Dose, Sheet and Four-point Probe Sheet

At the bottom right of our spreading resistance reports, we sometimes print some cryptic information. The following is an attempt to explain what it means. We will use the profile in Figure 1 as our example. In this case, we wrote:

1-N Dose = 1.9×10^{15} cm^{-2} Sheet = 35 ohms/sq
Four-point probe sheet = 32

We shall attempt to explain each line. "1-N" denotes the first layer and its type "N". We count the layers from left to right. Sometimes you will see several layers listed so this helps identify which layer the data refers to.

Figure 1

Dose

"Dose" refers to the dose calculated from the n layer of the spreading resistance profile. We break up the n layer into 19 sub-layers (the number of measurements made within the n layer). We approximate the dose (net charges per area) of the sub-layer by assuming that the sub-layer has a thickness equal to the depth increment and is of uniform concentration. We then sum the calculated doses from each sub-layer to get the total dose. In this example, concentrations within the n-layer were determined to be:

DEPTH (um)	CONC (cm^{-3})	DEPTH (um)	CONC (cm^{-3})
.020	1.22×10^{19}	.409	3.48×10^{19}
.058	1.83×10^{19}	.449	3.22×10^{19}
.098	2.86×10^{19}	.487	2.82×10^{19}
.137	4.09×10^{19}	.526	2.47×10^{19}
.175	2.85×10^{19}	.566	2.21×10^{19}
.214	3.75×10^{19}	.605	1.35×10^{19}
.254	4.49×10^{19}	.643	3.30×10^{18}
.292	4.13×10^{19}	.682	2.95×10^{17}
.332	4.38×10^{19}	.722	6.04×10^{16}
.370	3.84×10^{19}		

The dose of a sub-layer is then the concentration times the thickness (depth increment) which for this profile is 0.0391um or 3.91×10^{-6} cm. (1um = 10^{-4} cm)

So, the dose of the first sub-layer is approximated as:

1.22×10^{19} cm^{-3} x 3.91×10^{-6} cm = 4.77×10^{13} cm^{-2}

And the dose of the second sub-layer is:

1.83×10^{19} cm^{-3} x 3.91 x cm^{-6} cm = 7.155×10^{13} cm^{-2}

Okay, so we just do this calculation for all the sub-layers and then sum them for the total dose.

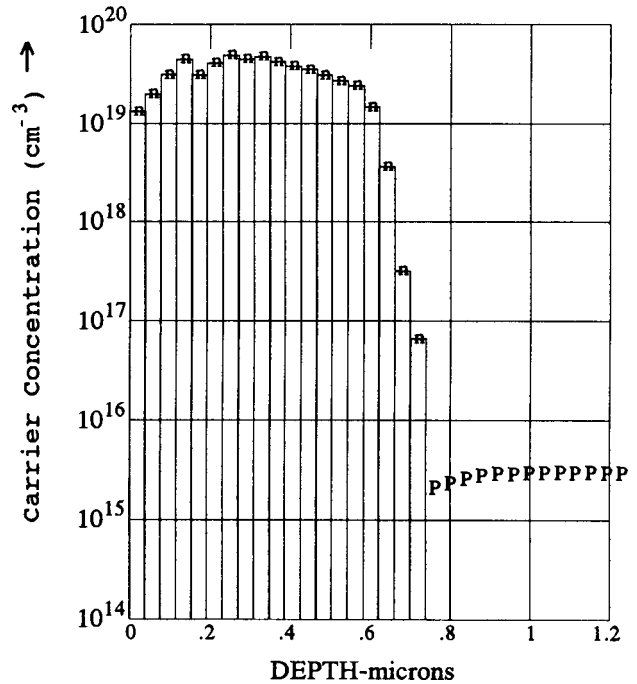| CONC(cm^{-3})	Conc. (cm^{-3}) x depth increm (cm)
1.22×10^{19}	4.77020×10^{13} cm^{-2}
1.83×10^{19}	7.15530×10^{13} cm^{-2}
2.86×10^{19}	1.11826×10^{14} cm^{-2}
4.09×10^{19}	1.59919×10^{14} cm^{-2}
2.85×10^{19}	1.11435×10^{14} cm^{-2}
3.75×10^{19}	1.46625×10^{14} cm^{-2}
4.49×10^{19}	1.75559×10^{14} cm^{-2}
4.13×10^{19}	1.61483×10^{14} cm^{-2}
4.38×10^{19}	1.71258×10^{14} cm^{-2}
3.84×10^{19}	1.50144×10^{14} cm^{-2}
3.48×10^{19}	1.36068×10^{14} cm^{-2}
3.22×10^{19}	1.25902×10^{14} cm^{-2}
2.82×10^{19}	1.10262×10^{14} cm^{-2}
2.47×10^{19}	9.65770×10^{13} cm^{-2}
2.21×10^{19}	8.64110×10^{13} cm^{-2}
1.35×10^{19}	5.27850×10^{13} cm^{-2}
3.30×10^{18}	1.29030×10^{13} cm^{-2}
2.95×10^{17}	1.15345×10^{12} cm^{-2}
6.04×10^{16}	2.36164×10^{11} cm^{-2}
TOTAL DOSE	**1.92980×10^{15} cm^{-2}**

Sheet

The calculation of the sheet resistance follows the same scheme as the dose except for a few twists. If you have resistors in parallel (Figure 2) the reciprocal of equivalent resistance is equal to the sum of the reciprocal of the resistance of each parallel leg.
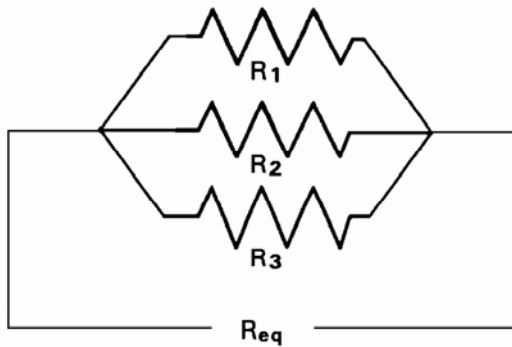
$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Figure 2

If the resistors were squares of material connected in parallel, the relationship would remain the same:
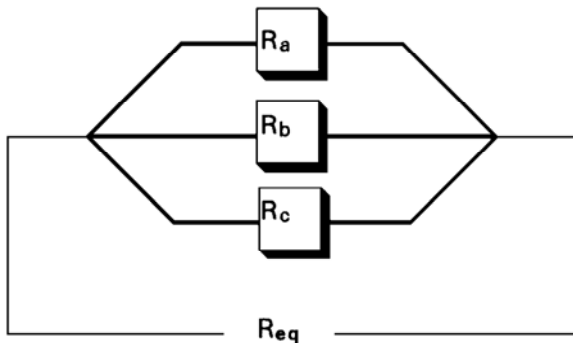
$$\frac{1}{R_{eq}} = \frac{1}{R_a} + \frac{1}{R_b} + \frac{1}{R_c}$$

Figure 3

Squares have a convenient electrical property - the resistance encountered between opposite sides is the same for a given material regardless of the size of the square. Because of this we talk of sheet resistance, ρ_s, in units of "ohms per square".

We can then substitute ρ_s for R in the above equation and we have:

$$\frac{1}{\rho_{S_{eq}}} = \frac{1}{\rho_{S_a}} + \frac{1}{\rho_{S_b}} + \frac{1}{\rho_{S_c}}$$

In the case of a "sheet" of uniform resistivity, the sheet resistance ρ_s is equal to the bulk resistivity divided by the thickness:

$$\rho_S = \frac{\rho}{t}$$

Let's approximate the sheet resistance of each sub layer as the resistivity determined by spreading resistance divided by the depth increment. In our example, the depth increment is 3.91 x 10^{-6} cm. In the table below, we have used the resistivity associated with each point and divided it by the depth increment to calculate a sheet resistance for each sub-layer.

We then calculated the reciprocal of each sheet resistance and added them together. Then we calculated the reciprocal of the total to get the sheet resistance for the n-layer. (Note that we could have introduced the idea of sheet conductance and avoided much of this talk of reciprocals, and we would have arrived at exactly the same result.)

Determined by SRA		Calculated from SRA data	
Depth	ρ (ohm-cm)	$\rho_s = \rho/3.91 \times 10^{-6}$ cm	$1/\rho_s$
.020	.00507	1296.675 ohms/sq	7.712×10^{-4}
.058	.00362	925.831	1.080×10^{-3}
.098	.00239	611.253	1.635×10^{-3}
.137	.00169	432.225	2.314×10^{-3}
.175	.00239	611.253	1.634×10^{-3}
.214	.00184	470.588	2.125×10^{-3}
.254	.00154	393.862	2.539×10^{-3}
.292	.00167	427.110	2.341×10^{-3}
.332	.00158	404.092	2.475×10^{-3}
.370	.00179	457.800	2.184×10^{-3}
.409	.00197	503.836	1.985×10^{-3}
.449	.00213	544.757	1.836×10^{-3}
.487	.00241	616.368	1.622×10^{-3}
.526	.00275	703.325	1.422×10^{-3}
.566	.00304	777.494	1.286×10^{-3}
.605	.00466	1191.816	8.391×10^{-4}
.643	.0117	2992.327	3.342×10^{-4}
.682	.043	10997.44	9.093×10^{-5}
.722	.12	30690.54	3.258×10^{-5}
Total $\frac{1}{\rho_s}$ (or $\Sigma\left(\frac{1}{\rho_s}\right)$)			2.855×10^{-2}
Sheet = $1/\Sigma\left(\frac{1}{\rho_s}\right)$	35.2 ohms/sq		

Four-point Probe Sheet

Finally, "Four-point Probe Sheet" (4PP) refers to the sheet resistance that we measured on our four-point probe. (You had already guessed that, hadn't you?) If the sample is big enough and unpatterned, and if there is a junction, and if the sheet rho of the top layer isn't too high, we will measure it. If there's room, we will probe at five locations and report the average.

Nearly always, the sheet resistance obtained by the four-point probe is more reliable than that obtained from SRA so this provides you a benchmark for the SRA measurements. If "Sheet" and "4PP" track each other pretty well, then the SRA is more credible.

Best of all, this quick and dirty "4PP" is free. If you would like something a little more elegant, we will be happy to provide you a 120 point four-point contour map for a little money.

If you have read this technical note in its entirety, we would like to thank you. You paid us a real compliment by bearing through it. And, as always, if you want more information, please let us know.