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APPLICATION OF INNOVATIVE PHYSICAL MODELS FOR THE SOLUTION OF TECHNOLOGICAL ENGINEERING PROBLEMS

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ABSTRACT

The most important trend in engineering education is the use of advanced physical models to solve technological problems.
We present two examples of such an innovative approach.
One of the common methods for treating industrial effluents in the coal industry is the use of sedimentation tanks, which are reservoirs into which water is supplied carrying particles of coal and solid rocks. The paper considers the movement of a two-phase medium under the action of gravity with an uneven distribution of the impurity concentration. Under the influence of gravity, a cloud of solid particles sinks to the bottom, and at the same time, due to the difference in concentrations, different parts of this cloud have nonzero velocities relative to each other. Precipitating, the particles engage the carrier medium in motion. As a result, the deposition of groups of particles occurs faster than individual particles. A two-phase convection model is used.
In the second example, a method for two-dimensional numerical simulation of submicron field-effect transistors with a Schottky gate is proposed, which allows one to take into account the effects of unsteady electron dynamics and to study complex carrier transport phenomena. The proposed approach allows one to take into

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account the edge effects at the drain end of the gates, which are manifested in the appearance of regions of high concentration of electric field strength, which significantly affect the nature of the motion of charge carriers.

1 INTRODUCTION

1.1 General basis and description of the presented tasks

The most important trend in engineering education is the use of advanced physical models to solve technological problems. We present two examples of such an innovative approach. Both examples are based on the use of complex physical and mathematical models of multiphase flow hydrodynamics to describe engineering problems. The unifying idea of the presented solutions is to take into account the features of the studied phenomena for the modification of generalized systems of equations of continuum mechanics.

At Tomsk State University and Tomsk State University of Control Systems and Radioelectronics, in the study of numerical methods for solving problems of continuum mechanics, special attention is paid to methods of simplifying the mathematical statement taking into account the physical features of the problems (as was done in the first example) and the application of the studied methods of continuous medium to solving problems in related areas (as was done in the second case by describing the problem of electrophysics with a hydrodynamic model).

1.2 Description of the problem of calculating the settling of the "cloud" of particles in the liquid

Currently, one of the important technological issues in the extractive industry is the task of treatment and recycling of industrial effluents. One of the common cleaning methods in the coal industry is the use of sedimentation tanks, which are reservoirs into which water is supplied carrying particles of coal and hard rock. Under the influence of gravity, the impurity settles and the liquid cleanses. To increase the efficiency of the process, it is necessary to be able to predict the movement of liquid and particles and take into account their mutual influence. In particular, this is explained by the fact that the fall time of a single coal particle is many times longer than the settling time of a group of particles of a similar size.

The paper considers the movement of a two-phase medium under the action of gravity with an uneven distribution of the impurity concentration. Under the influence of gravity, a cloud of solid particles sinks to the bottom, and at the same time, due to the difference in concentrations, different parts of this cloud have nonzero velocities relative to each other. Precipitating, the particles engage the carrier medium in motion, as shown by many experiments. As a result, the deposition of groups of particles occurs faster than individual particles. This phenomenon is taken into account in the work using the feedback mechanism. A two-phase convection model is used [1, 2]. The model is valid for particles with a diameter of 10-50 μm, the relaxation time of which is small compared with the characteristic process time.

Moreover, under the condition of sufficiently small volume concentrations of particles, the mechanism of interaction between particles is neglected.
The considered two-phase convection model is implemented to describe the deposition in the reservoir of a “cloud” of particles suspended in water.
Sedimentation of inclusions causes vortex flows, which deform the shape of the aggregate of particles and cause accelerated sedimentation of the impurity.

1.3 Application of a hydrodynamic model to the study of electron gas in a Schottky transistor

GaAs-based field effect transistors (PT) are known to occupy an important place in semiconductor microwave electronics. Since its inception, submicron membranous PT based on the Schottky barrier have gained the main distribution. The use of two-dimensional structures for the manufacture of PT can increase the operating frequency and increase the power of the transistor. However, for this it is necessary to reduce the size of the shutter, which makes the approximation of a smooth channel unacceptable. Moreover, the absence of a substrate makes it necessary to take into account the effects of hot electrons in the drain gate region of the closure of depleted regions.
In this work, we propose a method for two-dimensional numerical simulation of submicron GaAs-PT with a Schottky gate based on the solution of partial differential equations, the Poisson equation, and current continuity for electrons, which allows one to take into account the effects of unsteady electron dynamics and to study complex carrier transport phenomena. The proposed approach allows one to take into account the edge effects at the drain end of the gates, which are manifested in the appearance of regions of high concentration of electric field strength, which significantly affect the nature of the motion of charge carriers.
The simplest models, which do not take into account the nonlinearity of the dependence of the electron drift velocity on the electric field strength, allow one to calculate the characteristics of the transistor up to the channel overlap, which is true only up to certain field strengths, after which the velocity of the charge carriers v saturates and remains constant, and this still happens until the channel is completely blocked. Taking into account the effects of non-linearity of the drift velocity allows us to calculate the characteristics of the transistor for any drain-source displacements up to breakdown and allows us to switch to two-dimensional modeling of a field-effect transistor.
For a uniformly doped PT, when there is no diffusion current, the current continuity equation takes on a simple form. The model describing the motion of electrons in the workspace is reduced to the equation of transfer of electron concentration and the equation for potential.

2 METHODOLOGY

2.1 Statement of the problem of settling of a "cloud" of particles

As a rule, the problems of the motion of multiphase media are solved on the basis of a model of interpenetrating continua. However, the system of equations for free

convection in a two-phase medium proposed in [1, 2], used in solving this task, has a positive feature, which consists in the absence of small quantities at the highest derivatives in the equations of motion, which makes it possible to use a faster and simpler calculation algorithm.
The aforementioned model of two-phase convection is implemented to describe the deposition of clouds in the tank from particles suspended in water. The plane problem was considered for the square in the vertical cross section of the region into which the set of particles is immersed. At the initial moment, the liquid and impurity are motionless, the “cloud” of particles has a rectangular shape.
In the equation of fluid motion, the presence of particles and their influence on the medium are taken into account through the integral characteristic — the density of the particle cloud ρ_s , which is calculated by the method of labeled particles. The interaction of the solid phase with the carrier medium is taken into account according to the Stokes law under the assumption that the impurity fragments have a spherical shape. This type of interaction is accepted as valid for both viscous and inviscid representations of the carrier medium.

2.2 Statement of the problem of electron gas motion

For a uniformly doped PT, when there is no diffusion current, the current continuity equation takes a simple form [3]. A model describing the motion of electrons in the working region under the assumption that there is no generation of charge sources and that recombination is negligible reduces to the equation of electron concentration transfer *Eq. (1)* .and the equation for the potential *Eq. (2).*

$$\frac{\partial n}{\partial t} + u\frac{\partial n}{\partial x} + v\frac{\partial n}{\partial y} = 0 \tag{1}$$

$$\nabla^2 \varphi = \frac{\rho}{\varepsilon} \tag{2}$$

here *n* is the electron concentration, *u* and *v* are the components of the displacement velocity, *φ* is the electric field potential, *ρ* is the charge density, *ε* is the dielectric constant of the medium, *t* – time.

The field effect transistor is schematically represented in Figure 1 by a rectangular GaAs region bounded by the metallized source and drain contacts. The drain in the Figure 1 is designated as discharge.

According to the third coordinate, the field effect transistor is considered large enough so that it is possible not to take into account edge effects. The gates are located symmetrically along the wide side of the GaAs region. The figure also shows the region of the Schottky barrier under the gate depleted in charge carriers. The depleted region expands as it approaches the drain, and when large displacements are applied between the drain and the source (or gate and source), the current flow channel is blocked on the drain side of the gate. The method proposed in the article allows one to change the concentration of charge carriers in the active region and calculate uniformly and nonuniformly doped field-effect transistors.

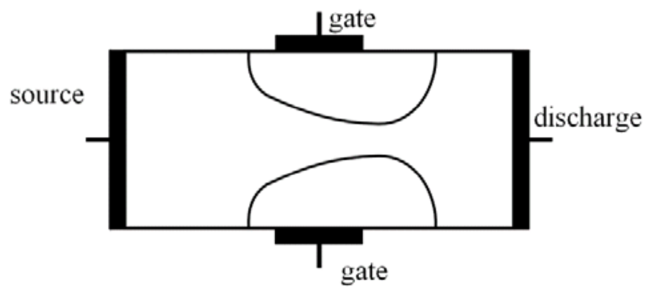

Fig. 1. Schottky Field Effect Transistor Model

3 RESULTS

3.1 Solution methods

Both problems under consideration are described by systems of partial differential equations. A more detailed presentation is given in the sources indicated in the reference.

To solve the equations, they are approximated by second-order finite differences, which makes it possible to obtain a system of algebraic equations, which is solved by standard methods

3.2 The results of the calculation of sedimentation of particles

Figure 2 shows the calculated field of fluid velocities and the arrangement of particles at various points in time. Sedimentation of inclusions causes vortex flows, which deform the shape of the aggregate of particles and cause accelerated sedimentation of the impurity. The nature of the behavior of the particle cloud is confirmed by the experimental data obtained by V.G. Khorugani [4].

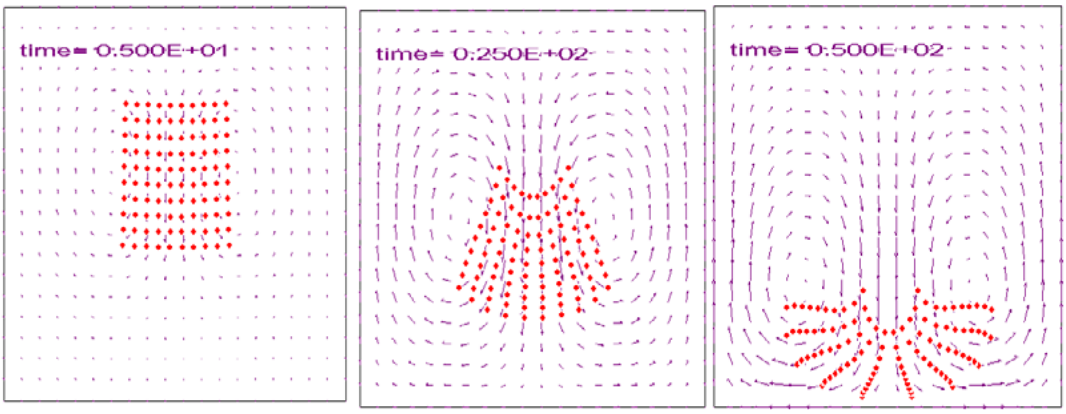

Fig. *2* Field of fluid velocities and the arrangement of particles at various points in time

Figure 3 shows the dependence of the particle cloud deposition time (t) in seconds on the particle concentration (ρ_s) for viscous (1) and inviscid (2) settings. The calculations were carried out at mass concentrations from 0.001 kg/m^3 to 0.04 kg/m^3.

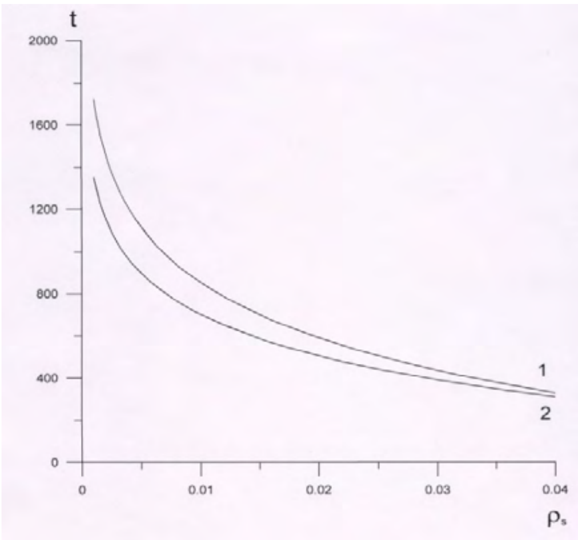

Fig. *3.* Dependence of the particle cloud deposition time (t) in seconds on the particle concentration (ρ_s):
1 – viscous settings ; 2 - inviscid settings

The results obtained for a viscous fluid are given in comparison with the results for an inviscid fluid. In a viscous medium, the deposition of particles is slower than in an inviscid medium, but with increasing concentration, the results gradually converge, which is explained by a decrease in the role of viscosity with respect to inertial forces.

Thus, taking into account the inverse effect of the aggregate of settling particles of an impurity involving the carrier medium in motion, it is possible to obtain the settling time of a “cloud” of particles significantly different from the settling time of a single particle. This is in full accordance with the data from practice

Comparison of the calculation results with similar ones performed on standard application software packages showed that the application of the proposed model can reduce the calculation time from 4 to 10 times.

Thus, the possibility of calculating by the proposed method the process of gravitational sedimentation of an impurity based on a two-phase convection model in industrial wastewater treatment plants is shown.

3.3 Results of the study of the motion of electrons

Figure 4 shows the lines of equal electron density, and figure 5 the lines of equal potentials for the drain-source displacements of 14 V, the gate-source displacements are 2.8 V. At such displacements, if we use the smooth channel approximation, the depletion regions should be overlapped and current flow is not possible. However, taking into account the effects of the nonlinearity of the drift velocity made it possible to calculate the characteristics of the PT, which are consistent with experimental data showing the presence of electron displacement from source to sink, i.e. the presence of current, as shown in Figure 4
An analysis of the potential and charge distribution showed that even at low potentials, a strong field exists at the gate and drain near the drain edge of the gate. It is established that for transistors with small geometric dimensions, the traditional approach of smooth channel approximation using the Poisson equation and the continuity condition becomes unsuitable.

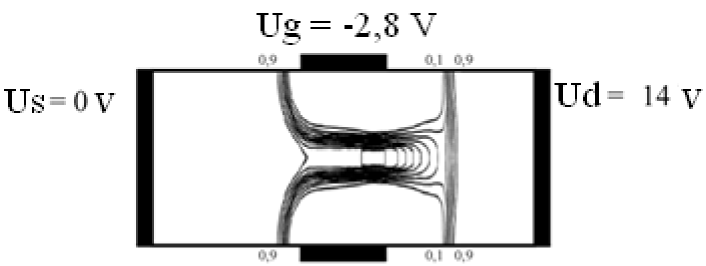

Fig. 4. Lines of equal electron density

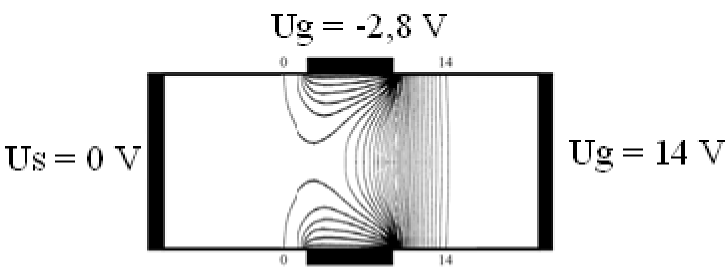

Fig. 5. Equipotential lines

The research results indicate the ability to simulate the current-voltage characteristics of field-effect transistors at a sufficient level that allows the design of devices of promising directions.

4 SUMMARY AND ACKNOWLEDGMENTS

The presented works show the relevance and need for students to study at a deep level physics, mathematics and numerical methods in the mechanics of a continuous medium. Taking into account the features of the processes under consideration allowed for the problem of settling a set of particles to significantly reduce the calculation time without losing accuracy, and to obtain data close to practical. The physical-mathematical model uses the concept of liquid concentration for a cloud of settling solid particles and allows to automatically take into account free convection and interaction of media without using complex models of interpenetrating continua. A more accurate simulation of the process of electron gas motion in a semiconductor made it possible to obtain a solution, which could not be obtained with a simple engineering approach. The representation of the electric current in a transistor in the form of a multidimensional particle flux allows the use of well-developed hydrodynamic models. It becomes possible to trace the entire process of electron movement, to determine the areas of change in their concentration and trajectory of their movement.
The solution found coincides with the operation of real transistors.
Only the use of more accurate innovative physical and mathematical models for solving engineering problems will allow us to move along the path of scientific and technological progress while preserving the ecology of our planet and rationally using natural resources.

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