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Numerical and analytical modelling of head resistances of diffused resistors

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Abstract

Head resistances of diffused resistors are investigated by means of numerical device simulation. Outgoing from an understanding of the current flow pattern, an analytical model for the calculation of the head resistance from known geometric and technological parameters is developed. The results of the simulations and the modelling are verified by comparison with experimental data.

1. Introduction

In analog integrated circuits, diffused resistors [1] are quite common devices. They consist of a conducting strip with contact structures to the metal layer (heads) at both ends (see Fig. 1). For circuit design, precise knowledge of the resistance of the whole structure is of importance. In particular for low-ohmic resistors, the contributions of the contact heads to the total resistance become significant. In a cooperation with Philips Semiconductors in Hamburg, we investigated the head resistance by simulations and measurements of industrially fabricated devices.

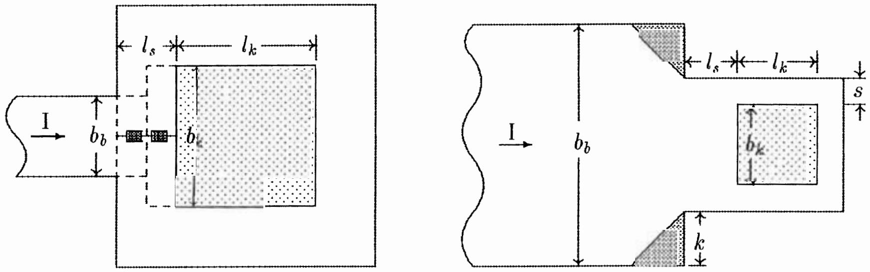

Figure 1: Contact head structures

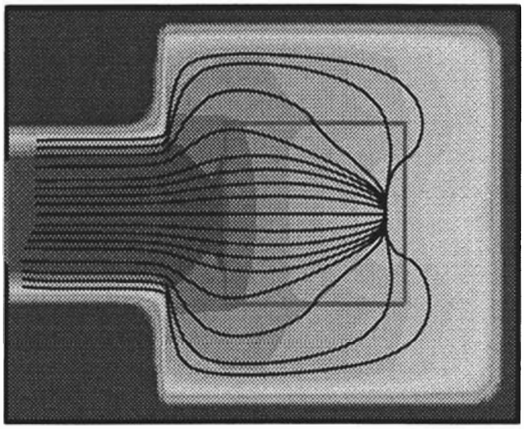

Figure 2: Current distribution of resistor head

width b_b [μm]	R_{head} [Ω] (simul.)	(meas.)
2.0	69.0	78
5.0	47.8	54

Table 1: Head resistances

2. Numerical simulations

We performed numerical 3D-simulations of the head structure using the device simulator PARDESIM [2]. The finite resistance of the metal-semiconductor interface [3] has been taken into account by our model of non-ideal contacts [4, 5, 6, 7]. Figure 2 [8] shows the result of a simulation of an example structure. The resistor is made by a p-type diffusion with a sheet resistance of $125\,\Omega_\square$ into low-doped n-type silicon. The contact window is indicated by the square. The dimensions are $3.5 * 3.5\,\mu\text{m}^2$ for the contact, $1.25\,\mu$m for the collar and $2.0\,\mu$m for the width of the resistor path. The shading indicates the absolute value of the current density on the semiconductor surface. The flow lines show that the current flowing from the resistor path spreads out into the head region, where it finally enters the contact.

We simulated the two basic structures shown in Fig. 1, i.e. the two cases where the resistor path is smaller resp. wider than the contact head. The extracted head resistances for these cases are shown in Table 1, together with values from measurements done by Philips. Good agreement is obtained. (The error is about 12 %, which is within the experimental uncertainty.)

3. Analytical modelling

Based on the current flow patterns (see e.g. Fig. 2) as obtained by the simulations, we developed an analytical model for the calculation of the head resistance from known geometric and technological parameters. The results are verified by simulations and measurements.

In Fig. 2, we identify three regions in the contact head with significant flow patterns: The region between the end of the resistor path and the contact metallization, where the current spreads into the wider head diffusion; the region under the contact itself, where the current sinks into the metal; and the region on both sides of the contact, where the current flows a considerable way around the contact before entering the contact area. These three regions are modelled each by a separate resistance, i.e. the spreading resistance R_{spread}, the contact resistance R_K, and the lateral resistance

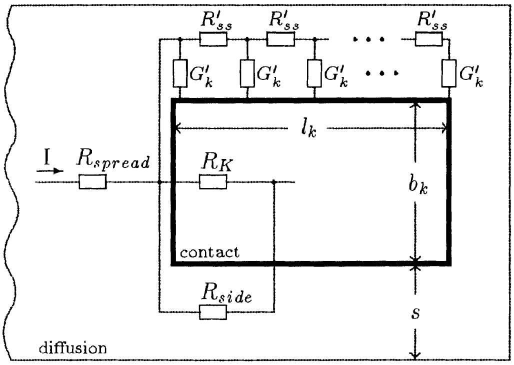

Figure 3: Modelling of lateral flow

R_{side} (cf. also Fig. 3):

$$R_{head} = R_{spread} + \left(\frac{1}{R_K} + \frac{2}{R_{side}}\right)^{-1} \tag{1}$$

The spreading resistance is composed simply by two resistors of distinct widths, as indicated in Fig. 1. The distributed inflow into the contact from underneath is modelled as a one-dimensional lossy transmission line, as shown in Fig. 4. The result is

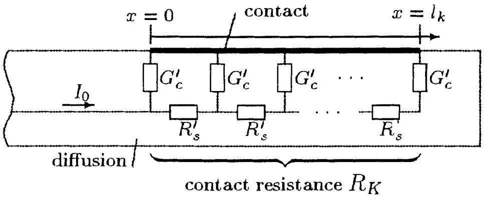

Figure 4: Modelling of contact flow

$$R_K = \frac{U(0)}{I(0)} = R_0 \coth\left(\frac{l_k}{l_t}\right), \tag{2}$$

where

$$l_t = \frac{1}{\sqrt{R'_s G'_c}} = \sqrt{\frac{\varrho_c}{R_s}}, \qquad R_0 = \sqrt{\frac{R'_s}{G'_c}} = \frac{\sqrt{R_s\,\varrho_c}}{b_k}. \tag{3}$$

A similar approximation is made for the lateral flow on both sides of the contact in order to obtain a model equation for R_{side}; see Fig. 3.

$$R_{side} = R_1 \coth\left(\frac{l_k}{l_1}\right), \tag{4}$$

$$l_1 = \frac{1}{\sqrt{G'_k R'_{ss}}} = \sqrt{s\, l_t \coth\left(\frac{b_k}{l_t}\right)}, \qquad R_1 = \sqrt{\frac{R'_{ss}}{G'_k}} = \sqrt{\frac{R_s}{s}\sqrt{R_s \varrho_c}\coth\left(\frac{b_k}{l_t}\right)}. \tag{5}$$

Eqns. (1-5) are the model equations for R_{head} as a function of the specific contact resistance ϱ_c, the sheet resistance R_s, and the geometric parameters.

b_k [μm]	l_k [μm]	b_b [μm]	R_{head} [Ω] (meas.)	R_{head} [Ω] (model)
3.5	3.5	2.0	78	78.9
3.5	3.5	5.0	54	55.4
6.5	3.5	8.0	33	33.2
6.5	3.5	11.0	40	41.5
12.5	3.5	17.0	24	23.4
18.5	3.5	23.0	18	16.3

Table 2: Measured and modelled head resistances

Several resistor heads with different dimensions have been investigated; the results are presented in Table 2. The table shows the measured and the modelled head resistance for various combinations of the contact size and the path width. Good agreement between the experimental results and the model is obtained.

In conclusion we note that the presented analytical model for contact head resistances can be used to accurately estimate the total resistance of diffused resistors during circuit design or process development.

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[8] Picture created with *Picasso*, developed by ETH Zurich and ISE AG, Zurich.