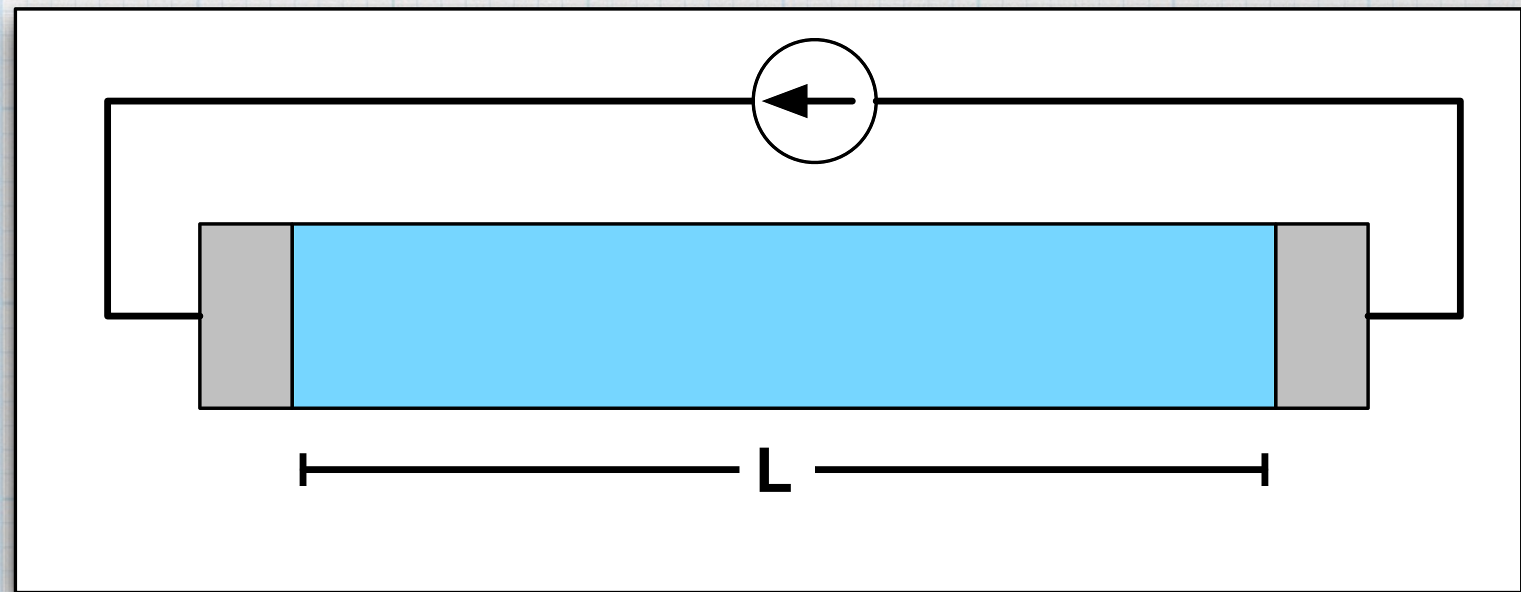
Contact resistance and TLM measurements

In measuring resistance with the four-point-probe or van der Pauw methods, we used 4 contacts (2 for current, 2 for voltage) to determine the sheet resistance of a layer while minimizing effects of contact resistance.

However, in transistors and other electronic devices, the contacts are a necessary part of the device, and it is useful to determine the contact resistance so that we can have some idea of how it might affect device performance.

We can measure the contact resistance using an extension of the resistance techniques employed earlier.

Consider the simple resistor geometry is shown at right in cross section.



The two contacts are located at the ends of the bar and each has a contact area of A_C.

The measured total resistance consists of several components:

$$R_T = 2R_m + 2R_C + R_{semi}$$

where R_m is the resistance due to the contact metal, R_C is associated with the metal/semiconductor interface, and R_{semi} is the usual semiconductor resistance.

The resistance of a single contact would be $R_m + R_C$. However, in most situations, the resistivity of the metal in the contact is so low that $R_C >> R_m$, and so R_m can be ignored.

The semiconductor resistance is

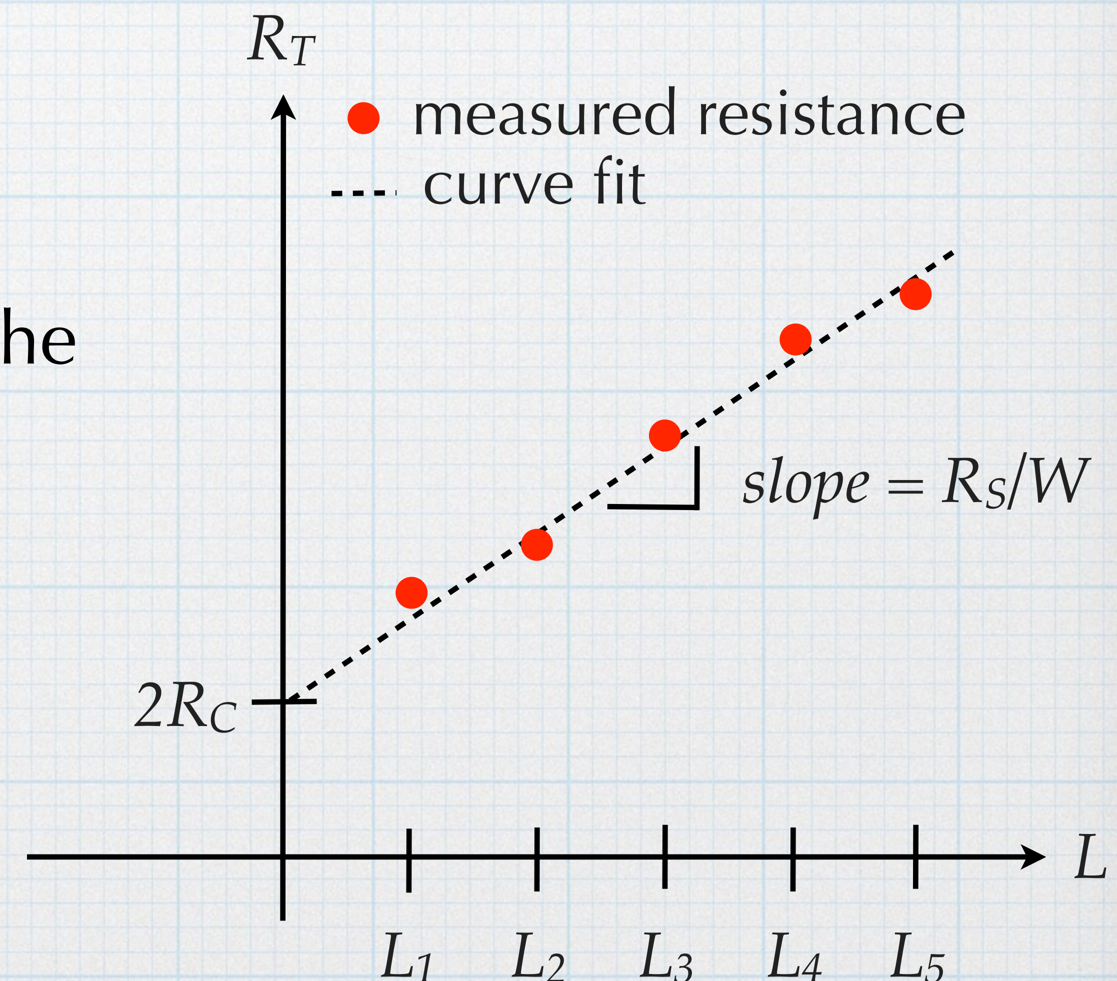
$$R_{semi} = R_S \frac{L}{W}$$

$$R_T = \frac{R_S}{W} L + 2R_C$$

These results suggest a method for measuring the contact resistance. If resistors of several different lengths are constructed, keeping all other details the same, the total resistances of each can measured and plotted.

In the limit of a zero-length resistor, the residual resistance would be just twice the contact resistance. The can be found from the graph by extrapolating back to $L = 0$.

As a secondary benefit, the sheet resistance of the semiconductor can be found from the slope of the line.



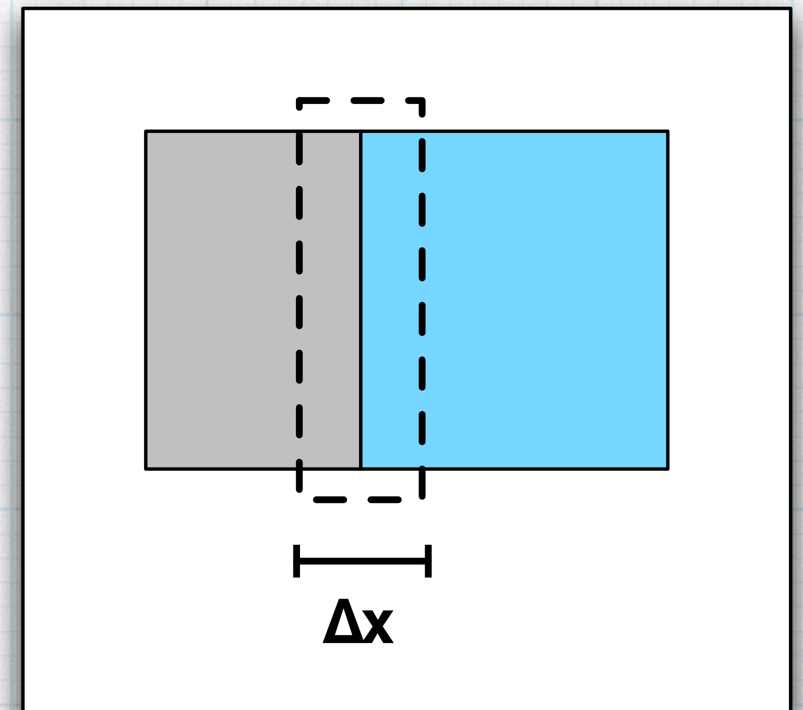
Contact resistivity

In looking at different methods of making contacts, we would like to have standard quantity as point of comparison. The contact resistance depends on the size of the contact, so it is not a good point of comparison. Instead, we can use the contact resistivity.

Consider a small region in the vicinity of the contact.

$$R_C = \rho' \frac{\Delta x}{A_C}$$

where A_C is the area of the contact.

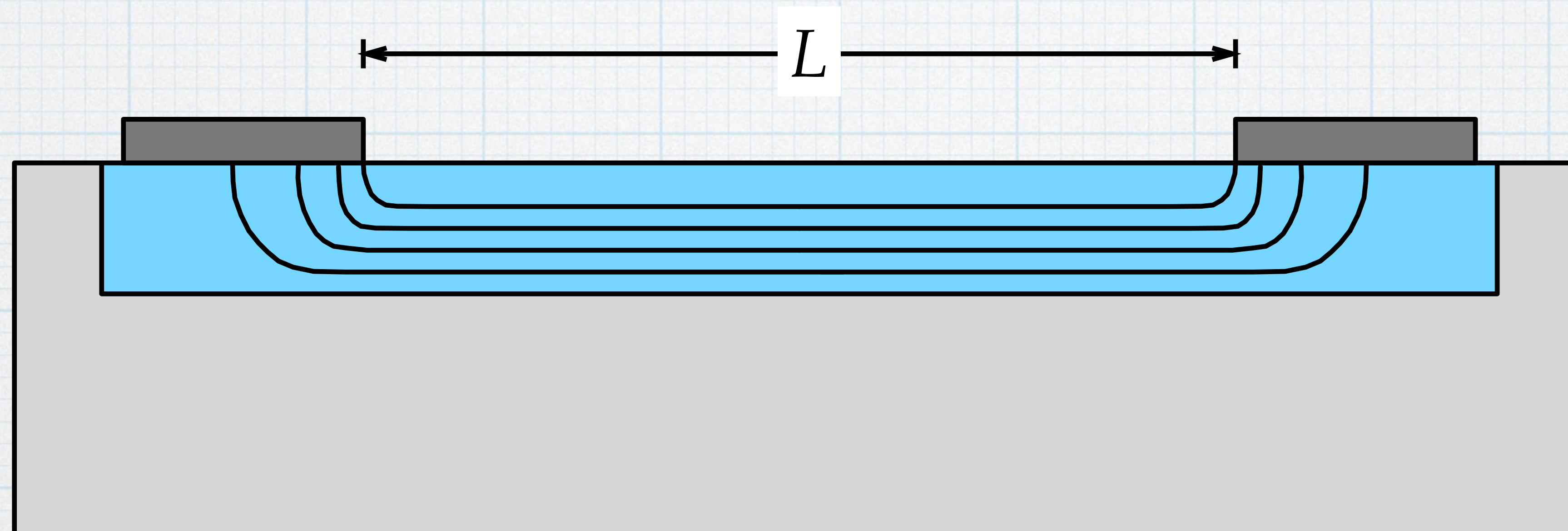


$$\rho_C = \lim_{\Delta x \to 0} (\rho' \Delta x) = R_C A_C$$

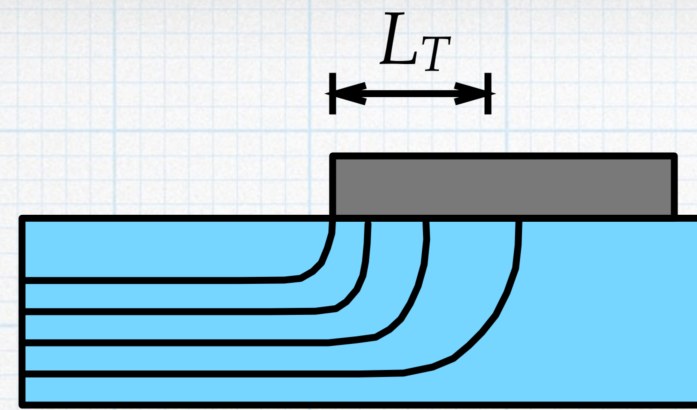
So the contact resistivity would have units of $\Omega\cdot m^2$. (or $\Omega\cdot cm^2$or $\Omega\cdot mm^2$.) Typical values would range from 10^{-3} to 10^{-8} $\Omega\cdot cm^2$

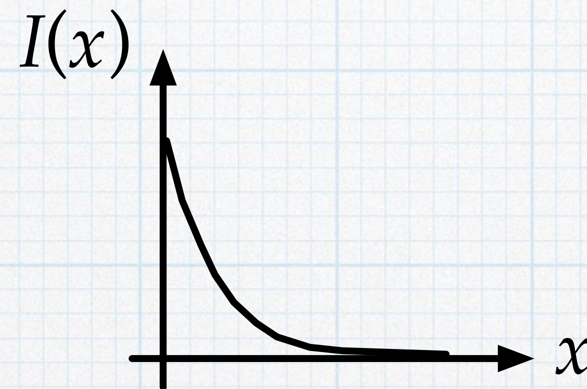
Using the geometry shown, finding contact resistivity should be a straight-forward exercise in measuring resistors of several lengths and then extracting the parameters, assuming that we know the area of the contacts.

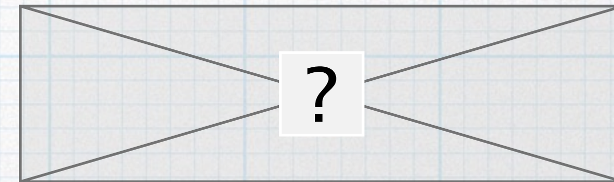
However, we don't use the contact geometry that was shown. Instead, we have contacts on the top, which is part of the planar geometry.



The current flow through the semiconductor is still uniform, but the flow into the contacts is not. Since the current does not flow uniformly in the contact, we can't use the physical length and width of the contact to determine the contact area.







At the edge of the contact, the current flowing in (or out) is significant. Moving away from that edge, the current drops off until, at the far edge, there is no current.

This is known as “current crowding”.

An analysis of current crowding shows that the drops off in an exponential fashion with a characteristic length of LT, which is known as the transfer length. This can be viewed as the effective length of the contact.

(For a more detailed discussion, see chapter 3 of “Semiconductor material and device characterization 2/e” by Dieter Schroder, John Wiley, 1998.)

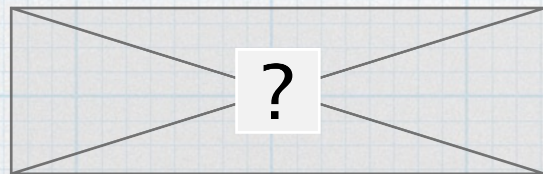
L_T is the transfer length, $L_T = \sqrt{\dfrac{\rho_C}{R_S}}$

The transfer length is the average distance that an electron (or hole) travels in the semiconductor beneath the contact before it flows up into the contact.

So the effective area of the contact can be treated as $L_T W$.

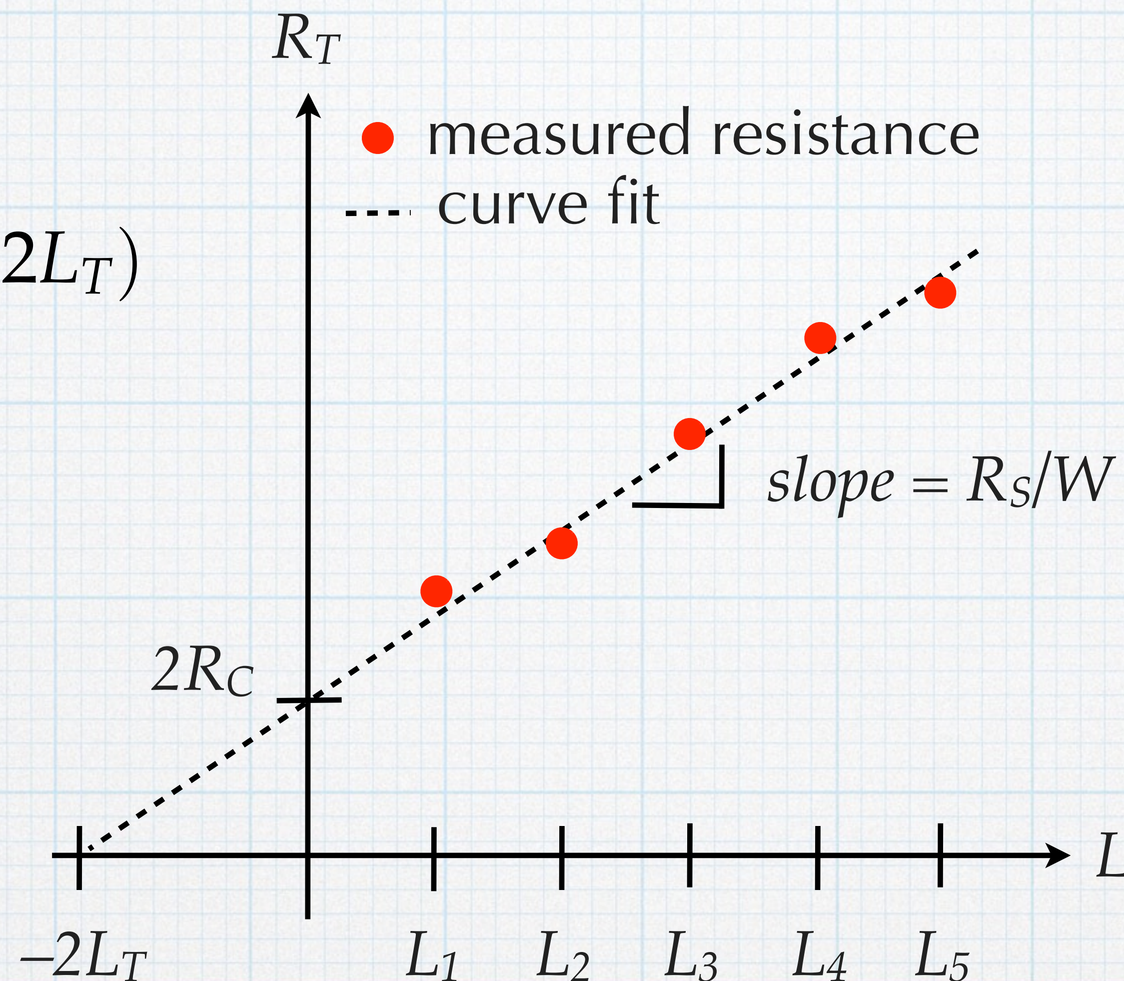
The contact resistance is then: $R_C = \dfrac{\rho_C}{L_T W} = \dfrac{R_S L_T}{W}$

$$R_T = R_{semi} + 2R_C$$



$$= R_S \frac{L}{W} + 2\frac{R_S L_T}{W}$$

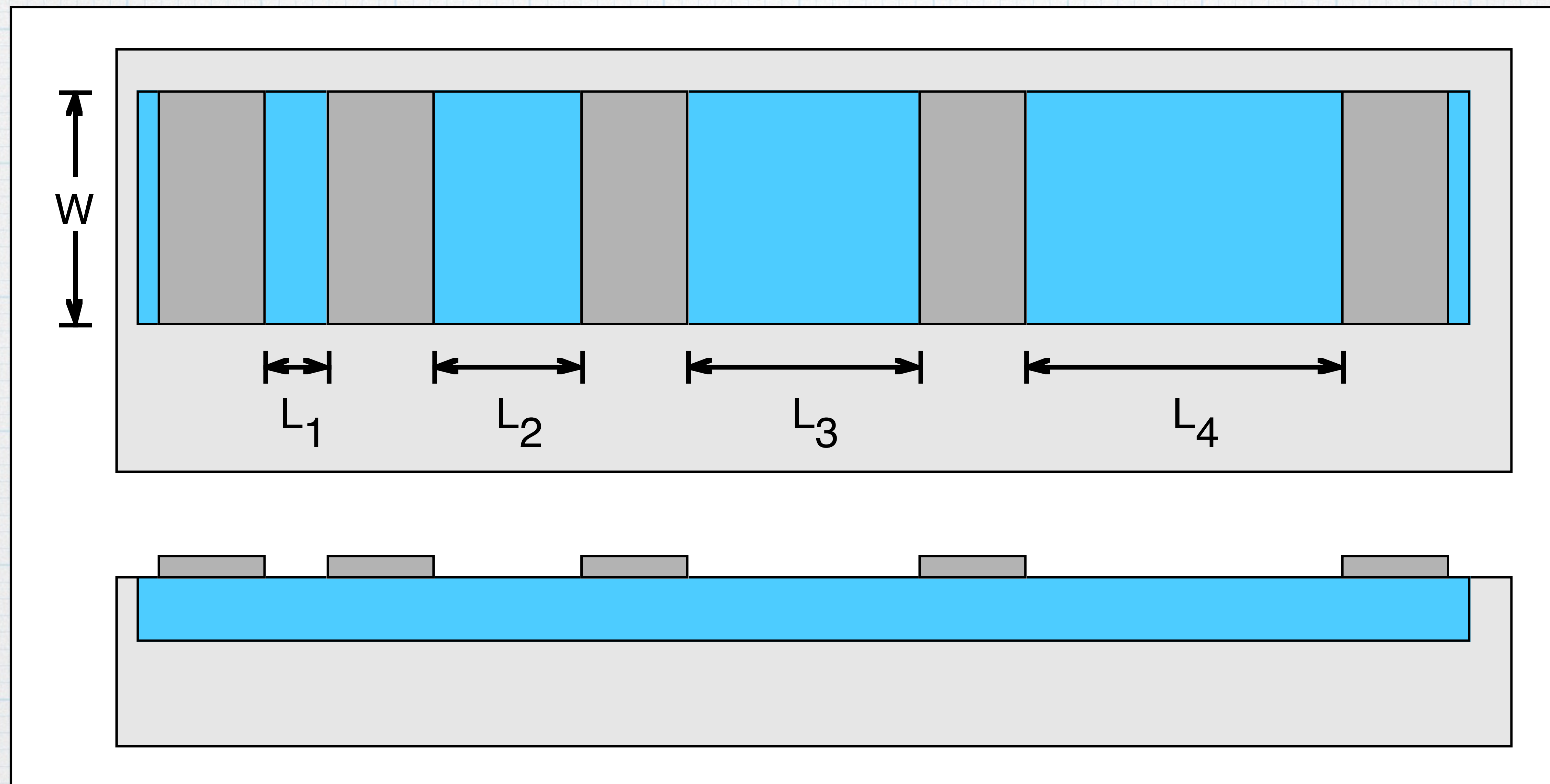
$$R_T = \frac{R_S}{W}\left(L + 2L_T\right)$$



The plot of R_T vs resistor length can also give the transfer length, by extrapolating back to the horizontal axis, where the intercept = $-2L_T$. Thus we know everything needed to find contact resistivity.

There are other techniques for finding contact resistivity. Most of these are discussed in detail in the text from Schroder (reference on slide 6).

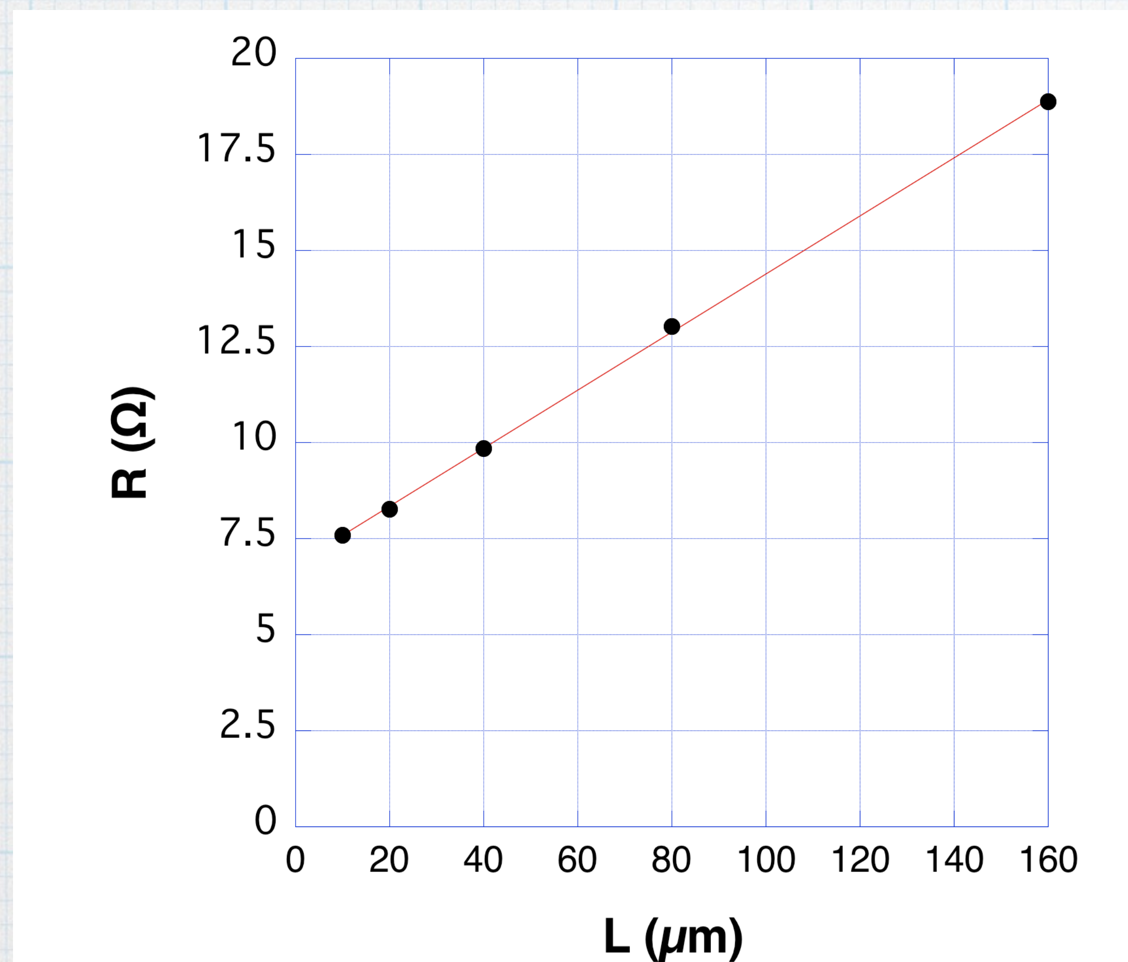
A typical arrangement for a TLM test pattern is shown below. There is a single rectangular region (blue in the figure) that has the same doping (i.e. same sheet resistance) as the contact areas of the devices. An array of contacts (darker gray in the figure), with various spacings, is formed over the doped region.



Resistance measurements between each pair of contacts can be used to construct the TLM graph. From the graph the parameters R_S, R_C, L_T, and ρ_C can be determined.

Example

The TLM patterns for the CyMOS process use, W = 100 μm and L = 10 μm, 20 μm, 40 μm, 80 μm, 160 μm. A set of measurements in the lab for TLM3 (NMOS source/drain diffusion) give the following resistances: R_1 = 7.59 Ω, R_2 = 8.26 Ω, R_3 = 9.85 Ω, R_4 = 13.02 Ω, and R_5 = 18.87 Ω.



$$R = 6.829\Omega + (0.0756\Omega/\mu\text{m})\, L$$

$$R_C = \frac{6.829\Omega}{2} = 3.415\Omega$$

$$R_S = \text{slope} \times W$$

$$= (0.0756\Omega/\mu\text{m})\,(\mu\text{m}) = 7.56\Omega/\square$$

$$0 = 6.829\Omega + (0.0756\Omega/\mu\text{m})\,(-2L_T)$$

$$L_T = \frac{6.829\Omega}{2\,(0.0756\Omega/\mu\text{m})} = 45.2\mu\text{m}$$

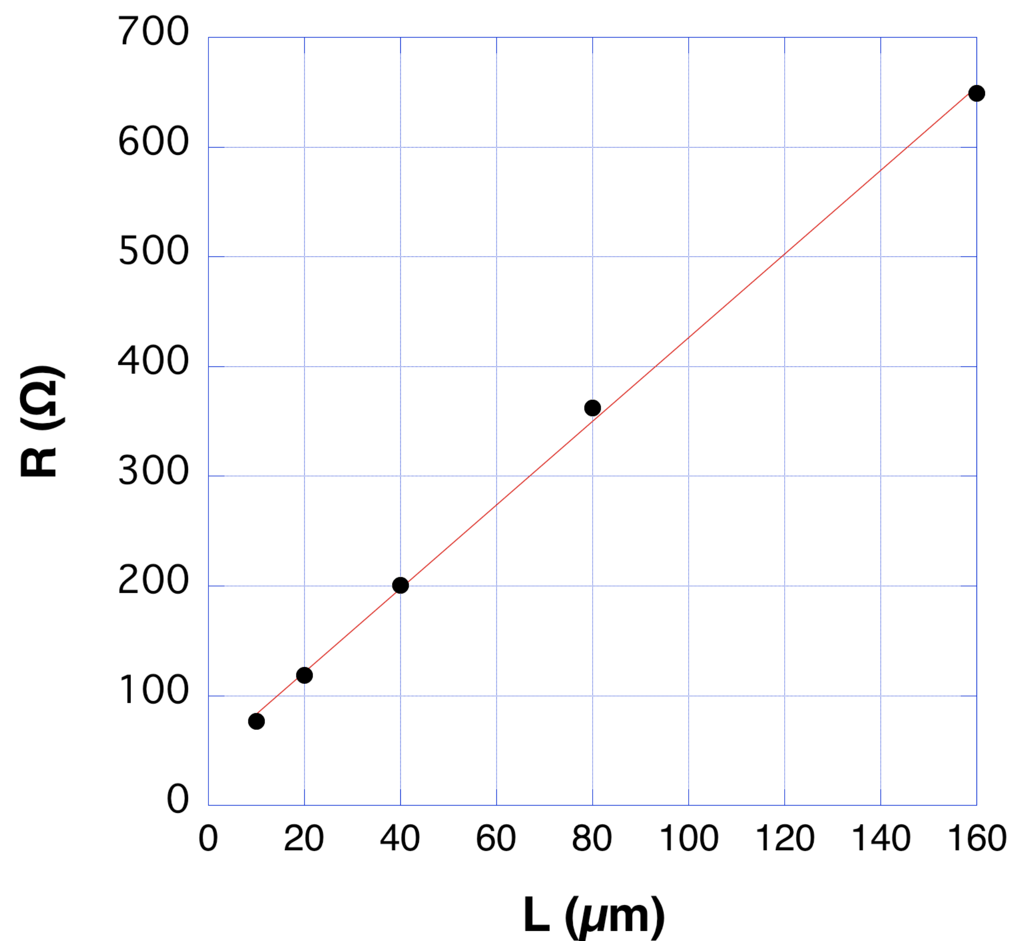
$$\rho_C = R_C L_T W$$

$$= (3.415\Omega)\,(0.009\text{cm})\,(0.01\text{cm})$$

$$= 1.54 \times 10^{-4}\Omega \cdot \text{cm}^2$$

Example

A set of measurements in the lab for TLM2 (PMOS source/drain diffusion) give the following resistances: $R_1 = 76.7\ \Omega$, $R_2 = 118.6\ \Omega$, $R_3 = 200.8\ \Omega$, $R_4 = 362.3\ \Omega$, and $R_5 = 648.9\ \Omega$.



Carrying through the same computations:

$R_C = 22.6\ \Omega$.

$R_S = 371\ \Omega\ / \square$

$L_T = 6.07\ \mu m$

$\rho_C = 1.37 \mathrm{x} 10^{-4}\ \cdot cm^2$

$$R = 45.1\Omega + (3.712\Omega/\mu m)\, L$$