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DESIGN METHOD OF DIFFUSION RESISTORS

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10-7 DESIGN METHOD OF DIFFUSION RESISTORS

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§1. Introduction

The first part of the present paper describes the method of analysis the changes of diffusion layer resistivity during the drive-in process in order to obtain diffusion layer with desire parameters. Second part of this paper deals with the method of design the diffusion resistors with small temperature sensitivity of resistance.

§2. Diffusion Layer Resistivity Changes During the Drive-in Process

The phenomena on the silicon-oxide interface during the oxidation time was investigated by various authors. Grove *et al.*[1~3] and Shannon[4] have investigated these phenomena for uniform doped silicon material. Kato and Nishi,[5] Huang and Welliver,[6] Margalit[7] have analysed problem for diffusion layer by numerical method. But until now, the diffusion processes are carried out in empirical way.

Resistance per square of diffusion layer is described by:

$$R_{\square}=\frac{1}{\int_0^x qN\mu dx}=\frac{1}{q\bar{\mu}Q} \tag{1}$$

where

$\bar{\mu}$: effective carrier mobility in diffusion layer,

Q: impurity charge in the layer per unit area.

Equation (1) can be rewritten in the form:

$$R_{\square_2}=R_{\square_1}\frac{\bar{\mu}_1Q_1}{\bar{\mu}_2Q_2} \tag{2}$$

where indexes 1 and 2 indicate parameters before and after drive-in process.

Introducing new parameters $g_\mu=\bar{\mu}_2/\bar{\mu}_1$ and $g_Q=Q_2/Q_1$ eq. (2) can be rewritten in the form:

$$R_{\square_2}=\frac{R_{\square_1}}{g_\mu\cdot g_Q} \tag{3}$$

where

g_μ: correction factor resulting from the change of effective carrier mobility,

g_Q: correction factor resulting from the reduced number impurity in the diffusion layer.

If the dependence of carrier mobility from impurity concentration is approximated by relation:

$$\mu=\mu_0\left(\frac{N_0}{N}\right)^a \tag{4}$$

then the effective mobility for diffusion layer with gaussian impurity distribution is:

$$\bar{\mu}\overset{\text{def}}{=}\frac{\int_0^\infty \mu(N)N(x)dx}{\int_0^\infty N(x)dx}=\frac{\mu_S}{\sqrt{1+a}} \tag{5}$$

where μ_S-carrier mobility near the surface.

Finaly the correction factor is expressed by the relation:

$$g_\mu=\left(\frac{Ld_2}{Ld_1}+1\right)^{\frac{a}{2}}=\left(\sqrt{\frac{D_2t_2}{D_1t_1}}+1\right)^{\frac{a}{2}}. \tag{6}$$

The starting point of the correction factor g_Q analysis was the assumption that the impurity charge which occurs in the diffusion layer in silicon is reduced by the impurity charge which has come into the oxide in the course of oxidation:

$$Q_2=Q_1-Q_{SiO_2} \tag{7}$$

and then

$$g_Q=1-\frac{Q_{SiO_2}}{Q_1}. \tag{8}$$

The number of impurities getting into oxide is decreasing during the oxidation time. Concentration of impurities in oxide is:

$$N_{SiO_2}(x)=N_{S1}\frac{k_1}{\sqrt{\frac{D_2t_2}{D_1t_1}+1}}=N_{S1}\frac{k_1}{\sqrt{\frac{Dx^2}{BL_{d2}^2}+1}} \qquad (9)$$

where

N_{S1} : impurity surface concentration before process,

$L_{d1}=\sqrt{D_1t_1}$: diffusion length for prediffusion,

$L_{d2}=\sqrt{D_2t_2}$: diffusion length for drive-in process,

$x=\sqrt{Bt_2}$: oxide thickness.

Parameter k_1 contains the segregation coefficient $m=N_P/N_{SiO_2}$ and N_S/N_P rate which slightly increase with the oxidation speed (Fig. 1). Parameter k_1 is a weak function of $\sqrt{D/B}$. In our analysis we assume $k_1=$ constant, which is measured experimentaly. Such proceeding can be simply taken from the fact that various segregation coefficients were published by various authors.

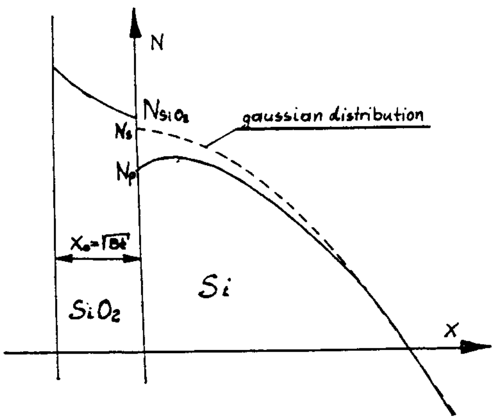

Fig. 1

The charge of impurities in oxide by integration of eq. (9) is as follows:

$$Q_{SiO_2}=k_1N_{S1}L_d\sqrt{\frac{B}{D}}\,arsh\left(\frac{L_{d_2}}{L_{d_1}}\right). \qquad (10)$$

The initial impurity charge in diffusion layer before drive-in process was:

$$Q_1=k_2N_{S1}L_{d_1}. \qquad (11)$$

Finaly the correction factor is expressed by the relation:

$$g_Q=1-K\sqrt{\frac{B}{D}}\,arsh\,\frac{L_{d_2}}{L_{d_1}} =1-K\sqrt{\frac{B}{D}}\,arsh\sqrt{\frac{B}{D}}\frac{x}{L_{d_1}}. \qquad (12)$$

If we regard the fact that after prediffusion on the surface remained an oxide layer with the thickness x_0, the calculations become a little more complicated but finally obtain:

$$g_Q=1-K\sqrt{\frac{B_2}{D_2}}\ln\frac{x+\sqrt{B_2t_2+L_{d_1}\frac{B_2}{D_2}}}{x_0+L_{d_1}\sqrt{\frac{B}{D_2}}}. \qquad (13)$$

A frequently used method for the obtaining of a diffusion layer of the required parameters after the drive-in diffusion, is the method of carrying out the drive-in diffusions in several stages. In this case the correction factor is expressed by the dependence:

$$g_Q=1-\sum_1^n K\sqrt{\frac{B_n}{D_n}}\ln\frac{x_n+\sqrt{B_nt_n+t_{n-1}D_{n-1}\frac{B_n}{D_n}}}{x_{n-1}+\sqrt{t_{n-1}D_{n-1}\frac{B_n}{D_n}}}. \qquad (14)$$

§3. Analysis of the Temperature Sensitivity of Diffusion Resistors

Starting point of the analysis was that the temperature properties of diffusion resistors depend mainly from temperature carrier mobility changes.[8,9] Lattice and impurity scattering are of crucial significance in transport phenomena. The resultant mobility was computed by the method proposed by Wolf.[10]

Assuming that the impurity concentration in the substrate is much lower than the surface concentration following expression for resistance per square of diffusion layer can be written:

$$R_\square L_d=\frac{1}{2q\int_0^\infty \mu(n,T),\,n(z,T)dz}. \qquad (15)$$

One may observe that in the above expression the right side of the expression does not depend from the diffusion process parameters $D(T)$ and t, but it depends only from the surface concentration of impurities after the process and of course from the temperature. The dependence of $R_\square L_d$ product from impurity surface concentration and temperature after taking into account the previously accepted assumption has been calculated by means of computer.

The dependence of relative changes of $R_\square L_d$ from temperature with the impurity surface concentration N_S as parameter is ilustrated in Fig. 2. Figure 3 presents the temperature sensitivity of diffusion resistors as a function of $R_\square L_d$ temperature as parameter.

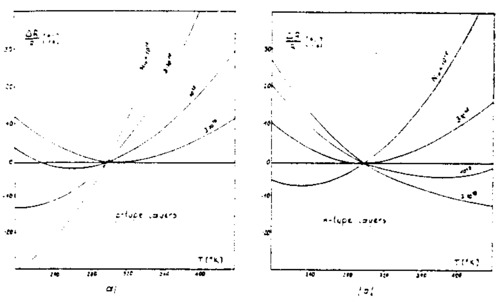

Fig. 2

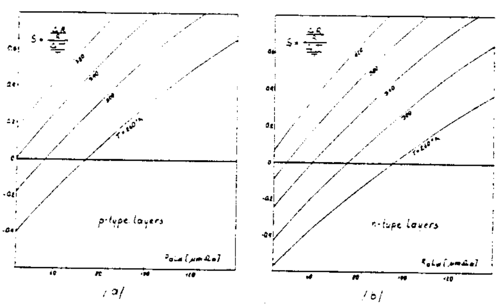

Fig. 3

§4. Conclusion

The practical sugestion is, that for obtaining low temperature sensitivity resistors in monolithic integrated circuits the parameters of diffusion processes should be so chosen as to fulfil the dependencies:

$$R_\square \sqrt{Dt} \approx 50 \ [\mu m\Omega] \text{ for } p\text{-type layer} \quad (16)$$

$$R_\square \sqrt{Dt} \approx 70 \ [\mu m\Omega] \text{ for } n\text{-type layer}. \quad (17)$$

Procedure for design of drive-in process from eqs. (3), (6) and (14) can be obtained. For boron diffusion in temperature about 1150°C and water bath temperature 70~90°C from experimental data the value of parameter k in relation (12) was measured as $k=0.35$. Few diffusion steps were also proceeded the results obtained were with a good agreement with the above analysis.

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