THE ANALYSIS OF ELECTRICAL PARAMETERS IN MULTILAYER HETEROSTRUCTURE

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Abstract

The calculation of the potential (ψ) and carrier concentration (N and P) distribution in multilayer heterostructure, such as METAL – DIELECTRIC – P^+ – N – N^+ – METAL for various thicknesses of particular layers and different values of applied voltage was made.

In order to make a calculation, the corresponding mathematical-physical model was designed, which describes the carrier transport in such structures. On the bassis of the model, using the wellknown procedures, the algorithms for numerical calculations were realized.

The graphical diagram of the obtained results is given and the analysis of the influence of particular parameters on the distribution of the calculated variables was done.

INTRODUCTION

In determining potential and carrier concentration distribution in arbitrary multilayer structures, we start from Maxwell's equations, continuity and transport eguations, equations for the carriers' concentrations and relations describing particular physical parameters. The mentioned relations in stationary case could be reduced through mathematical transformations, with defined restrictions, to the system of three simultaneous nonlinear partial equations of the form

$$\frac{\partial}{\partial x}\left(\mu_p(x,y)\,\frac{\partial \nu(x,y)}{\partial x}\,e^{-\frac{\Psi(x,y)}{U_T}}\right)+\frac{\partial}{\partial y}\left(\mu_p(x,y)\,\frac{\partial \nu(x,y)}{\partial y}\,e^{-\frac{\Psi(x,y)}{U_T}}\right)=$$

$$=\frac{R(x,y)}{n_i\,U_T}, \qquad (1)$$

$$\frac{\partial}{\partial x}\left(\mu_n(x,y)\,\frac{\partial\lambda(x,y)}{\partial x}\,e^{\frac{\Psi(x,y)}{U_T}}\right)+\frac{\partial}{\partial y}\left(\mu_n(x,y)\,\frac{\partial\lambda(x,y)}{\partial y}\,e^{\frac{\Psi(x,y)}{U_T}}\right)=$$

$$=\frac{R(x,y)}{n_i\,U_T} \qquad (2)$$

$$\frac{\partial^2\Psi(x,y)}{\partial x^2}+\frac{\partial^2\Psi(x,y)}{\partial y^2}=\frac{e}{\epsilon}\left(n_i\lambda(x,y)\,e^{\frac{\Psi(x,y)}{U_T}}-n_i\nu(x,y)\,e^{-\frac{\Psi(x,y)}{U_T}}-\right.$$

$$\left.-\,c(x,y)\right), \qquad (3)$$

where: μ_n, μ_p — electrons and holes mobilities, respectivelly, R — generation — recombination rate, U_T = RT/e — Boltzmann voltage, n_i — intrinsic concentration, λ and ν — substitution for exponential form of the quasi-Fermi potentials, ϵ — dielectric constant, e — elementary charge, c (x, y) — additional concentration.

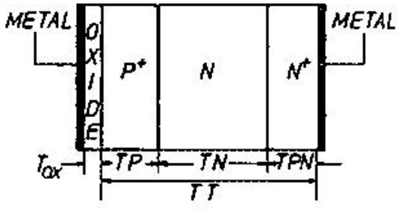

Fig. 1. The multilayer structure for the analysis

THE ALGORITHM FOR CALCULATION AND THE CALCULATION

Since the problem could not be solved analytically the numerical solving of the sistem (1) — (3) was approached, the well-known method of finite differences being used. At the discretization of the eguations the non uniform step was used, i.e. non uniform rectangular mesh network at two-dimensional theatment). The algorithms made for the calculation of ψ, N and P are such that they can be used for the analysis of other structures.

For easier solution of the system of equations (1) — (3), the normalization of physical variables figuring in them was made. By the discretization of equations the continuity problem was replaced by discrete one, so that the values of the unknown variables are determined in a finite number in selected grids ad the domain |2 — 7|. The nonhomogeneous step has enable a better following of rate of changes ψ, N and P in particularly parts of the structure without increasing the number of equations which are to be solved.

The algorithm for the analysis is of general character, and in this case it was applied to the structure in Fig. 1. For this structure it was sufficient to carry out a one-dimensional analysis (along the x-axis) due to the constant cross-section of this structure in the x, y — plane, normal on x — axis. For real treatment of the structure with unequal cross-sections a two-dimensional or a three-dimensional analysis will be made.

RESULTS AND DISCUSSION

The results for the potential and carriers distributions for various thicknesses of particular layers were obtained, with the unchanged dimensions of the complete structure from Fig. 1. The calculation is also made for various values of the applied voltages. The results of the calculation are presented in Figs. 2, 3 and 4. The changes of potential are quick at the boundaries P^+N and NN^+ of the region and they are larger for higher applied voltages and larger widths P^+ and N^+ regions (Fig. 2 and 3). The change of potential at the N^+N boundary of the region is considerably smaller and it is realized at considerably smaller width than is the potential drop at the P^+N boundary of the region. The concentration of holes and holes electrons in the N region depends on P^+ and N^+ region widths and it changes for several orders of magnitudes (Fig. 4).

Following the change of particular variables between electrodes it was found that the change of the potential is quick at diffusion depths P^+ and N regions as well as

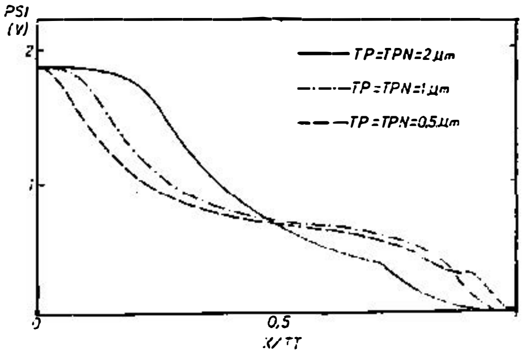

Fig. 2. Potential distribution in the structure of Fig. 1. for various thicknesses of particular regions

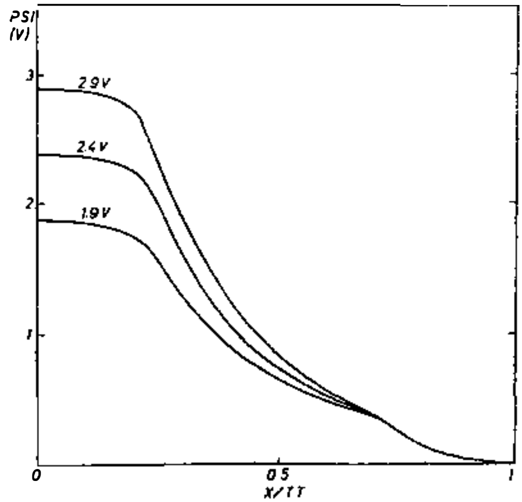

Fig. 3. Potential distribution for difference values of the applied voltages

the change of electrons and holes concentrations. The drop of potential at the boundary of the N^+ region is general tens of volts at the langth of tens of μm, which depends on the applied voltages at electrodes and concentrations of donors and acceptors impurities. The results obtained are not qualitatively compared with the results from literature, because they are not accessible to us for the structure studied. However, the qualitative comparison with the results for other semiconductor structures |4 – 7| point to the validity of the model which was used and the correctness of the result obtained.

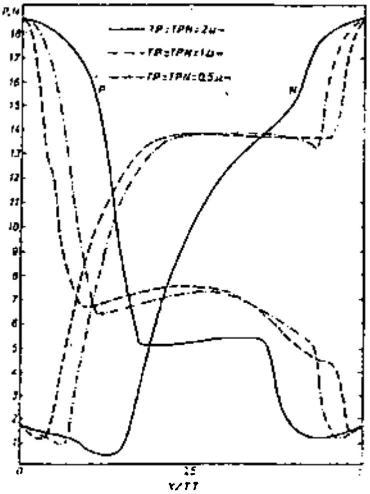

Fig. 4. Electron and hole distribution for various thicknesses of particular layers

CONCLUSION

The analysis carried out is very important because the considered structure in the present paper is encountered in modern electronic devices. The problem was treated generally, from point of view of the steady-state physics, and the algorithms for the calculation of potential and carrier distributions, so that they can be applied to the analysis of arbitrary complex structures. From obtained results, presented in Figs. 2, 3 and 4, the clear conclusions can be drawn about the influence of some geometrical and some electrical parameters on the behaviour of the structure under investigation. Certainly, there are possibilities of further improvenment of the mathematical-physical model as well as its extension to two- and three-dimensional form, where even more real imagnes of the considered phenomena could be obtained.

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