3.5.4. Contact resistance to a thin semiconductor layer

The contact between a metal contact and a thin conducting layer of semiconductor can be described with the resistive network shown in Figure 3.5.1, which is obtained by slicing the structure into small sections with length Δx, so that the contact resistance, R_1, and the semiconductor resistance, R_2, are given by:

$$R_1 = \frac{r_c}{W \Delta x} \tag{3.5.1}$$

and

$$R_2 = R_s \frac{\Delta x}{W} \tag{3.5.2}$$

r_c is the contact resistance of the metal-to-semiconductor interface per unit area with units of Ωcm^2, R_s is the sheet resistance of the semiconductor layer with units of $\Omega/\square$ and W is the width of the contact.

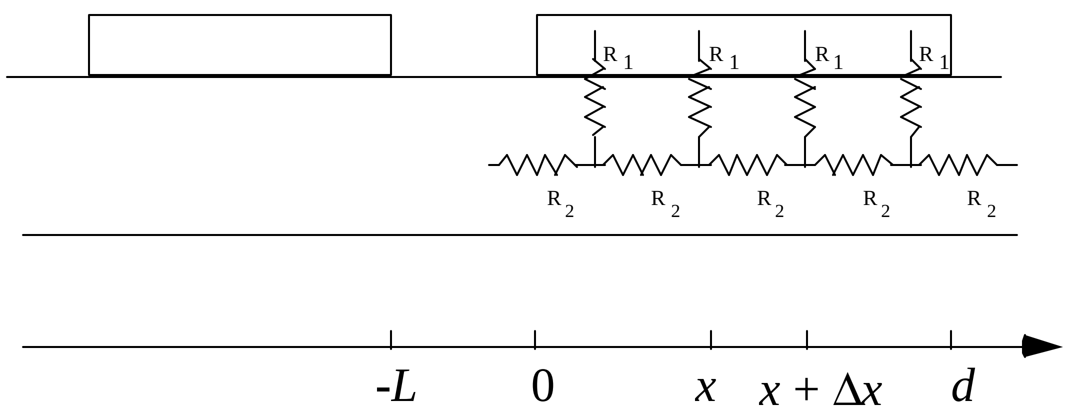

Figure 3.5.1 Distributed resistance model of a contact to a thin semiconductor layer.

Using Kirchoff's laws one obtains the following relations between the voltages and currents at x and $x + \Delta x$.

$$V(x+\Delta x) - V(x) = I(x) R_2 = I(x) \frac{R_s}{W} \Delta x \tag{3.5.3}$$

$$I(x+\Delta x) - I(x) = \frac{V(x)}{R_1} = V(x) \frac{W}{r_c} \Delta x \tag{3.5.4}$$

By letting Δx approach zero one finds the following differential equations for the current, $I(x)$, and voltage, $V(x)$:

$$\frac{dV}{dx} = \frac{I(x) R_s}{W} \tag{3.5.5}$$

$$\frac{dI}{dx} = \frac{I(x)W}{r_c} \tag{3.5.6}$$

Which can be combined into:

$$\frac{d^2 I(x)}{dx^2} = I(x)\frac{R_s}{r_c} = \frac{I(x)}{l^2} \text{ with } l = \sqrt{\frac{r_c}{R_s}} \tag{3.5.7}$$

The parameter l is the characteristic distance over which the current occurs under the metal contact and is also referred to as the penetration length. The general solution for $I(x)$ and $V(x)$ are:

$$I(x) = I_0 \frac{\sinh \frac{d-x}{l}}{\sinh \frac{d}{l}} \tag{3.5.8}$$

$$V(x) = I_0 \frac{l\ R_s}{W} \frac{\cosh \frac{d-x}{l}}{\sinh \frac{d}{l}} \tag{3.5.9}$$

Both are plotted in Figure 3.5.2:

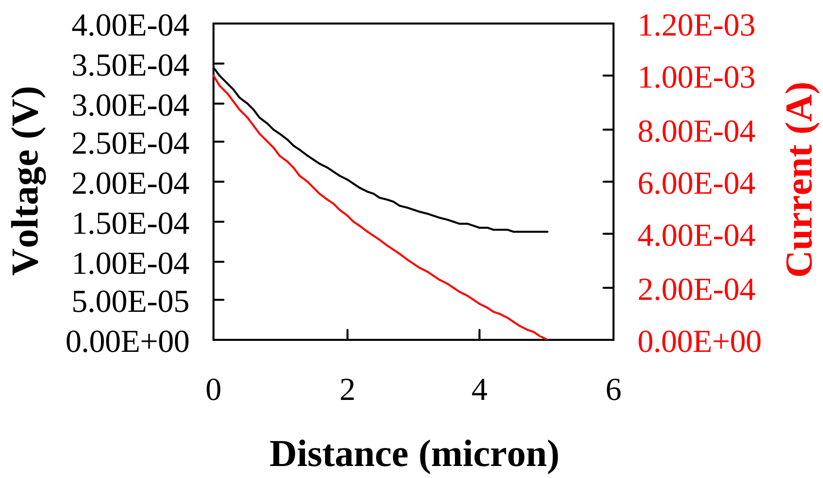

Figure 3.5.2 Lateral current and voltage underneath a 5 µm long and 1 mm wide metal contact with a contact resistivity of 10^{-5} Ω-cm^2 on a thin semiconductor layer with a sheet resistance of 100 Ω/□.

The total resistance of the contact is:

$$R_c = \frac{V(0)}{I(0)} = \frac{l\ R_s}{W} \coth\frac{d}{l} = \frac{\sqrt{r_c R_s}}{W} \coth\frac{d}{l} \tag{3.5.10}$$

In the limit for an infinitely long contact (or $d >> l$) the contact resistance is given by:

$$R_c = \frac{\sqrt{r_c R_s}}{W}\text{ , for } d >> l \tag{3.5.11}$$

A measurement of the resistance between a set of contacts with a variable distance L between the contacts (also referred to as a transmission line structure) can therefore be fitted to the following straight line:

$$R = 2\frac{\sqrt{r_c R_s}}{W} + R_s \frac{L}{W} \tag{3.5.12}$$

so that the resistance per square, R_s, can be obtained from the slope, while the contact resistivity, r_c, can be obtained from the intersection with the y-axis. The penetration depth, l, can be obtained from the intersection with the x-axis. This is illustrated with Figure 3.5.3.

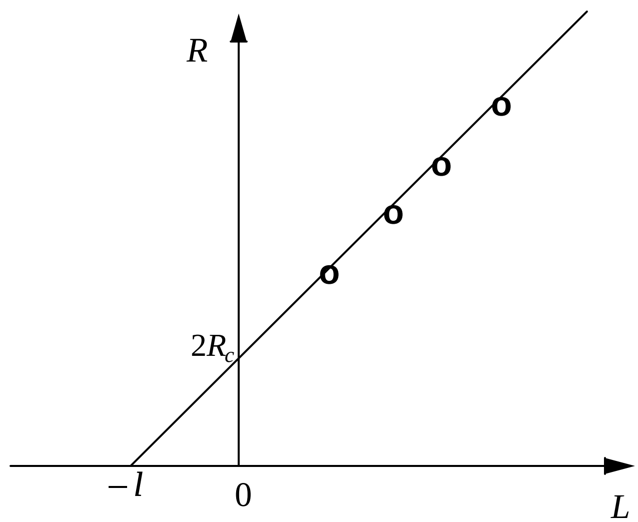

Figure 3.5.3 Resistance versus contact spacing, L, of a transmission line structure.

In the limit for a short contact (or $d << l$) the contact resistance can be approximated by expanding the hyperbolic cotangent[1]:

$$R_c = \frac{l\ R_s}{W}\left(\frac{l}{d} + \frac{d}{3l} + ...\right) = \frac{r_c}{Wd} + \frac{1}{3}R_s\frac{d}{W}\text{ , for } d << l \tag{3.5.13}$$

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[1] $\coth x = \frac{1}{x} + \frac{x}{3} + \frac{x^3}{45} + ...$ for $x << 1$

The total resistance of a short contact therefore equals the resistance between the contact metal and the semiconductor layer (i.e. the parallel connection of all the resistors, R_1, in Figure 3.5.1), plus one third of the end-to-end resistance of the conducting layer underneath the contact metal (i.e the series connection of all resistors, R_2, in Figure 3.5.1).