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RESISTANCE OF OHMIC CONTACTS BETWEEN METALS AND SEMICONDUCTOR FILMS

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The resistance is the principal property of an ohmic contact between a metal and a semiconductor. The value of this resistance has to be measured in order to determine the influence of contacts on the properties of devices and to develop the technology of contact fabrication. However, the known methods [1-3] are unsuitable for the direct determination of the resistance of a contact between a metal and a thin semiconductor film. This is because the experimentally measured total resistance of such a contact depends not only on the intrinsic resistance of the actual contact region but also on the spreading resistance in a thin layer of the semiconductor under the contact.

We shall consider the relationship between the total and intrinsic resistance of contacts in the shape of a rectangle, a circle, and an annulus (Figs. 1a and 1b). The thin semiconductor film, on which these contacts are deposited, is assumed to be lying on a high-resistivity substrate or a substrate with a different type of conduction. This situation corresponds to a heavily doped film subjected to diffusion, epitaxial growth or ion implantation. If the surface resistance of the contact metal is low compared with the surface resistance of the semiconductor, ρ_{ss}, and the width of the contact a is much greater than the thickness of the film, the contact may be represented by the equivalent circuit shown in Fig. 1c. We shall now give the differential equations which relate the voltage, the current, and the parameters ρ_c and ρ_{ss} for a rectangular contact:

$$di(x)=\frac{U(x)\,b\,dx}{\rho_c}, \tag{1}$$

$$dU(x)=\frac{i(x)\,\rho_{ss}\,dx}{b}, \tag{2}$$

where U_x is the potential difference between the metal and the semiconductor film at the point x;

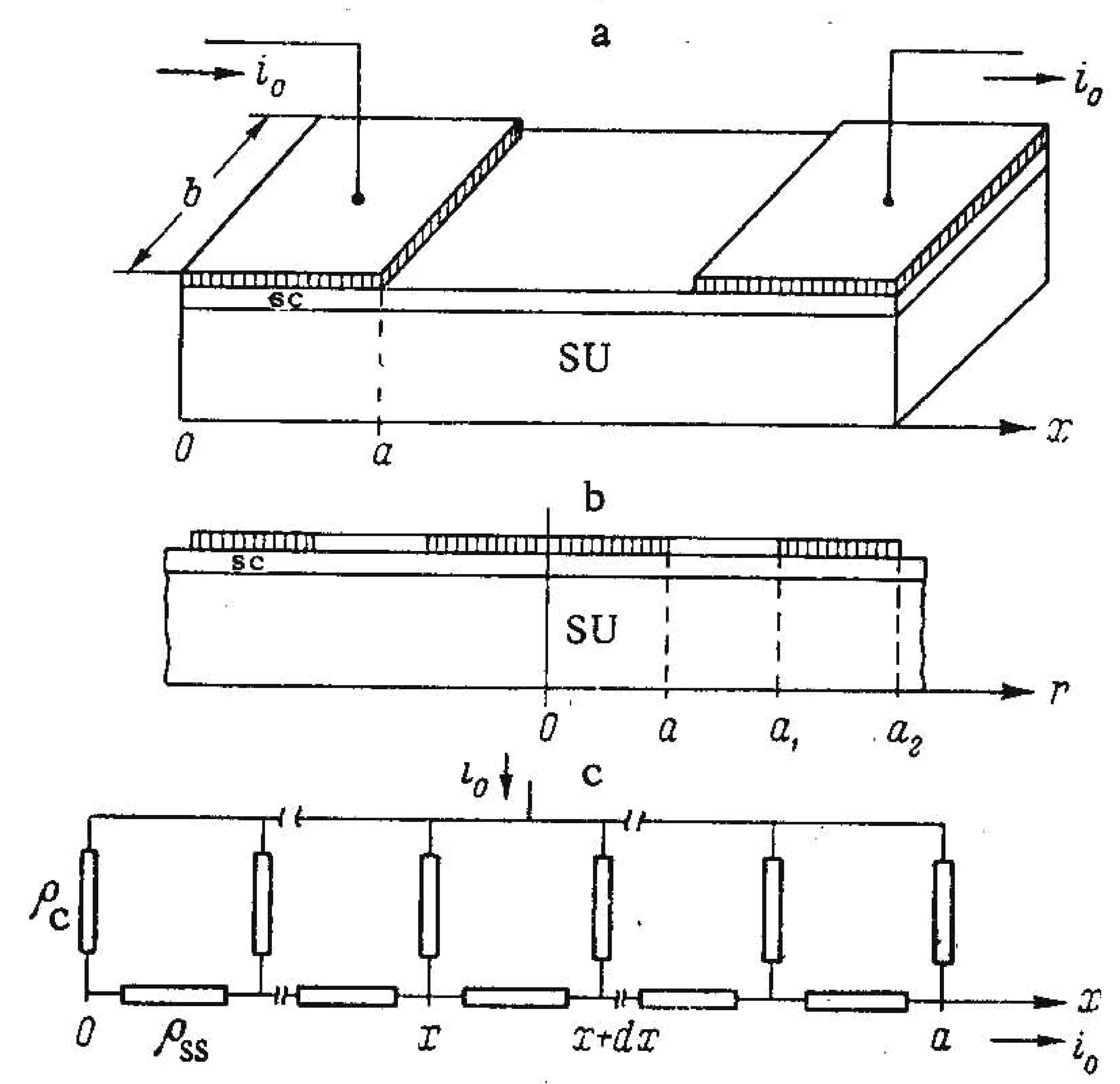

Fig. 1. a) Rectangular contact; b) circular and annular contacts; c) equivalent circuit of a contact with a thin film. SU is the substrate and sc is the semiconductor.

$i(x)$ is the current in the semiconductor film at the point x; ρ_c is the intrinsic resistivity of the contact; b is the length of the contact.

It follows from Eqs. (1) and (2) that

$$\frac{d^2 i(x)}{dx^2}-k^2 i(x)=0, \tag{3}$$

where

$$k^2=\frac{\rho_{ss}}{\rho_c}.$$

Similarly, we can derive a second-order differential equation for the voltage across circular and annular contacts:

$$r^2 \frac{d^2U(r)}{dr^2} + r\frac{dU(r)}{dr} - k^2r^2U(r) = 0, \quad (4)$$

where r is the radial coordinate. The solution of Eq. (3), subject to the boundary conditions

$$i(x)|_{x=0} = 0, \quad i(x)|_{x=a} = i_0$$

is of the form

$$i(x) = \frac{i_0 \operatorname{sh} kx}{\operatorname{sh} ka}. \quad (5)$$

The potential difference between the contact and the semiconductor film is given by the expression

$$U(x) = \frac{k\rho_c i_0}{b} \frac{\operatorname{ch} kx}{\operatorname{sh} ka}. \quad (6)$$

We can now determine the total resistance of the contact

$$R = \frac{U(x)}{i(x)}\bigg|_{x=a} = \frac{k\rho_c}{b} \operatorname{cth} ak = \frac{\rho_{ss} a}{b}\left[\frac{\operatorname{cth} ak}{ak}\right]. \quad (7)$$

The voltage drop across the semiconductor film is

$$U_s = \frac{k\rho_c i_0}{b}\left[\operatorname{cth} ak - \frac{1}{\operatorname{sh} ak}\right]$$

or

$$\frac{U_s}{U(a)} = \frac{\operatorname{ch} ak - 1}{\operatorname{ch} ak}.$$

The voltage drop across the intrinsic resistance of the contact is given by the expressions

$$U_c = \frac{k\rho_c i_0}{b \operatorname{sh} ak} \quad \text{or} \quad \frac{U_c}{U(a)} = \frac{1}{\operatorname{ch} ak}.$$

It is evident from Eq. (7) that the influence of the intrinsic resistance on the total resistance of the contact is important if $ak < 5$. If $ak > 5$, the total resistance is determined indirectly by the resistance of the semiconductor film under the contact. The total resistance can be represented in terms of the intrinsic resistivity and the effective area of the contact

$$R = \frac{\rho_c}{S_{eff}} = \frac{\rho_c}{ab}[ak \operatorname{cth} ak].$$

When $ak \to 0$, the effective area S_{eff} tends to become equal to the contact area S_c: $S_{eff} \to S_c = ab$; when $ak \to \infty$, we find that $S_{eff} \to S_c/ak = b/k$.

A solution of Eq. (4) is the sum of the zeroth-order Bessel functions with an imaginary argument $I_0(kr)$ and $K_0(kr)$:

$$U(r) = C_1 I_0(kr) + C_2 K_0(kr). \quad (8)$$

Using the appropriate boundary conditions and omitting, for the sake of brevity, all the intermediate steps, we obtain the following expressions for the total resistance of the circular and annular contacts: for the circular contact

$$i(r)|_{r=0} = 0, \quad i(r)|_{r=a} = i_0,$$
$$R = \frac{\rho_{ss}}{2\pi ak}\frac{I_0(ak)}{I_1(ak)}, \quad (9)$$

for an annular contact in the case of current flowing into the inner circumference of the ring, we have

$$i(r)|_{r=a_1} = i_0, \quad i(r)|_{r=a_2} = 0,$$

$$R = \frac{\rho_{ss}}{2\pi a_1 k}\left[\frac{K_1(a_2k)I_0(a_1k) + I_1(a_2k)K_0(a_1k)}{K_1(a_1k)I_1(a_2k) - K_1(a_2k)I_1(a_1k)}\right]$$

$$= \frac{\rho_{ss}}{2\pi a_1 k} A(a_1, a_2, k), \quad (10)$$

and for an annular contact in the case of current flowing into the outer circumference of the ring, we have

$$i(r)|_{r=a_1} = 0, \quad i(r)|_{r=a_2} = i_0,$$
$$R = \frac{\rho_{ss}}{2\pi a_2 k} A(a_1, a_2 k). \quad (11)$$

In Eqs. (9)-(11), the quantities I_1 and K_1 are, respectively, the first-order Bessel functions of the first and second kind with an imaginary argument.

The relationships (9)-(11) are valid also when the contact is in the shape of a circular or annular sector subtending an angle of α. In this case, the angle α should be substituted in place of the factor 2.

Equations (7) and (9)-(11) can be used to determine the intrinsic contact resistance if the dimensions of the contact and the values of ρ_{ss} and R are known. These expressions can be used also to analyze the influence of ρ_c, ρ_{ss}, and the dimensions of a contact on the total resistance of real contacts in semiconductor devices.

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