"Maximum Depth of Interest" and Related Matters

First, we want to assure you we are on your side. We ask you to fill out this form (figure 1) so that we can obtain as much information where it is most critical. (Of course, we all dislike filling out forms but experience has shown it to be very useful in this case.) When the technician starts a job, the first thing he or she does is review the Analysis Request Form and other information from the customer. One very important item is the "maximum depth of interest". We hope the following comments provide some insight into its importance.

Please see figure 2. The bevel angle* accomplishes two objectives: 1) It allows the probes to reach below the surface and 2) It spreads out the region of interest--increasing the resolution by orders of magnitude. We select the bevel angle (from our dozen options) considering the maximum practical bevel length and the depths given in the Analysis Request Form--among other things.

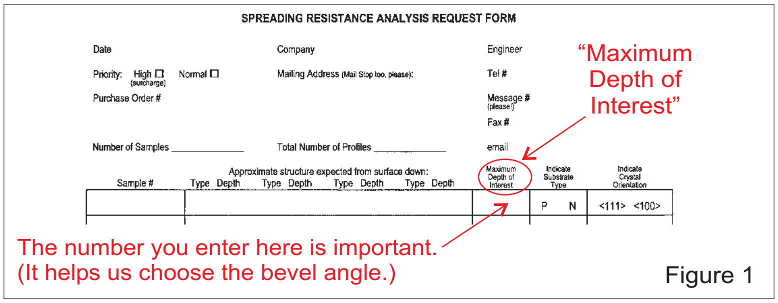
In the case of unpatterned wafers** or very long patterns, we make the length of the bevel as long as possible without causing harmful scratches. Although there are plenty of exceptions, this length is usually 500um to 1000um. We choose the bevel angle attempting to get most of the bevel within the maximum depth of interest. (There is a depth resolution calculator on our website at the link: http://www.solecon.com/sra/depth.resolution.html)

The "bevel angle" we report on the profiles is the sine of the bevel angle [sin(ϕ)]. (For small angles, the angle in radians and the sine of the angle are nearly the same.) The "step increment" we report on the profiles is the horizontal distance between adjacent probings (points). The depth increment is then the product of the sin(ϕ) and the step increment. For instance, if we report a bevel angle of 0.002 and a step increment of 5 microns, then the depth increment is 0.010 microns.

A damage crater is left every time the probes contact the sample. In order to avoid stepping into the previous damage crater, the minimum step increment is two microns (or more).

Example 1

In figure 3, a bevel block with a bevel angle ("10:1" or "0.10") was chosen. This allowed a depth of 30 microns to be reached within the pattern length. The minimum step increment of 2 microns was chosen to squeeze at least some characterization of the n+/p layers (emitter/base?) at the surface. To get better characterization of the n+/p, a shallower angle needs to be used. (A "50:1" or "0.02" would be a good choice.) With the shallower angle, the maximum depth of interest for the profile would be about six microns. This would allow about five times as many measurements within the emitter/base region.



SPREADING RESISTANCE ANALYSIS REQUEST FORM

Date
Company
Engineer
Priority: High ☐ (surcharge) Normal ☐
Mailing Address (Mail Stop too, please):
Tel #
Purchase Order #
Message # (please!)
Fax #
Number of Samples ____________
Total Number of Profiles ____________
email

Approximate structure expected from surface down:

Sample #	Type Depth Type Depth Type Depth Type Depth	Maximum Depth of Interest	Indicate Substrate Type	Indicate Crystal Orientation
			P N	<111> <100>

"Maximum Depth of Interest"

The number you enter here is important.
(It helps us choose the bevel angle.)

Figure 1

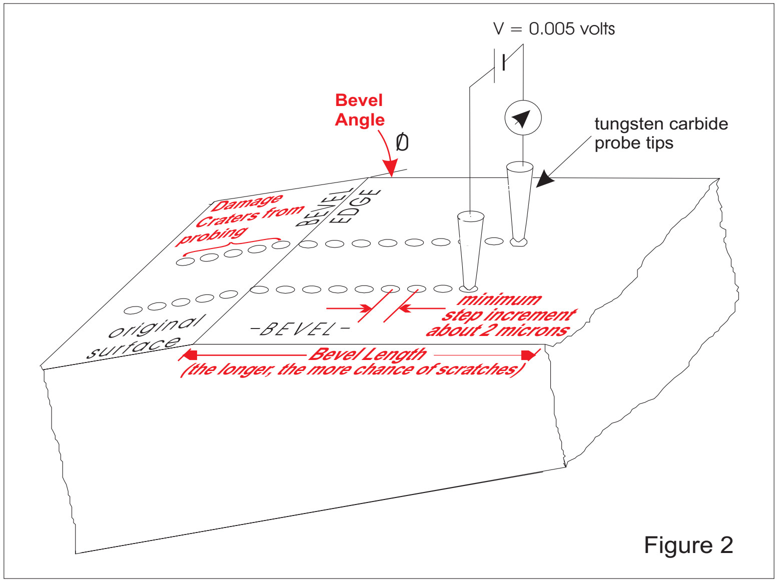
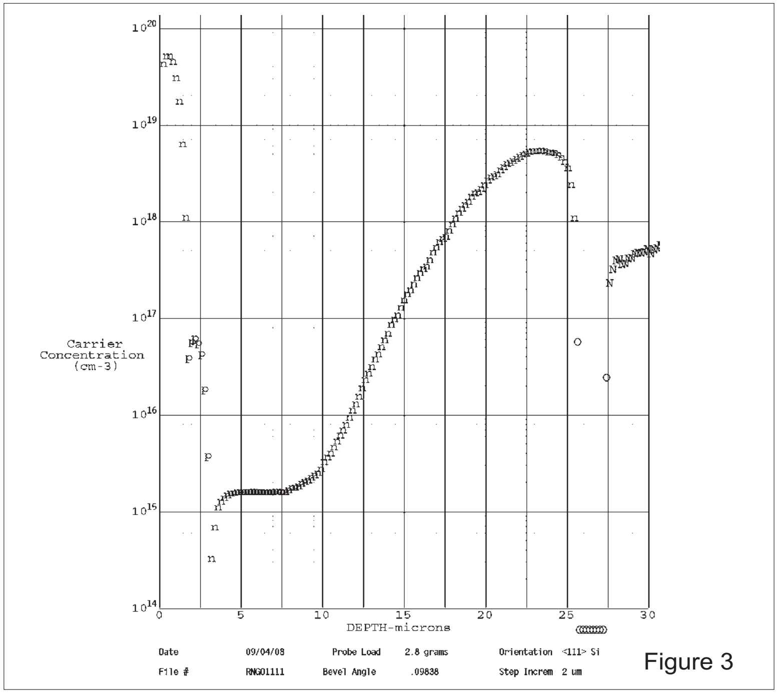


Figure 2



Date 09/04/08 Probe Load 2.8 grams Orientation <111> Si
File # RNG01111 Bevel Angle .09838 Step Increm 2 um

Figure 3

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* Bevel angles and a lot of other things are explained in the tutorial found at the link: http://www.solecon.com/sra.htm

**We call them "test wafers".

Example 2

Here is a case where both a shallow and a deep profile could be produced from the same (long) bevel. The bevel is about 1400um long and that is pushing it a bit but some liberties can be taken on relatively deep structures thanks to their relative noise immunity. (On deep structures, a 1% error in a measured resistance due to noise tends to get plotted out as a 1% error in resistivity and carrier concentration --- not much, all things considered.. Noise is a much bigger problem in ultra-shallow structures where the effective sampling volume is considerably larger than the depth increment -- causing amplification of the noise level.)

We were able to use a large depth increment (~ 0.3um) to reach 60um (figure 4). Then, with a smaller depth increment (~0.04um), we focused on the p-layer at the surface (Figure 5). The smaller depth increment yields a much more detailed characterization of the p-layer's shape. The junction depth is more clearly defined. The dose is higher and the SRP-calculated sheet resistance is lower due to the smaller step having a better probability of measuring at the location of the peak concentration value. (This is typical but there are exceptions.)

The two profiles shown in figures 4 and 5 would be billed as one profile. It is our policy to not charge for the second profile at the same location on the same bevel. (We move over a few microns in the y-direction to miss the previous probe marks*.)

It is obligatory to mention there is a limit in reducing the depth increment. Deep profiles can become prohibitively time consuming and the results can be quite messy. Also, as the depth increment is reduced, the difference between adjacent points (measured resistance) is reduced. When the noise level becomes a significant part of that difference, it frustrates the data reduction. (This is the same concern as having the depth increment much, much smaller than the sampling volume. Noise starts dominating the finished profile.)

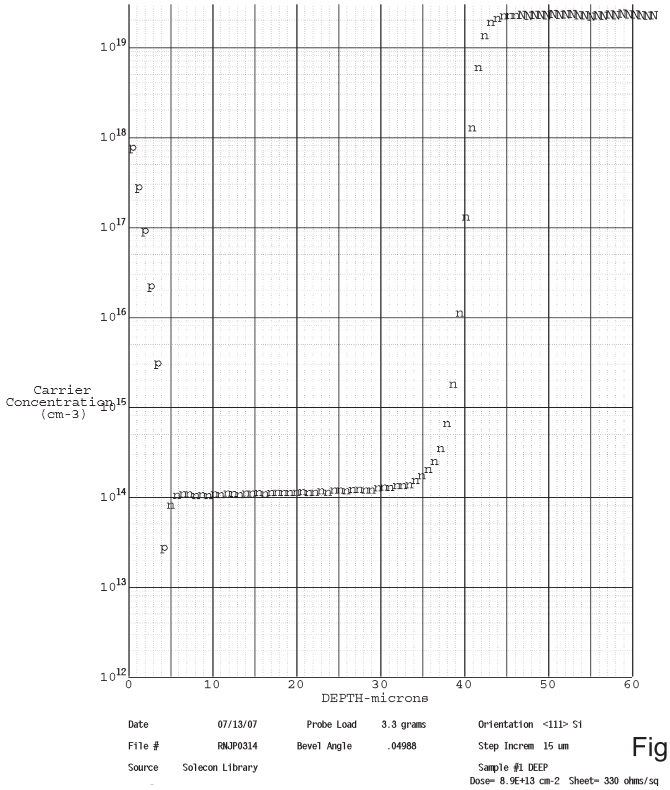

Figure 4

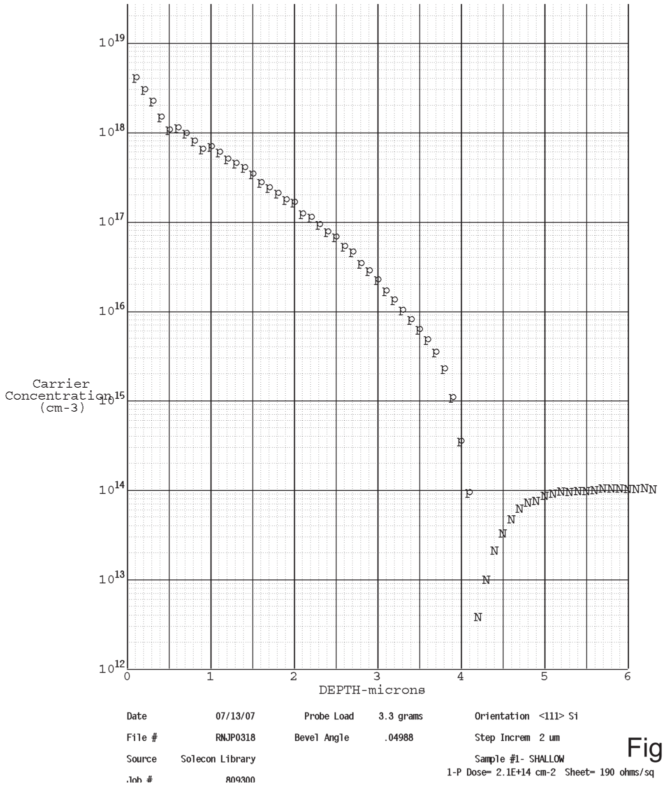

Figure 5

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* We refer to them affectionately as "foot prints".

Example 3

Here is a case where two bevels were needed to characterize both the shallow and deep portions of the structure. The length of the pattern was only 250 microns.

Figure 4 shows the profile of the structure all the way to substrate. Our steepest bevel (referred to as :“5:1”, “11°37’ ”, or “bevel angle = 0.2”) was used. The full-scale on the graph is 30-microns which requires a minimum bevel length of about 165 microns within the pattern.* Near the surface, there is only a hint of an n-layer and a possible enrichment of the p-epi just underneath the n-layer.

Figure 3 shows a higher resolution profile of the first 3-microns. A second bevel -- ten times as shallow as the previous was used. Now we see what may well be an n-epi layer having an n-enrichment at the surface. There is also a p-enrichment at the beginning of the p-epi. A nominal angle of 50:1 (“1°9’ ” or “bevel angle = 0.02”) was chosen. After beveling, the angle was measured by the Veeco WYCO optical profilometer as 0.02163. (An 8% difference between nominal and actual bevel angle is not unusual for a 50:1 block. For shallower blocks, the deviation can be greater. Measuring the resultant angles with a profilometer is imperative.)

Had there been no pattern constraint, both profiles could have been done on shallower blocks.

One more thought about bevel angles before going on to example 4. A shallow bevel angle and a large step increment is preferred to the other way around. A shallow bevel angle reduces the depth differences in the region surrounding the probe tips.

Figure 8 is an illustration of the same depth increment being accomplished by a steeper bevel angle and smaller step (figure 8a) and a shallower angle and a larger step. (For illustrative purposes, the angles and the size of the probe marks are much larger than what is really used. Also, a typical profile has many more probings than shown.)

The shallower profile (figure 8b) reduces the influences of adjacent material by having the surrounding material more nearly the same.

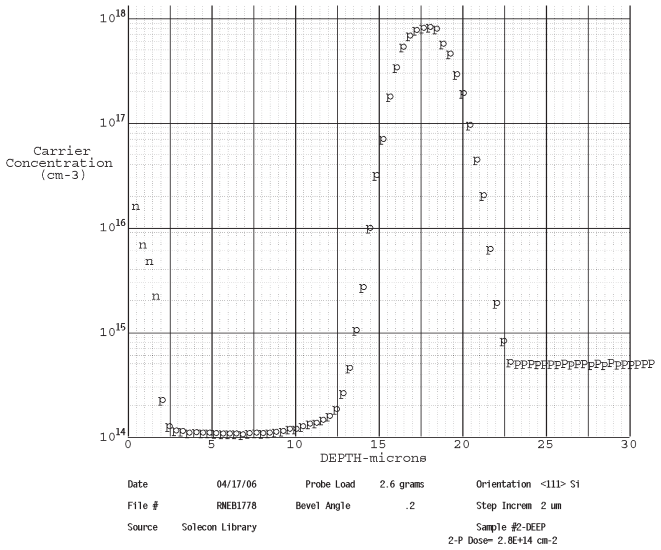

Figure 6

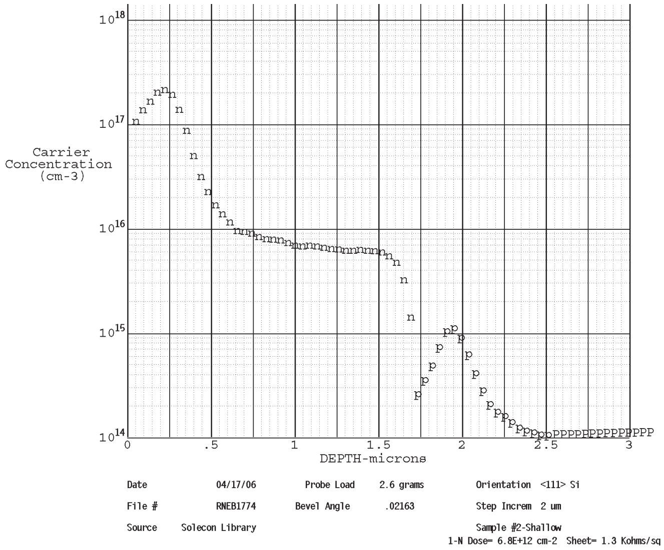

Figure 7

Each illustration has the same depth increment!

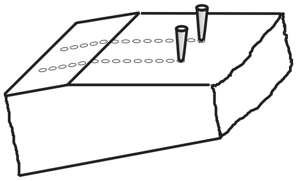

Figure 8a

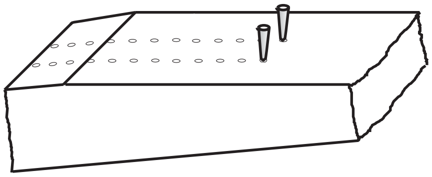

Figure 8b

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* Our policy is to stop beveling a minimum of 15 microns before reaching the end of the pattern. This will be discussed a bit more at the end of this technical note.

Example 4

Here is a case where two bevels were needed BUT only one pattern was available. Additionally, this example shows it is possible to “have too much resolution” as well as too little. The shallow profile MUST be done first. The next step is to be quite satisfied with the shallow profile. The following needs to be verified: bevel angle, bevel edge, step increment, probe separation, probe alignment to each other and the pattern, smooth bevel, satisfactory probe marks, and satisfactory raw data. In many cases the bevel will also be stained and photographed. We then re-mount the sample on a steep bevel block and destroy all the forensic evidence from the first profile. We prefer keeping the forensic evidence from all profiles. If there is a question later, we can check all those things listed above. We bevel over the previous bevel only as the last resort. (Indeed, I am uncomfortable even thinking about it.)

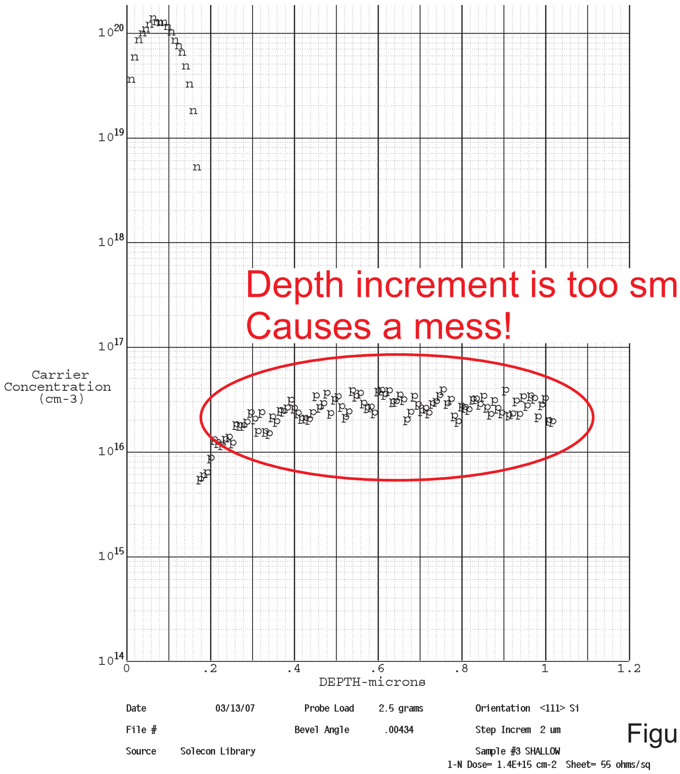
Both of these profiles provide examples of too many points in a layer. This tends to be inevitable when the profile goes through widely different layer thicknesses. In figure 9, the partial p-layer is obviously a mess yielding very little reliable information. Compare it to the complete p-layer in figure 10 having fewer points. In figure 10, one has a reasonable concept of the p-well although even fewer points would be better.

Perhaps the messiness in figure 9 provides a segue to a discussion of “resolution” -- a word with entirely too many meanings! When we talk of resolution, we are referring to the clarity or the amount of detail available in the profile.

Intuition suggests decreasing the depth increment will always increase the resolution. This is true only to a certain point. If the depth increment is reduced far enough, you start getting a mess. You have less clarity. You see less detail.

Additional Considerations When Profiling Patterned Wafers

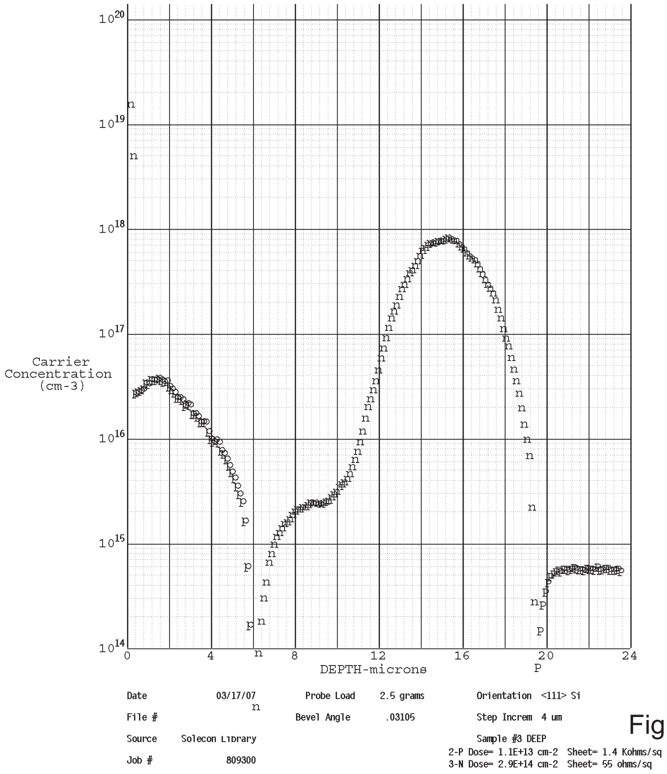
Beyond some of the obvious requirements (both probe tips must be in target pattern until they go through the bottom of the confined region), it is desirable to be a reasonable distance from the edge of pattern. For deeper profiles, lateral diffusions intruding into the target pattern must be considered as well. When possible, we prefer to have the minimum distance from the probe tip to the pattern edge to be half the probe separation. Please see figure 11.



Depth increment is too small! Causes a mess!

Date 03/13/07 Probe Load 2.5 grams Orientation <111> Si
File # Bevel Angle .00434 Step Increm 2 um
Source Solecon Library Sample #3 SHALLOW
1-N Dose= 1.4E+15 cm-2 Sheet= 55 ohms/sq

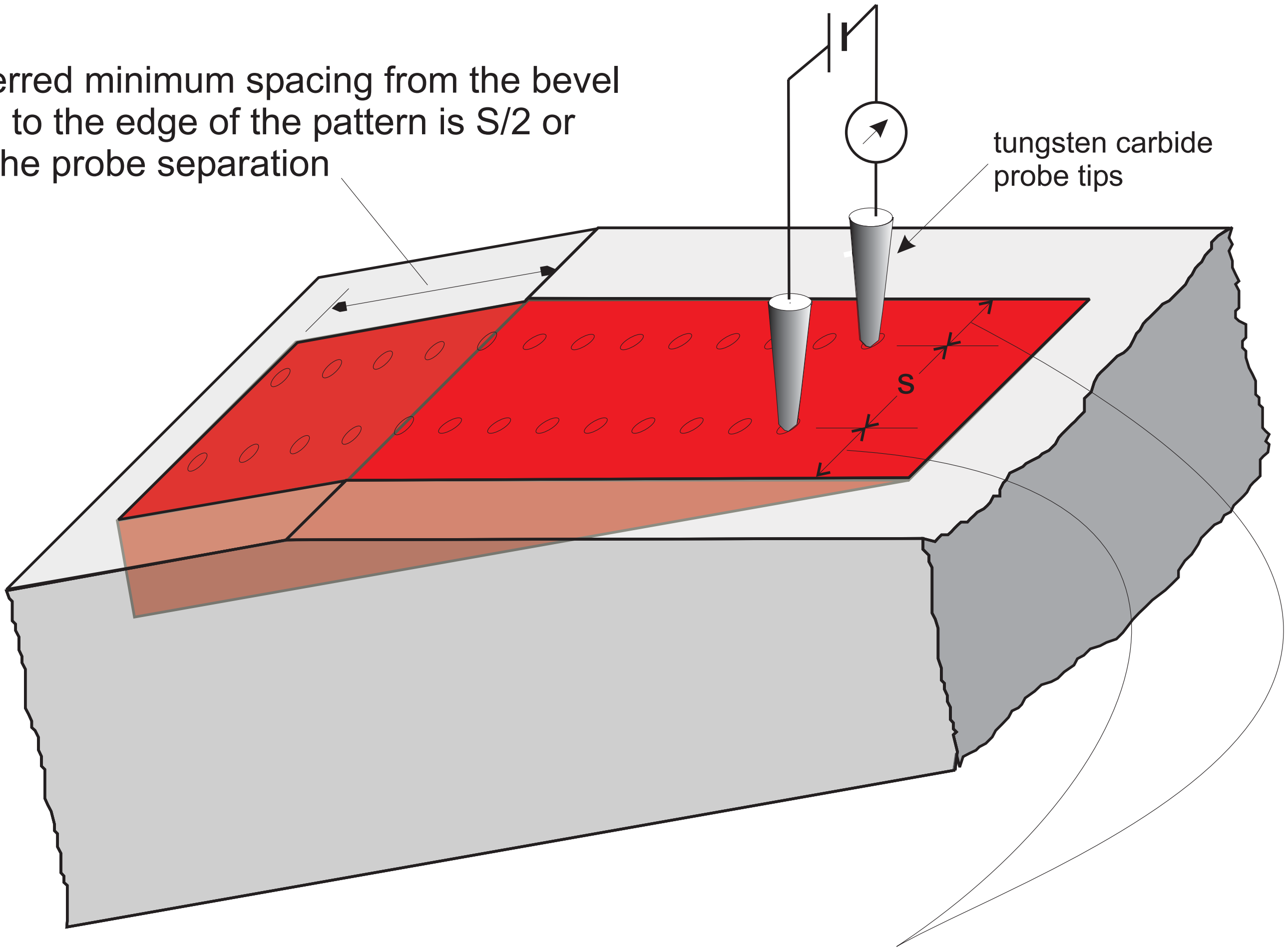
Figure 9



Date 03/17/07 Probe Load 2.5 grams Orientation <111> Si
File # Bevel Angle .03105 Step Increm 4 um
Source Solecon Library Sample #3 DEEP
Job # 809300
2-P Dose= 1.1E+13 cm-2 Sheet= 1.4 Kohms/sq
3-N Dose= 2.9E+14 cm-2 Sheet= 55 ohms/sq

Figure 10

Preferred minimum spacing from the bevel edge to the edge of the pattern is S/2 or half the probe separation



Preferred minimum spacing from probe tip to edge of pattern is S/2 or half the probe separation

Figure 11

For additional reading much on the same subjects, please see the earlier technical note, "How Big a Pattern Do We Need for SRA" at the link:
http://www.solecon.com/pdf/how_big_a_pattern_do_we_need_for_sra.pdf