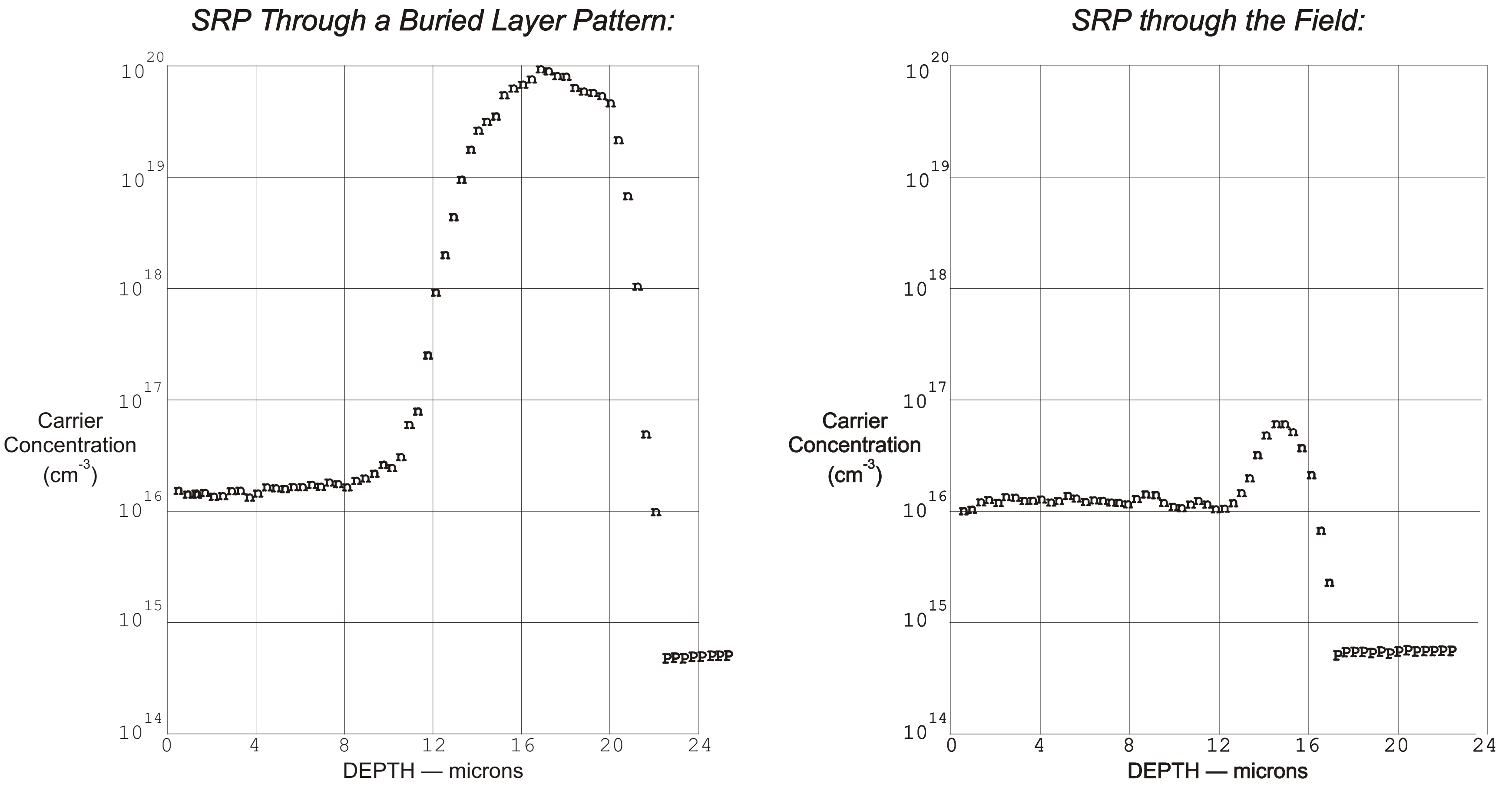
From *Megavolt Arsenic Implantation into Silicon,* a paper presented at the 1982 International Conference on Metallurgical Coatings and Process Technology by P.F. Byrne, N. W. Cheung, and D.K. Sadana, University of California, Berkeley.

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

P-TYPE CONTAMINATION
— PROBABLY FROM BORON CONTAMINATED ANTIMONY

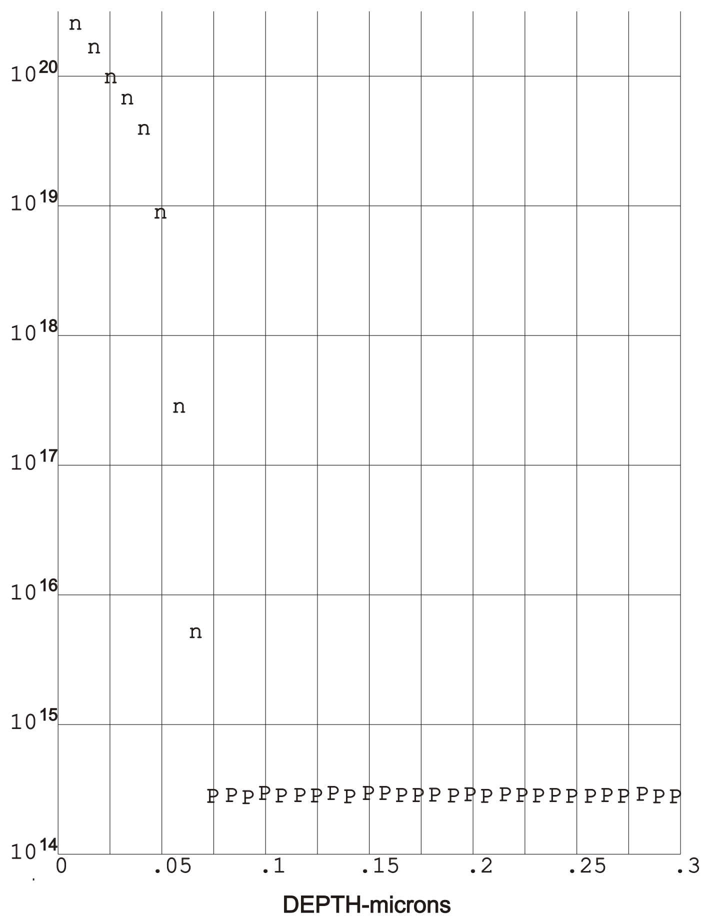


Arsenic Autodoping During Epitaxial Deposition

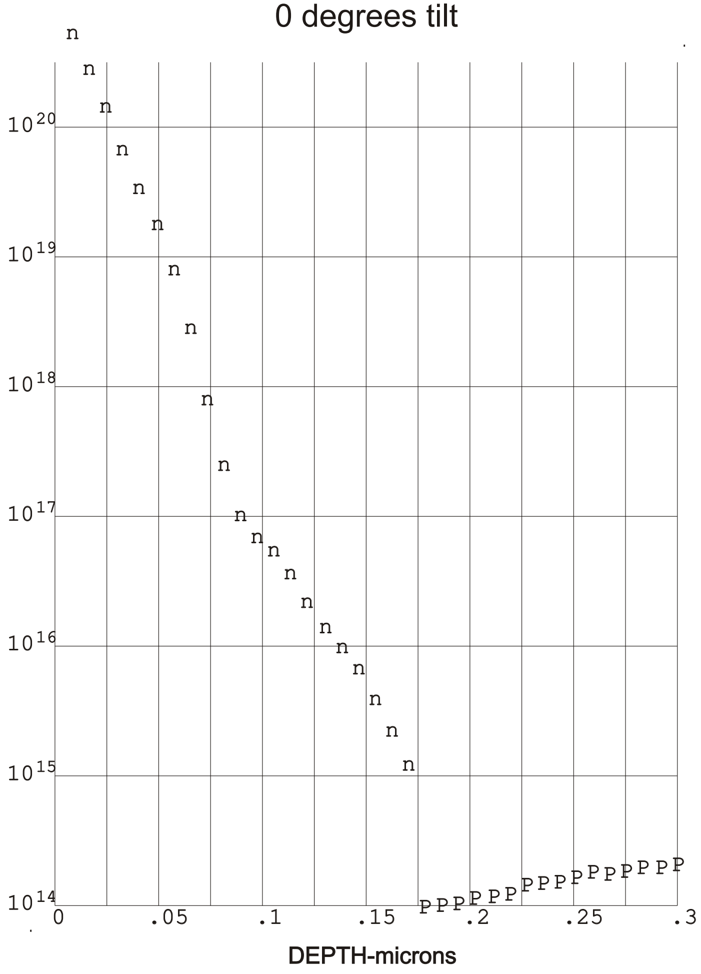


Ion Implant Channeling

10 degrees tilt

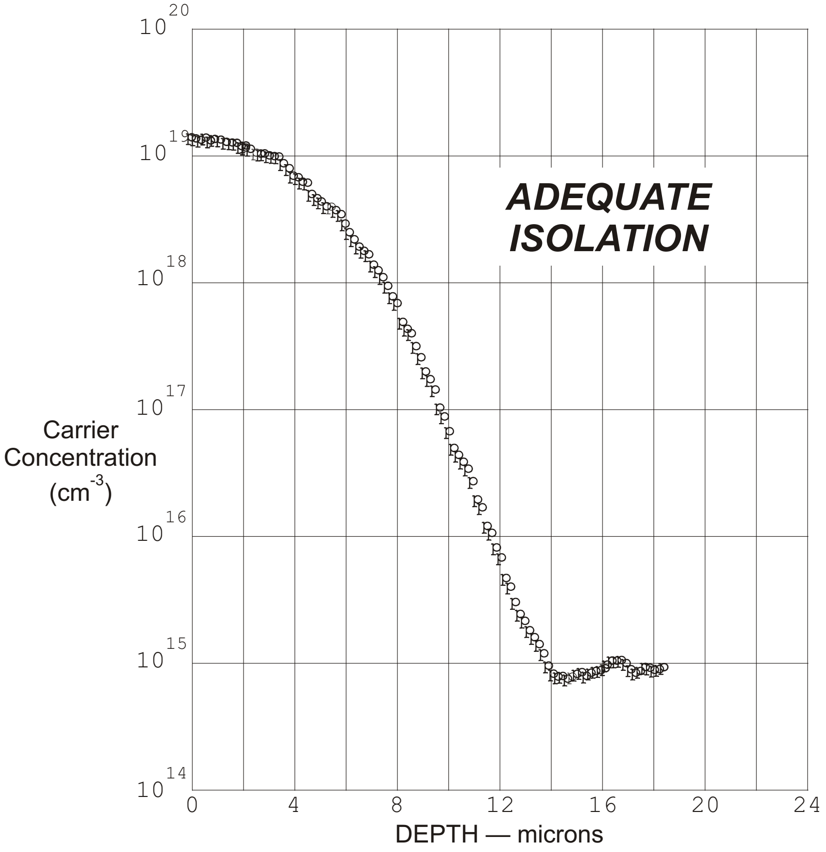


0 degrees tilt



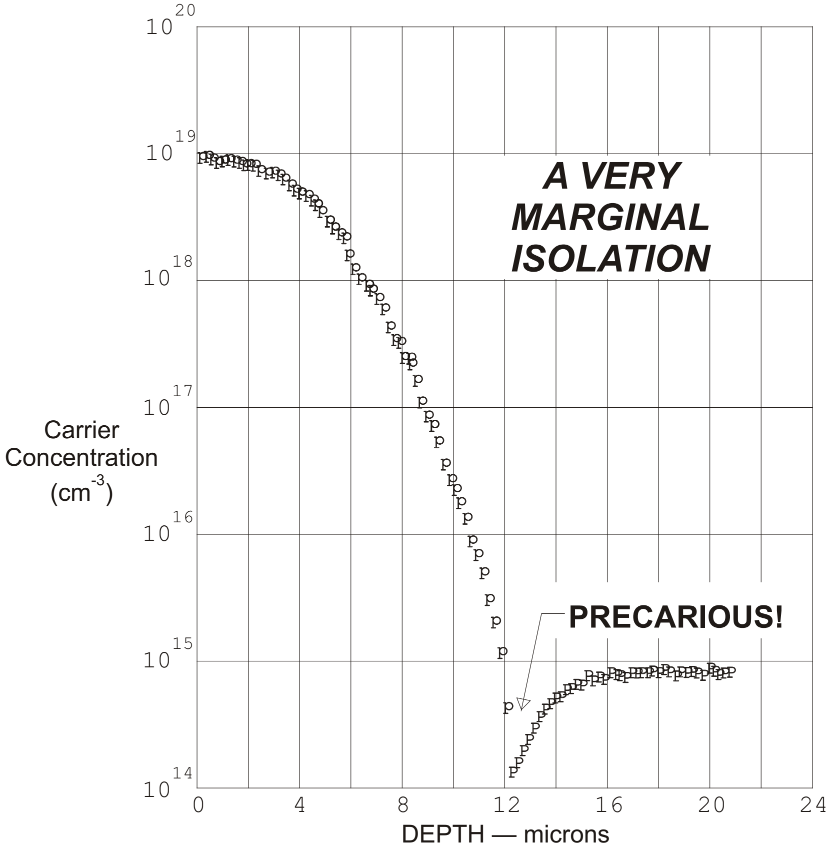
P+ Isolation Diffusion into N-Epi

Wafer A



ADEQUATE ISOLATION

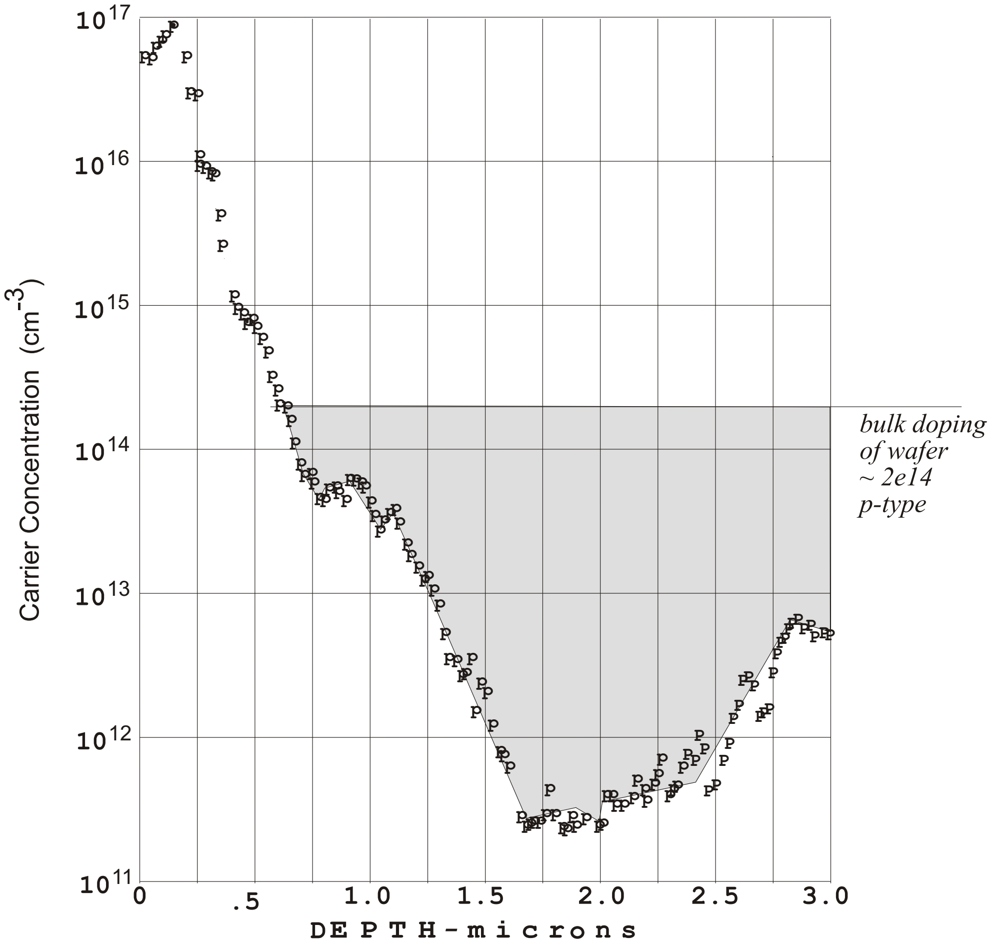
Wafer B



A VERY MARGINAL ISOLATION

PRECARIOUS!

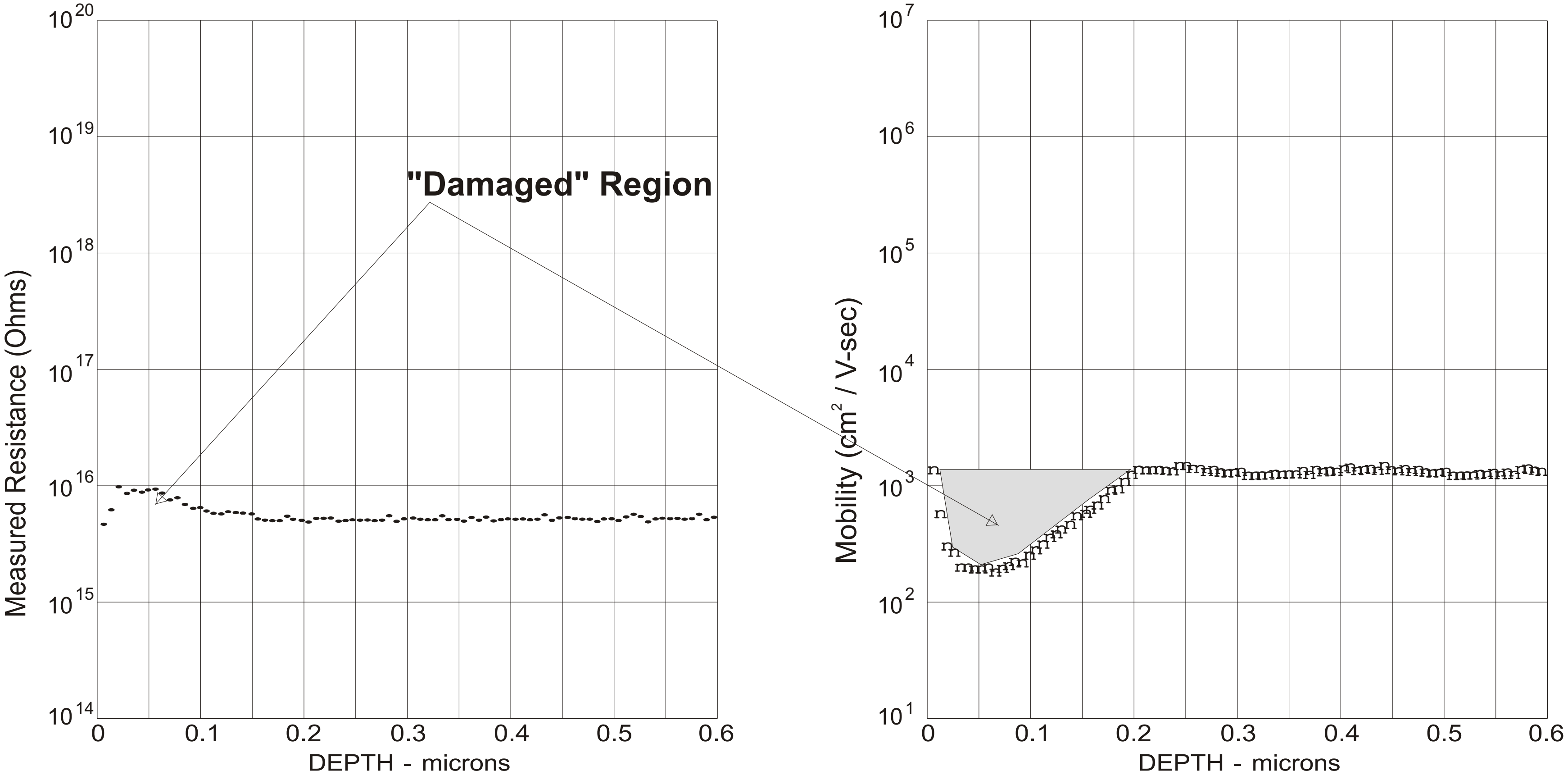
Thermal Donors — A Severe Case



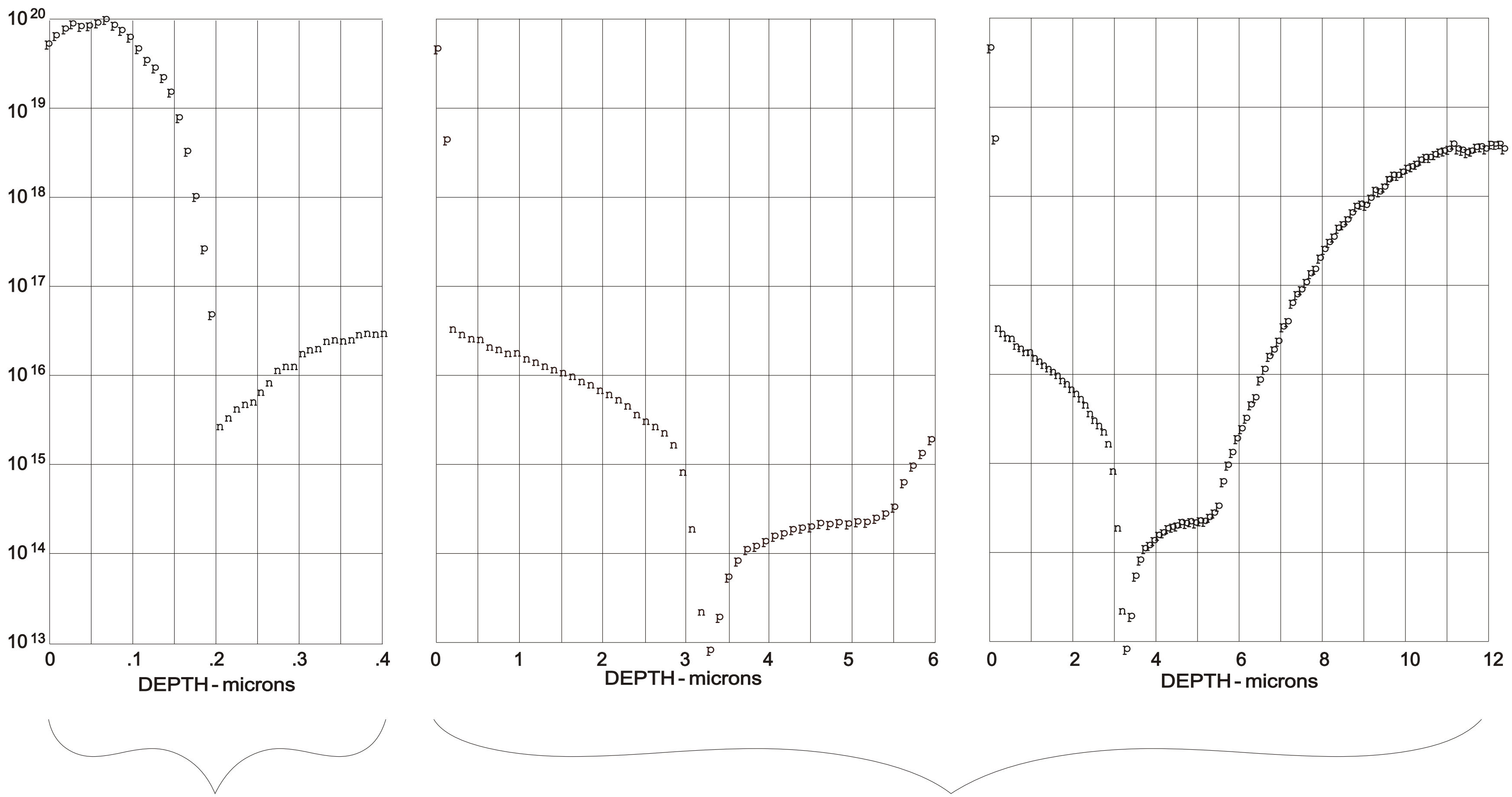
bulk doping
of wafer
~ 2e14
p-type

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.



CMOS (P-channel Source-Drain)

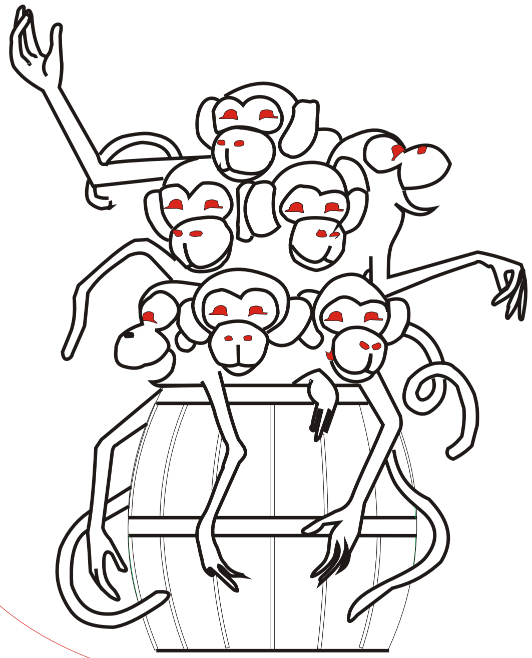


Shallow Profile to
Characterize the Source-Drain

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

In Closing...

- *Please Visit Us and Take the Tour*
- *SRA is Useful Whenever the Doping of Silicon is of Concern*
- *Web Page: www.solecon.com*



Best Wishes from the Folks at Solecon Labs.