MODELING AlGaN p-i-n PHOTODIODES

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I. INTRODUCTION

Until recently the main technique for modeling physical processes was to compose equations that would describe the processes and solve them with some math package, like in [1, 2]. But today's expert systems

for modeling different processes are not worse than “manual” modeling. At the same time they provide a rich apparatus to program equations and present their results. This report considers using COMSOL MULTIPHYSICS software to create a model of a p-i-n photodiode based on AlGaN alloy.

II. METHOD AND RESULTS

The model created makes it possible to estimate I–V curve, spectral sensitivity, absorption coefficient, and other parameters as a function of the proportion of aluminum in the alloy and the thicknesses of the layers forming the photodiode.

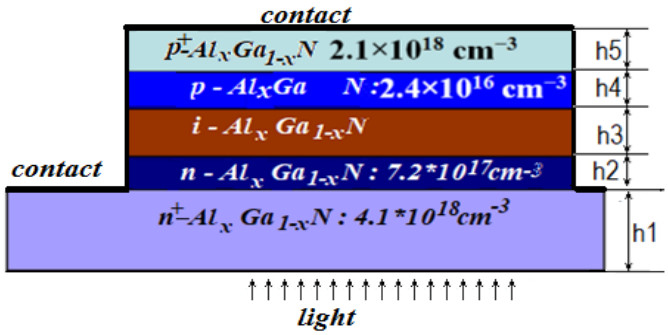

Figure 1. The model of the typical p-i-n photodiodes

The structure shown in Figure 1 is typical for nitride photodiodes. Between the n and p layers which have moderate electron and hole conductivity there is a pretty thick i-layer where most light is absorbed and converted into free charge carriers. This three-layer structure is complemented with highly doped n^+ and p^+ layers at the top and bottom which make it possible to obtain omic contacts with metallic leads. The lower n^+ layer solves some other problems except for contacting the leads. It reduces an intergrowth of dislocations from contact with the substrate into the overlying layers and compensates for errors in the etching depth of the upper layers when separating diodes. Therefore, the lower n^+ layer is much thicker than the others. It is applied on an AlN buffer layer which, in turn, rests on a sapphire substrate which does not participate in the modeling. Thicknesses of the h1 - h5 layers are parameters that can be easily changed before the model is calculated.

Taking into account the same processes along the horizontal axis, the structure shown in the figure is actually one-dimensional, which simplifies calculation. The COMSOL "optoelectronics" module solves the system of equations of the diffusion-drift model. It also offers several contemporary physical models for the interaction of a semiconductor with EMR.

The band gap E_g for $Al_xGa_{1-x}N$ at room temperature is calculated by using the well-known formula (1) which approximates actual dependence of E_g on x molar fraction of aluminum by the quadratic dependence [3]:

$$E_g^{AlGaN} = x\,E_g^{AlN} + (1-x)E_g^{GaN} - 1.1x(1-x) \quad (1)$$

It is known that electronic affinity potential of AlGaN decreases as the proportion of aluminum increases and the band gap increases according to a law close to linear. The calculation is based on the following formula from [4]:

$$\chi = 4.1 + 0.7(E_g^{GaN} - E_g^{AlGaN}) \quad (2)$$

Effective densities of the states in the conduction and valence bands are approximated by linear dependences on the fraction of aluminum [4]:

$$N_c^{AlGaN} = \left(\frac{T}{1K}\right)^{\frac{3}{2}}\left((1.8x + 4.6(1-x)\right)10^{14}cm^{-3} \quad (3)$$

$$N_v^{AlGaN} = \left(\frac{T}{1K}\right)^{\frac{3}{2}}\left((10.6x + 9.2(1-x)\right)10^{15}cm^{-3}$$

The dielectric constant ε and the relative effective masses of electrons (holes), m_e (m_h) are also assumed to be linearly dependent on the fraction of aluminum and determined as [4]:

$$\begin{aligned} \varepsilon^{AlGaN} &= 10.1x + 10.4(1-x) \\ m_e^{AlGaN} &= 0.314x + 0.2(1-x) \\ m_h^{AlGaN} &= 0.417x + 1.0(1-x) \end{aligned} \quad (4)$$

Other parameters and results of modeling are presented in the report.

III. CONCLUSIONS

We proposed the new numerical model using COMSOL MULTIPHYSICS software to estimate I–V curve, spectral sensitivity, absorption coefficient, and other parameters as a function of the proportion of aluminum in the AlGaN alloy and the thicknesses of the layers forming p-i-n photodiode based on AlGaN. This model was able to calculate the voltage and current dependency similar to device simulation as a continuous solution and could be useful for device development as a quick calculation. It could be also useful to academical and educational understanding the behavior of the electrical characteristics.

ACKNOWLEGMENTS

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REFERENCES

[1] N.N.Vorsin, A.A.Gladyshchuk, T.L.Kushner, N.P.Tarasiuk, S.V.Chugunov, “Modelirovanie i razrabotka AlGaN p-i-n fotodiodov”, Vestnic BSU, № 4. pp. 5-14, 2018.

[2] E.V.Lutsenko, A.V Danilchyk, N.P.Tarasuk, A.Andryeuski, V.N.Pavloskii, A.L.Gurskii, G.P.Petrovich, H.Kalish, R.H.Jansen, Y.Dikme, B.Schineller, M. Heuken.” Laser threshold and optical gain of blue optically pumped InGaN/GaN multiple quantum wells (MQW) grown on Si”, Phys. Stat. Sol. (c) , Vol. 5, Iss. 6, pp. 2263–2266.

[3] A.P.Nikonov, K.O.Boltar, N.I.Yakovleva, “Jpticheskie svoistva geteroepeksitalnih sloev AlGaN”, Prikladnaya fizika, № 2. pp. 50-52, 2014.

[4] ATLAS User’s Manual, Device Simulation Software, Version 5.20.2. R, SILVACO International, Santa Clara, CA, 2016.