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Optimisation and Problems of the Channel Area Formed by Two Ion Implantations in NMOS Structures

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Introduction

Formation of MOS transistor structures consists of many different technological operations (TO). TO depend on one another. Dependency can usually be identified by impurity redistribution $n+1$ TO. In the design phase it is crucial to select and determine the most accurate parameters of all TOs. Correct TO modes ensure lower percentage of manufacturing defects and faster choice of TO modes in the manufacturing process.

Optimization of the technological process in accordance with all TO parameters (factors) x, to ensure the selected MOS transistor structure's parameters y, is very complex due to a high variety of factors x.

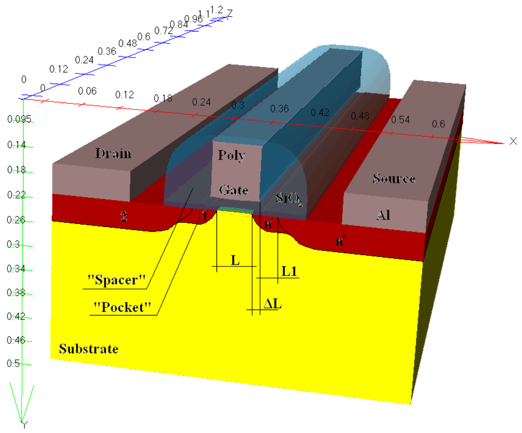

Fig. 1. Cross-sectional diagram of the NMOS transistor with lateral impurity implantation. n areas formed by way of 1,2 ion implantation [1]

Forming MOS transistor structures with the desired channel length (in this case L=90 nm) we face the problem of ensuring the channel length L. In view of the course of the MOS transistor manufacturing process we can see that the main TO that determine the L accuracy are TOs of the II upon which the source and drain areas are formed [1].

As we know that the MOS structure optimization is a complex process and it is not feasible to carry it out through classical experimental methods because of the resulting large sets of tests, and a series of tests must be carried out for the determination of each factor. In addition, it is not possible to evaluate the interaction between factors and its impact on the output parameter, since their transitions simultaneously is not analysed [2].

This work presents the optimization method of the ion implantation (II) modes. The main attention is paid only to the optimisation of the parameters of the source and drain formation TO (II TO). In this case, other technological modes of fabrication are kept stable. Then we have a 4-factor experiment, which output characteristic y is assigned the set channel length L [2].

Manufacturing process simulation is performed on the Athena software package. Regression coefficients b_n are calculated at the optimal values x and the optimal factor values x_{opt} are presented at the set values of y_{opt}.

Technology

The selected NMOS structure which technological route of manufacture consists of 23 main TOs (diffusion, implantation, etching etc.). Sketch of the structure is presented in Fig. 1. The analysed transistor is NMOS with the polysilicon gate, the width of which must match the channel length L. Initial channel length is L=90 nm [2,3].

In this case, the NMOS structure is formed on the 100 crystallographic orientation Si plate. After the preparatory TOs, the gate is formed on the basis of polysilicon [4]. After this TO, n^- impurities are introduced, in this case phosphorus (P), by the use of ion implantation. The main modes of this II are the implantation dose and energy. The dose of this TO in the optimization equation is a factor x_2, and energy is a factor x_1. During the P implantation (for the n^- field formation) the ion dose ranges between 10^{13} cm^{-2} and 10^{14} cm^{-2} , and the energy from 1 keV to 50 keV. Then "spacer" oxide is formed, which will enable local doping of the source and drain areas n^+ [1, 3, 5]. The dose of this TO in the optimization equation is a factor x_4, and energy is a factor x_3. During the implantation of arsenic (As) (for the n^+ area formation) the ion dose ranges between 10^{15}cm^{-2} and 10^{16}cm^{-2}, and the energy from 1 keV to 50 keV. All of the TO (factor) parameters have an impact on the output parameter y, which in this case is the channel length L. Parameters of these TOs and their selection during the manufacture will depend on the set output parameters y [4].

Factor optimization algorithm

MOS transistor simulation which is usually carried out at the design stage, is crucial to the quality parameters. In the production of NMOS the aim is to obtain the minimum channel in L, the minimum overlap ΔL, the optimal channel width B, the set output characteristic $U_{DS}=f(I_D)$ and transconductance S. All these desired parameters can be attributed to the optimization function's output parameters $y_1, y_2, ..., y_n$. Meanwhile, there are more than one input parameters in the same manufacturing phase. These are the TO parameters – TO modes, II energy, II dose, and so on. These are the input parameters or factors $x_1, x_2, ..., x_n$.

The optimization model is described as the incomplete square polynomial (1) [2]

$$\hat{y} = b_0 + \sum_{i=1}^{n} b_i x_i + \sum_{i=1}^{C_n^2} b_{il} x_i x_l + \sum_{i=1}^{C_n^3} b_{ilh} x_i x_l x_h \,. \tag{1}$$

To find the optimal values of the optimal x managed factors it is common practice to use the extremal experiment (search for extremes) [2]. For this, we firstly prepare an adequate model.

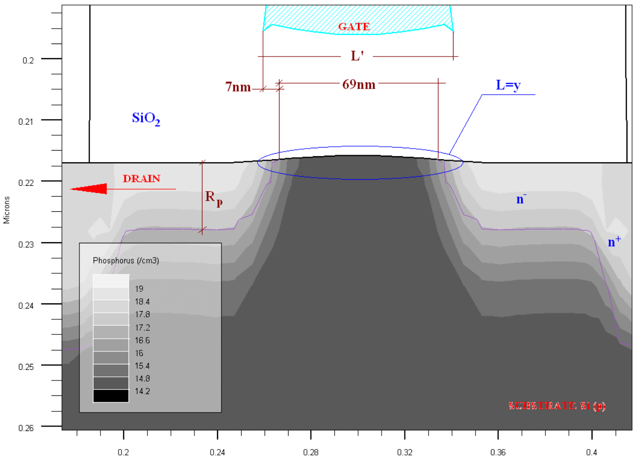

Fig. 2. Cross-sectional diagram of the NMOS transistor with lateral impurity implantation. When the TO parameters of phosphor ion implantation – energy 5 keV, dose $5{*}10^{13}$ cm^{-2}, As – energy 5 keV, dose $5{*}10^{14}$ cm^{-2}

Controlled factors will be the main TO modes of the P II – energy and dose, the main TO modes of the As II – energy and dose. As described above, these factors will correspond the factors x_1, x_2, x_3, x_4. So we will have the 4 factor plan, and tests $N=2^4$. As an output parameter, we accept the channel length L. In this case, look for the optimal values of x at which $y=y_{opt}$.

Typically by applying the extremal multifactor optimums search method, values x_{opt} are found at which $y=y_{min}$ or $y=y_{min}$ [2].

From the earlier tests we know that at the maximum dose, the value channel L is destroyed when the II energy exceeds 10 keV, so we will set the range of changes and choose the initial factor values. Initial values of factors are assumed x_1=5 keV, $x_2=5\text{x}10^{13}$ cm^{-2}, x_3=5 keV, $x_4=5\text{x}10^{14}$ cm^{-2}. NMOS structure with the initial values of factors is presented in Fig. 2. The plan of 16 tests is prepared, where the step of edge values for energy is ±0,1 keV, and for the dose P is $\pm 0{,}1\text{x}10^{13}$ cm^{-2}, for the As dose $\pm 0{,}1\text{x}10^{15}$ cm^{-2}.

Thus, the proposed algorithm based on which the optimum search steps in the design of the NMOS might be as follows:

1) Selection of the initial simulation parameter (factor) x_i values;
2) The model for the search of the optimum is described as the polynomial (1);
3) The experimental plan is drafted (it can be a full factorial experiment method). The least number of tests to be carried out is $N=2^n$. In this case n=4. The step of changing the plan factors λ_i is selected;
4) According to the selected plan, by using the existing Athena simulation software, we model the y output values;
5) We check the adequacy of the optimum search model;
6) The equation regression coefficients b_i are calculated;
7) According to the mathematical expression (2) we calculate the values of the new factors $x_{i,k+1}$

$$x_{i,k+1} = x_{ik} + \lambda_{ik} b_i \,; \tag{2}$$

8) We perform steps 1-7 in the new factor space point;
9) We repeat steps 1-8 until the optimum search model becomes inadequate;
10) We check the obtained y_{opt} and x_{iopt} according to the condition (3, 4, 5) and identify the position of values of the identified optimal factors by searching the true X_{iopt} at which y is equal to the output parameter we want to obtain, with the given allowable tolerance ε. In the analysed case, the channel length L'

$$y_{opt} > L' \pm \varepsilon \rightarrow x_{i\,max} \,, \tag{3}$$

$$y_{opt} < L' \pm \varepsilon \rightarrow x_{i\,min} \,, \tag{4}$$

$$y_{opt} = L' \pm \varepsilon \rightarrow x_{iopt} \,; \tag{5}$$

11) If $y_{opt}=L'\pm\varepsilon$ then the optimum search is considered to be terminated. But if not, then we select the step Λ of changing the initial factor values x in the factor field $x_{imin} \leq x \leq x_{imax}$. It is recommended that the Λ value is the same as λ_{ik} or less if necessary. We continue repeating steps 1-11 until the condition (3, 4, 5) is satisfied.

Certainly one has to compare whether in the optimum point b_i=0 and the condition (6) must be satisfied

$$\sum_{i=1}^{n} b_i \le \varepsilon \,. \qquad (6)$$

NMOS structure optimization results

According to the selected NMOS technology and prepared 4 factor optimization algorithm we found the optimal values of TO factors x_{1opt}, x_{2opt}, x_{3opt}, x_{4opt} for II. At these values, the optimisation function output y_{opt} is close to the set L'.

It should be noted that this optimisation is important to apply in the design stage. Certainly, it is necessary to evaluate the parameters of all stages to the analysed output parameter of their group in manufacture. In this case, the area of optimisation factors is defined only with the TO parameters of As and P II. Other factors existing in the NMOS manufacture constant, therefore it is not possible to state that a complete optimisation of the full structure formation has been carried out.

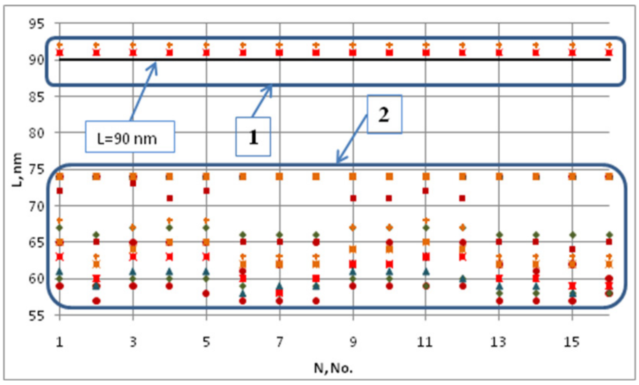

Fig. 3. Area of values of the y output parameter obtained during simulations according to the prepared pan: 1 – area of output values is closest to the set L'; 2 – the bottom part of the area of output values

This, in the analysed case, the set $\varepsilon = 1{,}0$ nm. The part of the area of output parameter values carried out according to the algorithm 1-11 steps is presented in Fig. 3. In this case, according to step 10 we determined the maximum and minimum values of factors and then determined the field of factors x_i Fig. 4. As we see, for both impurities, the II energy area is established - $5 \le x_{1,3} \le 6$ keV, dose area for P - $5\text{x}10^{13} \le x_2 \le 6\text{x}10^{13}$ cm^{-2}, dose area for As area - $5\text{x}10^{14} \le x_4 \le 6\text{x}10^{14}$ cm^{-2}. Next, the average parameter values from the defined area TO (II) were verified which indicated the further optimization direction. From the defined and obtained results we can determine (to make a hypothesis on) the direction of change of the NMOS channel length L or any searched parameter y. In this particular case of the NMOS structure it has been determined that y approaches the set $y=L'\pm\varepsilon$ nm when energy parameters (factors) for both implantations will change in the $5 \le x_{1,3} \le 5{,}5$ keV value field, P II dose will change in the $5\text{x}10^{13} \le x_2 \le 5{,}5\text{x}10^{13}$ cm^{-2} value field, and As II dose will change in the $5\text{x}10^{14} \le x_4 \le 5{,}5\text{x}10^{14}$ cm^{-2} value field.

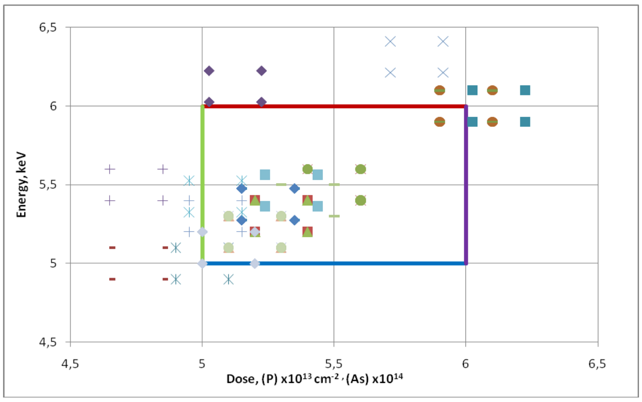

Fig. 4. x_i field of values according to the prepared factor change plan (step 3 of the algorithm)

Thus, according to the proposed algorithm and after the verification of additional conditions (5, 6) the optimal factors x_i values are determined. Accordingly, in this particular NMOS case the resulting x_1=3,3 keV, x_2=5,18x10^{13} cm^{-2}, x_3=5,05 keV, x_4=5,3x10^{14} keV. Received y_{opt}=91nm. NMOS structure according to the x_{iopt} values is presented in Fig. 5.

$$L' - \varepsilon \le y_{opt} \le L' + \varepsilon \,. \qquad (6)$$

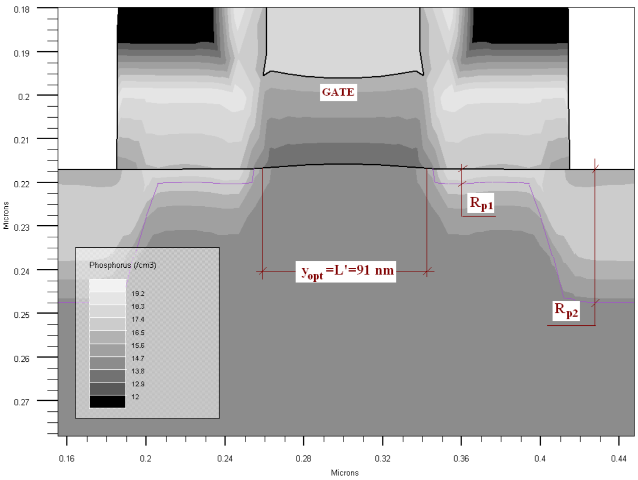

Fig. 5. Simulated NMOS structure at optimal x_{iopt} values. P ("pocket" formation) ion implantation energy 3,30 keV, dose 5,18x10^{13} cm^{-2}; As ion implantation energy 5,05 keV, dose 5,30 cm^{-2}

At such TO parameters of such NMOS source and drain area formation, the obtained channel length L does not ensure, however, brings closer to the optimum NMOS transistor output parameters. As seen in Fig. 5, we succeeded in L optimisation and proposing an algorithm, but did not succeed mathematically to ensure the designed pn junction depth. Therefore considerable attention was focused on the orthogonal deviation ΔR_p of the ion stretch, rather than the ion penetration depth R_{p1} and R_{p2} of separate TOs. We can state that the proposed optimisation algorithm does not ensure the set, and simultaneously the optimal NMOS output parameters, that are dependent from R_{p1} and R_{p2}.

Conclusions

1. The NMOS transistor structure selected for the channel area optimisation allowing the implementation of the structures with the channel length of 90 nm. The source and drain areas of the structure, and simultaneously the channel is formed by two ion implantation TOs.

2. For the optimization of the n^- and n^+ area formation TO parameter values, the 11 step and 3 cycle algorithm was proposed.

3. The optimisation of factor (TO parameter) values according to the desired (designed) output parameter (channel length) can be applied for the chosen technology.

4. The proposed algorithm assesses the 4 factor x_i mutual interaction effect on one output parameter y, therefore this algorithm can not be applied to the optimization of the complete NMOS manufacturing where x>4, and even more so when y>2.

5. After performing the optimization of the selected technology NMOS structure we obtained the following optimal TO parameter values of ion implantation – P ion implantation energy 3,30 keV, dose 5,18x10^{13} cm^{-2}; As ion implantation energy 5,05 keV, dose 5,30 cm^{-2}.

6. The NMOS model, according to the received optimization results, showed that in the manufacture of nano-structures it is not enough to optimize factors according to a single given output value y because when changing the input parameters, other parameters of structures output are changing (*pn* junction depth, parasitic capacities etc.).

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NMOS nano-structure channel structure depends on a number of technological processes. It is important to find and evaluate depend of technological operationts (TO) parameters to NMOP structures and output caharacteristics. The number of TOs in fabrication process is big, therefore it is difficult to evaluate and carry out optimization of all factors x_i (TO parameters). Wherefore proposed optimization algorithm of 4 factors x_i (energy and dose of to ion implantations parameters) by set output parameter value y (L) with the given allowable tolerance ε. This model is applicable for NMOS structures with designed 90 nm chanel. Ill. 5, bibl. 9 (in English; abstracts in English, Russian and Lithuanian).

В. Кашаускас, Р. Анилёнис. Оптимизация и проблемы области канала, сформированного двойной ионной имплантацией в НМОП наноструктуре // Электроника и электротехника. – Каунас: Технология, 2010. – № 8(104). – С. 35–38.

Области канала всех НМОП наноструктур зависят от целого ряда производственных процессов. При проектировании НМОП важно оценить влияние параметров технологических операций (ТО) на изменения НМОП структуры и на выходные характеристики. Поскольку в производстве бльшое число ТО, трудно оценить и выполнить x_i оптимизацию всех факторов (ТО параметров). Поэтому предлагается алгоритм оптимизации 4 факторов x_i (ТО параметры двойной ионной имплантации – энергии и дозы) по заданному значению выхода (длина канала L) с выбранной точностью. Модель приспособляют к транзисторной структуре НМОП, предназначенной для канала длиной в 90 нм. Ил. 5, библ. 9 (на английском языке; рефераты на английском, русском и литовском яз.).

V. Kašauskas, R. Anilionis. Dviem jonų implantacijomis NMOS nanostruktūrose formuojamo kanalo srities optimizavimas ir problemos // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 8(104). – P. 35–38.

Visų NMOP nanostruktūrų kanalo sritis priklauso nuo daugelio technologinių procesų. NMOP projektavimo etape svarbu įvertinti technologinių operacijų (TO) parametrų įtaką NMOP struktūros pokyčiams ar išėjimo charakteristikoms. Kadangi gamyboje atliekama daug TO, yra sunku įvertinti ir atlikti visų faktorių (TO parametrų) x_i optimizavimą. Todėl yra siūlomas keturių faktorių x_i (dviejų jonų implantacijos TO parametrų – energijos ir dozės) optimizavimo algoritmas pagal duotą išėjimo (kanalo ilgio L) vertę y su pasirinktu tikslumu ε. Modelis pritaikomas NMOP tranzistorinei struktūrai su projektuojamu 90 nm ilgio kanalu. Il. 5, bibl. 9 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

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