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AlGaN Simulation Optimization for LEDs and Photodetectors

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Abstract— **InAlGaN photodetectors are of great interest for applications involving detection and imaging in the whole spectral range. In this work we present phototransistors parameters simulation for improving efficiency and performance characteristics. We made optimization in active area for QW quantity, width and it doping. During photodetectors simulation the Al mole fraction in the collector and emitter was varied from X=0.2 to X=0.3. The collector and emitter thickness was taken as 0.9 µm. The doping level in the emitter and collector was varied from 10^{17} to 10^{19}cm^{-3}. The p-GaN base thickness was taken as 0.3 µm, with doping of 10^{17}-10^{18}cm^{-3}. The electron and hole lifetimes in the base were taken as 12 ns.**

Keywords— Simulation, LEDs, photodetector, nanoheterostructure, nitride

I. Introduction

In this paper an actual problem of creating semiconductor photodetectors for the ultraviolet spectral range is discussed. Such devices can be widely used in various fields of technology, including devices that analyze the gases and liquids composition, and in the open optical communication lines with increased noise immunity in high solar radiation.

One of the most promising ways to create UV photodiodes is $Al_XGa_{1-X}N$ heterostructures usage and the base technology of their growth is metal organic chemical vapour deposition compounds (MOCVD), which allows producing heterostructures with high performance. Theoretically, these heterostructures allows creating photodiodes in the wavelength range 220 – 350 nm. Now it has been developed and manufactured a photodiode AG38S-SMD with sensitivity 0.12- 0.16 A/cm^2 for the radiation wavelength range of 250-350 nm.

Our investigations based on computer simulation showed that, based on such heterostructures not only photodiodes can be produced but also phototransistors (PT) with a sensitivity of more than 100 A/cm^2, in this wavelengths area. It has been proposed ultraviolet phototransistor (UV PT) structure, based on the capabilities of this technology with GaN and AlGaN collector. In this paper it is investigated the first step of the PT development - defining the multilayer heterostructures design by computer simulation: the structure type (n-p-n or p-n-p), the aluminum content, dopants thickness and concentration in the layers structure and other parameters.

II. Experimental part

$Al_XGa_{1-X}N$ phototransistor simulation with disabled base. SimWindows software (SW) was used in current investigation.

For $Al_XGa_{1-X}N$ photodiodes and phototransistors simulation special materials and devices files were created. Each individual Het. in its device file contained characteristics, such as the geometric dimensions of the emitters, quantum wells and barriers, the quantum well and barrier numbers, the solid solution content, the conductivity type, concentration, and the activation energy of dopants in each of the Het. areas. In the materials file for solid solutions, more than 25 parameters such as the band gap, refractive index, optical absorption, thermal conductivity, mobility and lifetime of charge carriers, electron affinity, the coefficients of radiative and non-radiative recombination, etc. were included.

This device is characterized by high values of gain for both shift polarities. Effective injection capacity is provided by the fact that the p-GaN base layer has a narrower bandgap than the emitter and collector layers. Thus delete limitation of conventional transistors eliminated. The limitation consistence of the need to create a light doped base layer and it can be realized the conditions under which the depletion region of reverse-shifted transition is mainly concentrated in the collector layer. The device has a high gain.

During heterostructure simulation for high efficiency and high sensitive phototransistor the structure consisted of the p- $Al_{0.3}Ga_{0.7}N$ collector, n-$Al_{0.3}Ga_{0.7}N$ emitter with an aluminum content of 30 % and a p-GaN base. The emitter and collector thickness was 0.875 µm, the base thickness - 0.3 µm. Acceptor concentration in p-$Al_{0.3}Ga_{0.7}N$ collector was 10^{17} cm^{-3}, donors in n- $Al_{0.3}Ga_{0.7}N$ emitter was 10^{17} cm^{-3}, the acceptor concentration in the p-GaN base - 10^{17} cm^{-3} or 10^{18} cm^{-3}. The lifetimes values of the nonequilibrium electrons and holes in all areas of PTs were equal to 50 ns. The device files have been created for both the concentration of acceptors in the base.

Method for PT characteristics simulation at two acceptor concentrations in PTs base (Na = 10^{17} cm^{-3} or Na = 10^{18} cm^{-3}) was: for the dark current density value J_{Ph} determination at different voltage U between the PT emitter and collector (plus on p- $Al_{0.3}Ga_{0.7}N$ collector), the voltage range was U = (1-9) V.

For the photocurrent density value J_f determination at various lighting power density values P, W/cm^2 was P = (10^{-6} - 10^{-1}) W/cm^2 and voltage between the PT emitter and the collector (plus on p- $Al_{0.3}Ga_{0.7}N$ collector) was U = (1-9) V. The energy of quanta during lighting was E = 3.5 eV. The Al mole fraction in the collector and emitter was varied from X=0.2 to X=0.3.

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III. RESULTS AND DISCUSSION

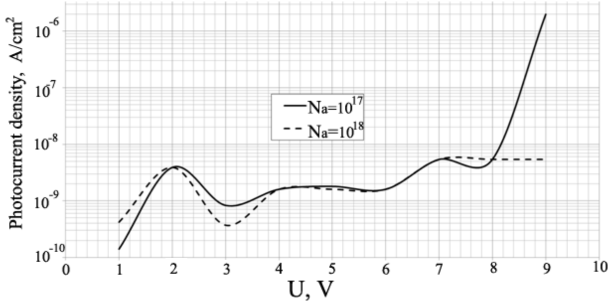

Fig. 1 Dark current density j_{ph} vs the PT voltage

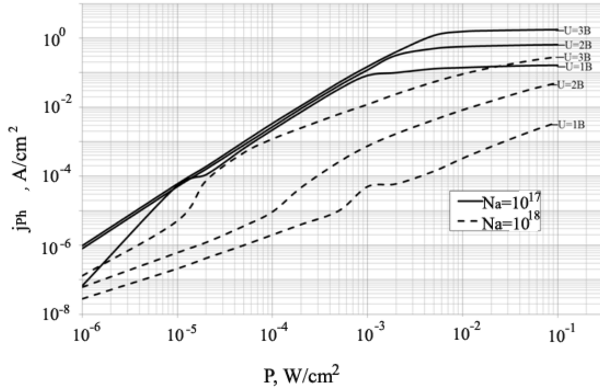

Fig. 2 Photocurrent density j_F vs irradiation power P, @ U=1 - 3 V

Dark current density J_{Ph} dependence at the voltage on PT is shown in Fig. 1. It is clearly seen that in the PTs at a acceptors concentration in the base Na = 10^{17} cm^{-3}, dark current begins to rise sharply at a voltage greater than 8 V, which is obviously corresponds with start of the clamping of the emitter and collector (Early's effect). When the acceptor concentration in the base Na = 10^{18} cm^{-3}, this effect occurs at higher voltages. At voltages less than 8 volts dark current density does not exceed 10^{-8} A/cm^2. This value limits the minimum magnitude of photocurrent density and, consequently, the minimum value of the recorded radiation power.

Photocurrent density j_F trend dependence at the light power density P at a constant voltage U between the PTs emitter and the collector are shown in Fig. 2. Lighting power range was P = (10^{-6} – 10^{-1}) W/cm^2; the voltage range was U = (1- 9) V. Due to huge data, it is presented by three sub-range voltage (1-3) (4-6) and the (7-9) V.

In Fig. 3 it is clearly shown that at the acceptors concentration in the base Na = 10^{18} cm^{-3}, the PTs sensitivity has a large value in a wide range of lighting, especially in the region of small power values P. At the same time, at the acceptor concentration in the base Na = 10^{17} cm^{-3} the PT sensitivity is maximum at relatively larger values of the power P, which makes them very promising in a variety of applications.

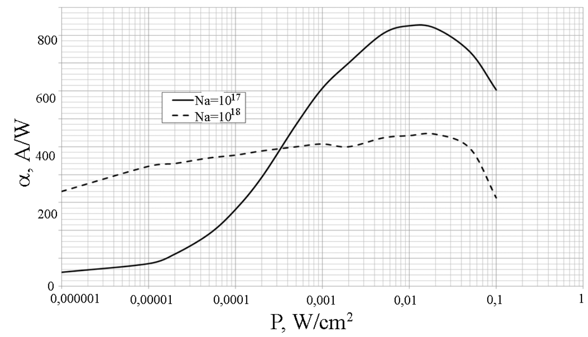

Fig. 3 Phototransistor sensitivity vs light power @ U= 9V.

IV. CONCLUSIONS

Conclusion of this dependence is quite obvious - to obtain a high sensitivity at voltage, applied to the PT, must be in the range from 6 to 9 volts. At the end of the discussion of UV phototransistor characteristics simulating we present data of the PTs sensitivity spectral dependence (Fig. 4).

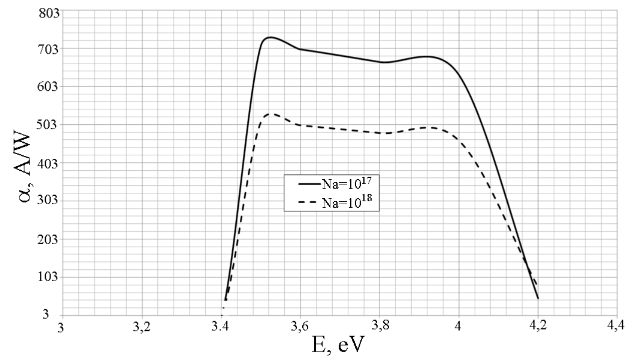

Fig. 4 Phototransistor sensitivity vs quanta energy E, eV @ P= 10^{-3} W/cm^2 and U= 9V

It is clearly seen that the PTs sensitivity is very high in the range of photon energies from 3.5 eV to 4 eV (wavelength range from 354 nm to 309 nm), which allows to use them as selective photodetectors. PTs selectivity can be increased by reducing the aluminum concentration in the p-$Al_{0.3}Ga_{0.7}N$ collector up to 20 %. Sensitivity also can be increased by improving MOCVD technology for more high quality AlGaN multilayer structures (with minimum defect concentration). If the sapphire substrate could be replaced by a gallium nitride substrate grown on sapphire, the lifetimes of nonradiative recombination in the PTs base will be increased significantly.

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