PHYSICS AND CHEMISTRY OF SOLID STATE
V. 20, № 4 (2019) p. 453-456

DOI: 10.15330/pcss.20.4.453-456

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ФІЗИКА І ХІМІЯ ТВЕРДОГО ТІЛА
Т. 20, № 4 (2019) С. 453-456

PACS ISSN 1729-4428

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Photosensitivity of MESFETs on Epitaxy Layers of GaAs with Monocrystalline Silicon Wafer

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In this paper described researched essentials and physical mechanisms which determine photosensitivity of MESFET on epitaxy layers of GaAs with monocrystalline silicon wafer under their illumination in impure zone absorption spectrum. Conducted experiments showed that source current changing with the type of deep centers, change of value is determined by two factors: change width of volumetric charge barrier contact layer and width of dipole layer on border section of active heterojunction layer of Si-wafer.

Keywords: electronics, LSI, Schottky FET, electroscopy, GaAs.

Стаття поступила до редакції 08.09.2019; прийнята до друку 15.12.2019.

Introduction

Semiconductors compounds in particular aluminium gallium arsenide, nowadays widely used for creating fast digital and analog either UHF devices or IC(LSI). That's why for practical realisation of active LSI components, for example, MESFETs used thin epitaxial layers, doped epilayers, which formed on a mono-Si wafer of large diameter > 150mm. This technology provides creating deep impure levels which sufficiently influence parameters and characteristics of active components.

For researching heterojunction MESFET we used an interesting method of photoinduced current spectroscopy which included in our manual about electrophysical diagnostics of submicron LSI structures. Electrophysical diagnostics was performed using test structures, in particular hilotrons for estimating speed and mobility of charge carriers.

Purpose of our research was the research of essential physics mechanisms which determine photosensitivity of GaAs MESFETs under their illumination in impure zone absorption spectrum which corresponds to the middle of GaAs band gap – this is important during their using as a photodetector for optical receiver module in fiber optic transmission systems.

I. Analysis of physical processes in heterojunction MESFETs

Change of channel resistance of MESFETs under infrared illumination determines by modulation of the width of volumetric charge layer under barrier contact and change of dipole layer in channel on the border between active GaAs layer and Si-wafer which caused by optical recharge of deep centers in band gap of GaAs. Here in general case in volumetric charge layer of barrier Schottky and dipole layer on the border between active layer and GaAs-Si-wafer can exist either donor or acceptor levels. Under illumination of MESFET structure, optical radiation in impure zone absorption spectrum(when the energy of quanta of radiation is smaller than band gap of GaAs) depending on type and degree of filling of deep levels possible two types of transfers.

Stability and character of influence of these processes on modulation of channel resistance will be determined there, in which particular area they happen.

In volumetric charge layer of Schottky barrier absorption of optical radiation can lead to next processes. When acceptor deep level is located higher than Fermi level, close to the edge of free zone, for acceptor levels probability of transfers of the first type is lower than probability of transfers of the second type and therefore illumination with optical radiation will lead to increasing of density of positive charge in Schottky barrier. This leads to narrowing of band gap and expanding of MESFET channel. If acceptor level located lower than Fermi level, then probability of first type transfers becoming higher than probability of second type transfers, in result density of positive charge is decreasing and expanding depleted zone under barrier contact respectively. For transfers with participating of donor levels will be observed inverse processes of modulation.

Width change of volumetric charge layer under barrier contact under illumination can be determined by solving Poisson equations for this area. Width of this layer of volumetric charge for structures in which concentration of shallow ε deep levels is not dependent from thickness with taking into account of charge captured by deep levels, then change of their charge states under illumination, can be described with this equation:

$$W_d = \left(\frac{2\varepsilon\varepsilon_0 \cdot (\varphi_b + U_g)}{\rho}\right)^{1/2}$$

At high enough level of excitation in saturation conditions of impure absorption at particular correlations of deep centers parameters, change of value W_d under illumination can be described:

$$W_d(U_g) = \pm\left(\frac{2\pi\varepsilon\varepsilon_0 \cdot (\varphi_b + U_g)}{qN_d}\right)^{1/2} \cdot \frac{kN_E}{N_d}$$

Here "+" sign corresponds to first type transfers with participating of acceptor levels and second type transfers with participating of donor levels. Absorption of optical radiation in dipole layer on the border between channel and wafer also leads to change of charge state of deep centers and corresponding to change of its thickness. Here depth of penetration of depleted dipole layer on the border of channel and wafer will be represented:

$$W_e = \left(\frac{2\pi\varepsilon\varepsilon_0 \cdot (\varphi_u - U_s)}{\rho_0 \cdot (\rho_0 + \rho_s)}\right)^{1/2}$$

Thereby, conducted analysis of photosensitivity of GaAs transistors with Schottky barrier(MESFET), gives possibility to determine: character of change of source current of MESFETs under illumination and radiation in impure zone absorption spectrum will be determined by type of deep centers in band gap, and change of value by sum of next effects: change of volumetric charge layer on barrier contact, width of dipole layer on border of channel and wafer under optical recharging of deep centers and by photo effect in quasi-neutral area of channel itself.

Analysis of physical processes confirmed by volt-ampere characteristics either of gas epitaxial or ione-dopped MESFET structures.

II. Experimental data and results

Illuminations of MESFETs with optical radiation with energy of quanta which somewhat smaller than band gap, causes thin transfers with participation of EL2 deep levels in band gap of GaAs. Behavior and value of change of source current under illumination determine with corresponding changes of conductance of drain, source, channel and a transitive layer of heterojunction channel-wafer, which actually are consequences of photogeneration of free charge carriers and variable charge state of deep level which determine thermofield stability of these phototransistors.

With method of photoinduced current electroscopy as informative diagnostic method researched normal MESFETs, made as test structures based on GaAs-layers, sedimented on mono-Si-wafers. The concentration of charge carriers in active layer , width of channel 0.15-0.2 μm, which formed by submicron LSI technology with using high-contrast lithography[1]. As resistances source-drain contacts were used AlSiHo-1-1(aluminium-silicon-holmium) films doped in magnetronic way of thickness 1.2 μm, same films composed gate system. Structure of MESFET shown on figure 1. Influence of optical radiation with a wavelength from 0.9 to 1.8 μm on characteristics of MESFETs was researched with the plant of photon annealing "Impulse 3M", electrophysical parameters of active and passive zone were researched with methods which were developed by the author for submicron technology LSI. Spectral characteristics of source current (figure 2) indicate existence of deep centers with energy

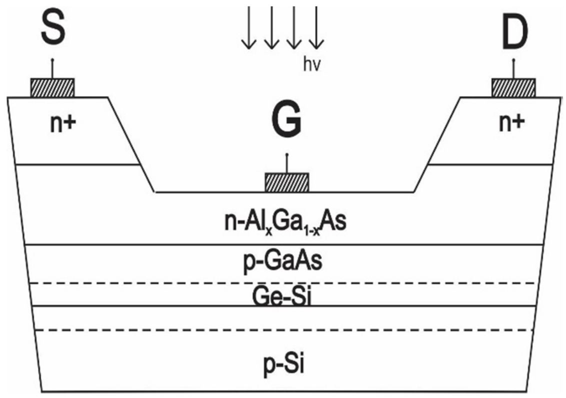

Fig. 1. Structure of heterojunction MESFET.

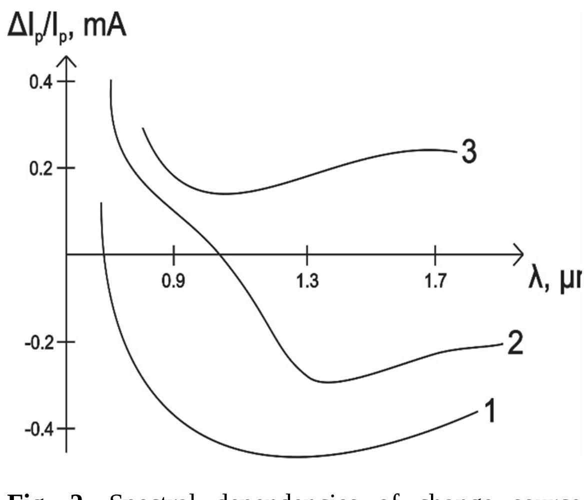

Fig. 2. Spectral dependencies of change source current of MESFET which based on gas-epitaxial layers (1,2) and ione-doped (3) structures.

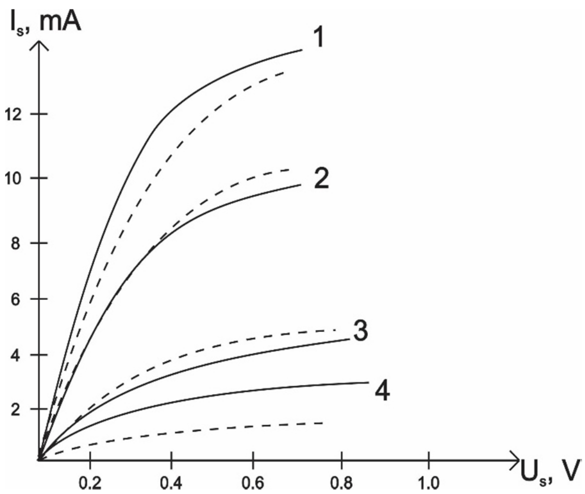

Fig. 3. Output volt-ampere characteristics of MESFET based on gas epitaxial layers (4) and ione-doped layers GaAs (2,3) without illumination continious and with illumination dashed.

0.72-0.91 eV. Based on analysis of GaAs MESFETs photosensitivity was calculated change of channel conductance with next formula:

$$\Delta\sigma/(q\cdot\mu\cdot N_d\cdot L/l) = F(t - w(U_{sh}))$$

which were formed in two versions:

1) gas epitaxial layers

2) ione-dopped layers by multicharge implementation.

It was established from analysis of source current spectral characteristics, for first version gas epitaxial structures typical presence of deep-centers acceptors, which gives for transistor positive tangent of the angle of inclination (fig.3) curves 1, 4, where source current during illuminations: radiation in impure absorbance zone is decreasing. Here during voltage offset on gate from zero to pinch-off voltage, transfers provided by volumetric charge on Schottky barrier.

And it was shown from the spectral dependency of source current for another version - ione-dopped MESFETs typical presence of deep donor levels and this experimentally visible on MESFET output characteristics (fig. 3, curves 2,3), where is negative tangent of the angle of inclination. For deep donor levels typical electron transfers from deep level to conductance gap(direct transfers), which leads to photoionization of deep levels, here density of volumetric charge in heterojunction increasing, causing decreasing band gap, here already passes decreasing of the channel during impure absorbance under particular voltage on the gate.

Conclusions

Based on conducted research its possible to make the next conclusions:

– Spectral dependencies of photocurrent of MESFET gate during controlling source current either straight or rear gate which based on gas epitaxial(1, 2) and ione-doped(3) structures (fig. 2), point to existence of deep centers of one type in volumetric charge layer under gate and dipole layer on border of active GaAs layer and Si-wafer.

– Experimental length dependencies of MESFET channel have different inclination based on ione-doped and gas epitaxial structures, which point to different physical nature of deep levels which contribute instability to output characteristics of the transistor (fig. 3).

– Introducing of buffer layer of Germanium between epitaxial GaAs layer and monosilicon wafer demonstrates a positive effect of generation of acceptor-donor centers which allows improving stability of output characteristics of MESFETs of both types. This shows the possibility of forming CMOS transistors with GaAs.

– Determined basics mechanisms of physical processes which is responsible for the stability of source current of MESFETs and allows to form test structures for electrophysical diagnosing with submicron LSI technology.

– Photostimulated gas epitaxial and multi-charge implementation of forming gate system of MESFETs give possibility to set up serial production with submicron technology of epilayers on mono-Si-wafer of LSI structures with high speed and noise immunity.

– In MESFETs based on gas-epitaxial structures conductance channel somewhat shifting to wafer because of expanding of volumetric charge under the gate and decreasing of depth penetration dipole field in contact;

– In MESFETs based on ione-dopped layers in structure conductance channel shifting in direction of Schottky barrier.

– This technology allows to form silicon and arsenide gallium transistors on single crystal for analog, digital, power LSI circuits.

Brought researches allow making a conclusion about possible use of MESFETs as photodetectors in receiving optical modules of digital fiber optic transmission systems.

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Фоточутливість польових транзисторів Шотткі на епішарах GaAs на моно-Si-підкладці

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В даній статті описані досліджені основи і фізичні механізми, які визначають фоточутливість арсенідгалієвих ПТШ на моно-Si-підкладках на бар’єрі Шотткі при їх освітленні випромінювання в області домішкової смуги поглинання. Проведені експерименти показали, що характер змін струму стоку в такій структурі при освітленні визначаються типом глибоких центрів, а величина його зміни визначається в основному дією двох факторів: зміни ширини шару об’ємного заряду бар’єрного контакту та ширини дипольного шару на межі розділу активний гетероперехідний шар-Si-підкладка.

Ключові слова: електроніка, ВІС, польові транзистори Шотткі, електроскопія, GaAs.