Donatas SAULEVIČIUS

RECOGNITION OF SELF-FORMED SEMICONDUCTOR ELEMENTS

Summary of Doctoral Dissertation
Technological Sciences, Informatics Engineering (07T)

1639-M

Vilnius VGTU LEIDYKLA TECHNIKA **2009**

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY
INSTITUTE OF MATHEMATICS AND INFORMATICS

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VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS
MATEMATIKOS IR INFORMATIKOS INSTITUTAS

Donatas SAULEVIČIUS

SAVAIMINGAI BESIFORMUOJANČIŲ PUSLAIDININKIŲ ELEMENTŲ ATPAŽINIMAS

Daktaro disertacijos santrauka
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Introduction

Topicality of the problem. The new self-formation simulation technologies for electron devices and integrated circuit manufacturing were developed. The topological approach allows performing the analysis and synthesis of real world structures known in the areas of microelectronics, nanotechnology, photovoltaic and fuel cell technology. Self-formation simulation results are two-dimensional geometric figures from the Euclidean space. The analysis of such object structures in order to meet defined characteristics becomes an actual problem since it is an extremely labour consuming process. Automatic recognition of self-formed semiconductor element can speed up the analysis process.

Subject of research is self-formed semiconductor elements structures.

Aim of the work – to propose the solution for the recognition of self-formed semiconductor elements structures by classifying them into two classes, namely, class $\mathbf{\Omega_1}$ (good structure) and class $\mathbf{\Omega_2}$ (bad structure).

Tasks of the work. In pursuance with this aim the following issues where dealt with:

1. The creation of method and algorithm for recognition of the self-formed semiconductor elements structures.
2. The creation of recognition system of the self-formed semiconductor elements structures.
3. The performance of the proposed system suitability.

Methodology of research includes comparative analysis, induction and experimental analysis of methods for the theoretical researches. The semiconductor elements recognition system was built using Microsoft Visual Studio .NET 2003 development environment.

Scientific novelty

1. The method for recognition of the semiconductor elements, based on Regional Connection Calculus, was presented.
2. The algorithm of computer system in recognition of the self-formed semiconductor elements structures has been created.
3. The software application for recognition of the self-formed semiconductor elements structures has been developed.

4. The experimental research for the suitability of the software application for recognition of the self-formed semiconductor elements structures have been performed.

Practical value. The analysis proposed in the dissertation allows setting a task for recognition of any self-formed semiconductor elements sets. This method is useful for recognizing any self-formed two-dimensional elements structures if the suitability of elements can be described by substances (regions) which participate within the structure and connections between the substances no matter what the forms of the regions are.

Automation of self-formed semiconductor elements structure recognition can help to:

- accelerate objects selection;
- reduce designers work volume;
- get higher selection results.

This work presents a reliable criterion for various elements sets classification with presumptive further use.

Defended propositions

1. Features set of the self-formed semiconductor elements are characterized by the substances (regions) and connections between the substances.
2. Analysis of the self-formed semiconductor elements structures is based on spatial entities (regions of space) – the qualitative spatial reasoning approach, instead of traditional point-based one.
3. The proposed qualitative spatial reasoning theory and created recognition system method are suitable for the recognition of self-formed semiconductor elements structures.
4. Developed self-formed semiconductor elements structures recognition system is flexible for recognizing any self-formed two-dimensional structures if the suitability of elements can be described by the participation of the substances within the structure and by connections between the substances.

Approval of the work. The main results were published in two reviewed periodical publications from the list approved by the Science Council of Lithuania. The results were presented in one international conference and in seminars of the Institute of Mathematics and Informatics.

The scope of the scientific work. The scientific work consists of four chapters, the list of publications and two appendixes. The total scope of dissertation is 116 pages, 42 pictures, 8 tables and 2 appendixes. The dissertation is written in Lithuanian.

1. Review of Image Recognition Methods

The problem is to classify two-dimensional geometrical figures into two sets, two classes. Class $\mathbf{\Omega_1}$ describes semiconductor elements structures which are suitable for mass production, class $\mathbf{\Omega_2}$ – unsuitable ones. In this case the main objects for recognition are the regions of the two-dimensional image and connections between those regions.

Extraction of separate objects in the image using special image processing techniques is not important in this case. The essential reasons to assign pattern to class $\mathbf{\Omega_1}$ are relations between the regions within the image not depending on its geometrical form.

The importance of the inspection process has been magnified by the requirements of the modern manufacturing environment. In electronics mass-production manufacturing facilities, an attempt is often made to achieve 100 % quality assurance. A variety of approaches for automated visual inspection of printed circuits are widely used in the semiconductor industry for reliability testing and product inspection due to its ability to non-destructively detect defects in Integrated Circuit packaging.

In many cases recognition of two-dimensional pictures is based on segmentation and image smoothing techniques, or furthermore, using multiple classifiers, e.g. colour, shape and relational classifiers. Relational classifier has been published by few authors where are two types of topological relationships between two regions: one is adjacent relationship when two regions are adjacent with each other, the other one is contained relationship when a region is contained in another region. The distance between the regions is the most important thing here. Nevertheless, colour, shape and relational classifiers uses samples to find similarities, but do not analyze structure relevancy.

The criteria for qualitative evaluation of self-formed semiconductor elements might be based on the theory of Qualitative Spatial Reasoning initially developed by Clarke and further refined by many authors, including Cohn et al.

The fundamental approach of RCC is that extended spatial entities, i.e. regions of space, are primary rather than the traditional mathematical dimensionless point. The primitive relation between regions is that of connection, thus giving the language the ability to represent the structure of spatial entities.

Qualitative spatial reasoning theory is used for GIS, image analysis, etc. This theory is also called C theory, as from ‘Connectivity’, and characterized by essential axioms. The basis of the system is one primitive dyadic relation **C(x,y)** read as “*x connects with y*”.

The essential axioms are as following:

$\forall x[C(x,x)]$ (reflexivity); (1)

$\forall x \forall y\ [C(x,y) \rightarrow C(y,x)]$ (symmetry); (2)

$DC(x,y) \equiv_{def} \neg C(x,y)$ (*x* is disconnected from *y*); (3)

$EC(x,y) \equiv_{def} C(x,y) \wedge \neg O(x,y)$ (*x* is externally connected to *y*); (4)

$O(x,y) \equiv_{def} \exists z[P(z,x) \wedge P(z,y)]$ (*x* overlaps *y*); (5)

$P(x,y) \equiv_{def} \forall z[C(x,z) \rightarrow C(z,y)]$ (*x* is a part of *y*); (6)

$EQ(x,y) \equiv_{def} P(x,y) \wedge P(y,x)$ (*x* is identical with *y*); (7)

$CON(x) \equiv_{def} \forall yz[sum(y,z) = x \rightarrow C(y,z)]$ (continuous), (8)

where sum(x,y) – the quasi-Boolean function sum of *x* and *y*.

Graphical interpretation of axioms illustrated in Fig. 1.

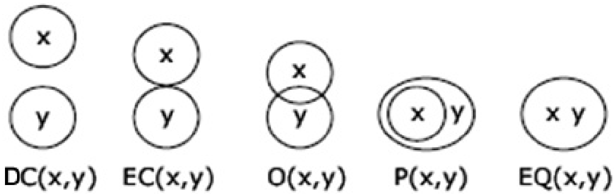


Fig. 1. Essential RCC axioms

2. Qualitative Spatial Reasoning for Recognition of the Self-formed Semiconductor Elements

Self-formation results – sets of semiconductor elements – depend on different initial conditions, e.g., having a different geometric structure and different substances (regions). According to these conditions self-formed elements obtain a particular geometry, but probably don’t meet the definite electrical characteristics.

Self-formed artificial objects structure contains n substances (regions) X = (x_1,...,x_n). Presented feature vector describes object structure belonging to class **Ω_1**:

$$Z_i = \begin{pmatrix} z_{i1} \\ z_{i2} \\ \cdot \\ \cdot \\ z_{ij} \end{pmatrix}; \tag{9}$$

where $i = 1,...,k;\ j = 1,...,l;\ where\ k,l \in N$; then

$$X(Z_i) \in \Omega_1; when \quad i = 1; \tag{10}$$

$$X(Z_i) \in \Omega_2; when \quad i = 2,...k. \tag{11}$$

In order to satisfy the required electrical characteristics semiconductor elements structure from set R1 has to meet the following requirements:

$z_{1\,1}$ – Structures must contain six different regions (P, F, N, C, N+, D),
$z_{1\,2}$ – Regions P and C must be continuous,
$z_{1\,3}$ – Region F cannot be continuous,
$z_{1\,4}$ – Regions C and D are externally connected, but not overlapping,
$z_{1\,5}$ – Regions C and N+ are externally connected, but not overlapping,
$z_{1\,6}$ – Regions P and N are externally connected, but not overlapping,
$z_{1\,7}$ – Regions P and N+ are externally connected, but not overlapping,
$z_{1\,8}$ – Region D is isolated from regions P, N and N+.
(12)

More substances can participate in the process of self-formation of semiconductor elements but they will not appear in the ultimate result.

The results of self-formation simulation of semiconductor elements are two dimensional geometrical figures from the Euclidean space. The criteria for qualitative evaluation of such results are based on the theory of Qualitative Spatial Reasoning, the separate formalism – RCC (Regional connection calculus), initially developed by *Clarke* and further refined by many authors, including *Cohn*, *Randell, Cui, Bennett*.

An example of artificial semiconductor element (solar cell) structure is given in Fig. 2. The notation of regions is given in Table 1.

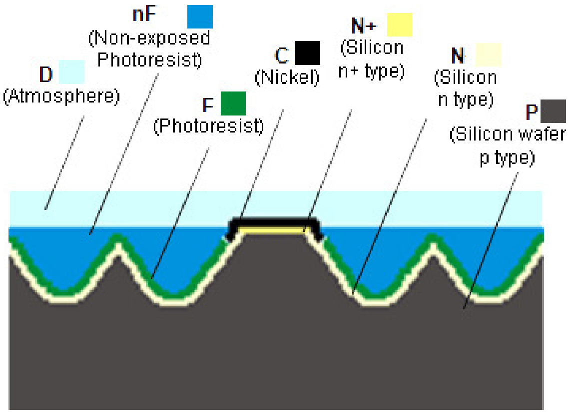


Fig. 2. Example of the structure of a semiconductor element

Table 1. Semiconductor element regions notation

Notation of region	Colour of region	Substance
P	Grey	Silicon wafer p type
N	Primrose yellow	Silicon n type
C	Black	Nickel
N+	Yellow	Silicon n+ type
D	Blue	Atmosphere
F	Green	Photoresist

In conformity with RCC axioms and requirements for the structure of semiconductor elements, the rules which show that semiconductor element belongs to class $\mathbf{\Omega}_1$ have been described:

CON(P) ∧ CON(C) ∧ ¬CON(F) ∧ EC (C,D) ∧ EC (C,N+) ∧ EC (P,N) ∧ EC (P,N+) ∧ DC(D,P) ∧ DC (D,N+) ∧ DC (D,N) (13)

CON (1,P) – Region P must be continuous.
¬CON (0,F) – Region F cannot be continuous.
EC (P,N) – Region P is externally connected to region N.
DC (D,P) – Region P is disconnected from region D.

In case when n=6 and X = (P, N, N+, C, D, F), object belongs to class $\mathbf{\Omega}_1$ ($X \in \mathbf{\Omega}_1$) unless and until all conditions of feature vector Z_1 are met:

$$Z_1 = \begin{pmatrix} z_{1\,1} = \exists(\mathrm{P, F, N, C, N+, D}) \\ z_{1\,2} = CON(1, P) \\ z_{1\,3} = CON(1, C) \\ z_{1\,4} = CON(0, F) \\ z_{1\,5} = EC(C, D) \\ z_{1\,6} = EC(C, N+) \\ z_{1\,7} = EC(P, N) \\ z_{1\,8} = EC(P, N+) \\ z_{1\,9} = NC(D, P) \\ z_{1\,10} = NC(D, N+) \\ z_{1\,11} = NC(D, N) \end{pmatrix}. \quad (14)$$

The results from the set R1 can be classified by using the generated criteria, based on RCC technique. The criteria can be refined if needed and be used on the other sets of self-formed semiconductor elements if the initial conditions are known.

An object belongs to class $\mathbf{\Omega_1}$ if all the rules (13) are met. Otherwise, the object belongs to class $\mathbf{\Omega_2}$. These rules are implemented within the recognizer.

3. Self-formed Semiconductor Elements Recognition System

The main task for a recognizer is to analyze generated patterns – semiconductor elements – by using the proposed criteria, e. g. to extract features of elements, to classify elements and to output results. The pattern is divided into chromatic regions (substances) and connections between the regions are identified for feature extraction. Then, the RCC rules are checked to classify the object either into class $\mathbf{\Omega_1}$ (when all the rules are met) or class $\mathbf{\Omega_2}$ (otherwise).

A sequence of the actions performed by the recognizer is as follows:

- *Read image*;
  - System reads image pixels (RGB values) and coordinates into an array;
- *Initialize regions*;
  - System initializes regions of the object while analyzing the label values of each pixel. The result is the label of the region and ID of the region;

- ○ System identifies connections of the region with the other regions;
  - ○ Conjunction of the neighbouring regions with the same label;
- *Check rules*;
  - ○ System checks all the rules;
- *Output results*.

The recognition system processes are presented in the use-case diagram, shown in Fig. 3.

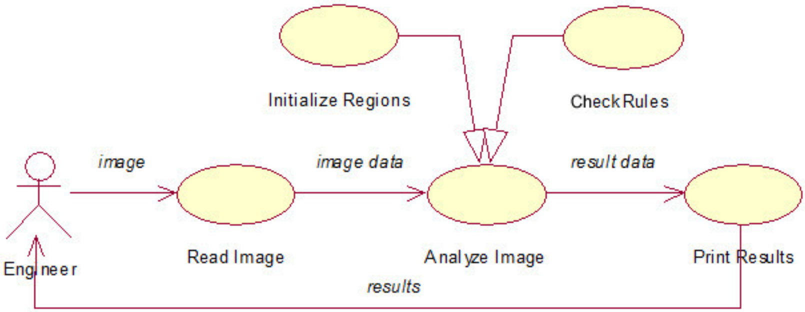


Fig. 3. Processes of the recognition system

Read Image process (Fig. 3) describes image reading and normalisation functions of pixel colour. Specification of the process is given in Fig. 4.

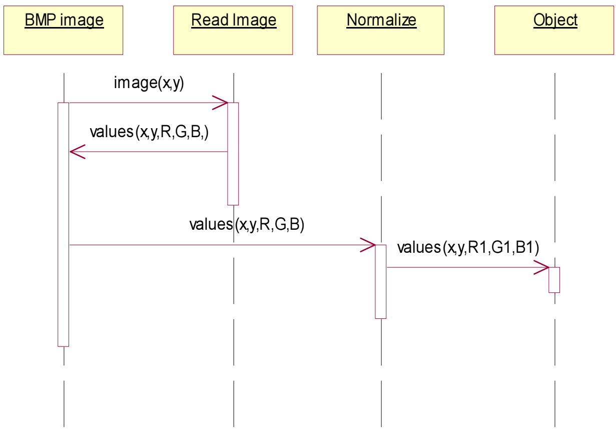


Fig. 4. Sequence diagram for the *Read Image* process

In this stage the image (semiconductor element) is read into an array whose elements are RGB values of image pixels. The RGB values are generalized according to the range of colour values (Table 2). Depending on the RGB range, the pixel RGB value is recalculated to the pixel label value.

Table 2. RGB values – labels

Label	Substance	*R*	*G*	*B*
101	P	77	73	72
103	N	255	251	156
150	C	0	0	0
105	N+	229	222	86
0	D	210	255	255
140	F	0	210	63
141	nF	0	147	221

The Process *Analyze Image* (Fig. 3) aggregates two particular processes – *Initialize Regions* and *Check Rules*. First of all the system identifies image regions using the read image data (array of image pixels) (Fig. 5).

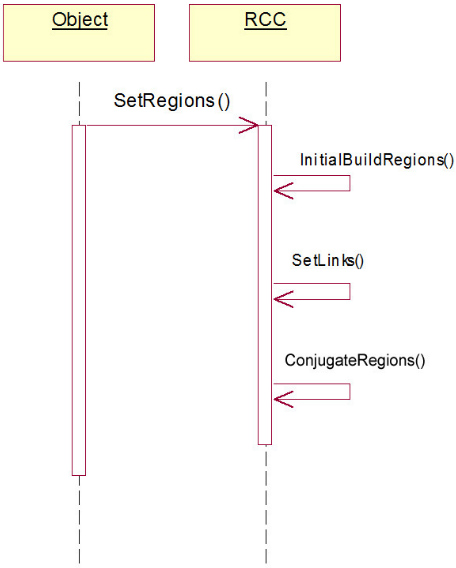


Fig. 5. Sequence diagram for the *Initialize Regions* process

The system reads regions of the image structure while analyzing the array of the image pixels. Each region is marked by the colour value-label (according to pixel value-label) and the region ID number. This number is necessary in the case where two or more not connected regions of the same colour exist within the structure. The region initialization process also includes identification of connections of the regions.

Analysis of image pixels starts from the top left pixel to the right and moves down by one pixel row in each step. Due to that, the region often might be divided into more regions with the same label, but different ID. Thus, the system implements conjunction of the regions. The original view of a semiconductor element and the same element with a few regions coloured after the region initialization step is presented in Fig. 6. In this example 12 different regions are coloured (other regions are in black), but lots of them will be conjugated later (see Fig. 6).

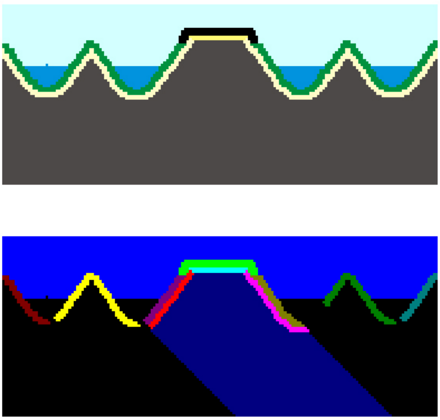


Fig. 6. Initial result of regions initialization

Connected regions with the same label but different ID values will be conjugated.

After the regions have been initialized, conjugated and connections between the regions have been identified, the system checks the rules. The sequence diagram of the process *Check Rules* is presented in Fig. 7.

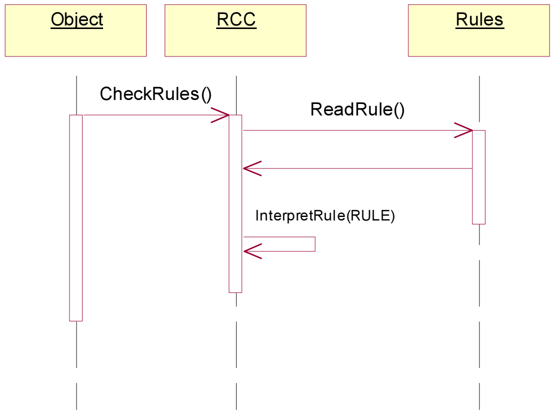


Fig. 7. Sequence diagram of the process *Check Rules*

In this stage application reads the RCC. Rules are specially described in an external text file. The rules may vary according to the type of semiconductor element, the structure of composing substances (regions) and connections between them. Thus, the recognition system might be used in various occurrences of self-formation.

4. Recognition System and Experimental Results

The System

The software application „*BMPRCCv1*" for the recognizing semiconductor elements structures was realized. The software for recognizing semiconductor elements is based on C++ dot Net technology. This recognition system is designed for analysing *bmp* files.

The test results show that recognition of one element takes about 100 milliseconds. The computer parameters for testing software were as follows:

- Processor: Intel(R) Core^{TM} 2 CPU, 6600 @ 2,4 GHz, 2 Cores, 2 Logical Processors; 8192 Kb cache memory
- Physical Memory (RAM): 2,00 GB
- OS Name: Microsoft(R) Windows Wista^{TM} Ultimate

In the first step, the system reads a semiconductor element into the array of RGB values of the pixels. Subsequently RGB values of the pixels are generalized and the system outputs a re-coloured image to the user (this is necessary when the quality of images is different or rough) (Fig. 8).

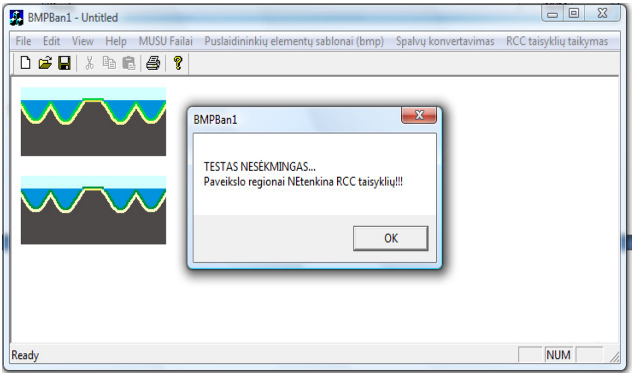
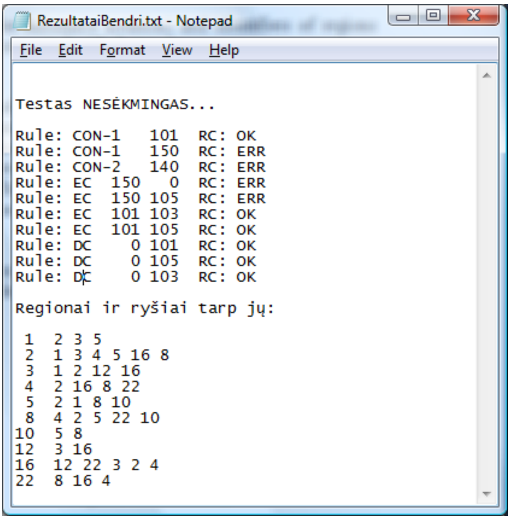


Fig. 8. Recognition result

As we see in an example which is given in Fig. 8 the software outputs a message about a failed test. The regions of semiconductor element don't meet the described connection rules – the structure of the semiconductor element is not suitable.

The system forms the file of test results with the comprehensive results for each test (see Fig. 9).


RezultataiBendri.txt - Notepad

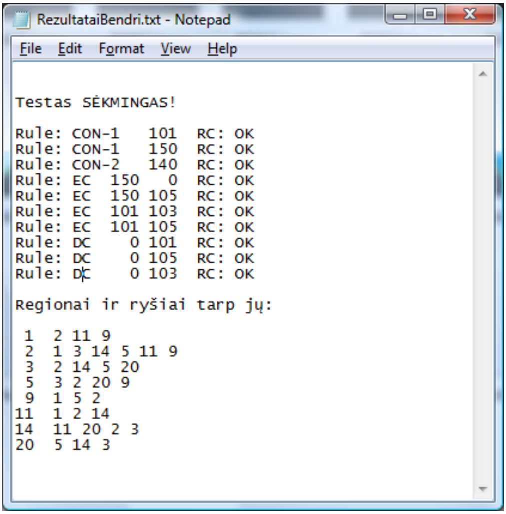
File Edit Format View Help

```
Testas NESĖKMINGAS...

Rule: CON-1    101   RC: OK
Rule: CON-1    150   RC: ERR
Rule: CON-2    140   RC: ERR
Rule: EC   150    0  RC: ERR
Rule: EC   150 105   RC: ERR
Rule: EC   101 103   RC: OK
Rule: EC   101 105   RC: OK
Rule: DC     0 101   RC: OK
Rule: DC     0 105   RC: OK
Rule: DC     0 103   RC: OK

Regionai ir ryšiai tarp jų:

 1   2 3 5
 2   1 3 4 5 16 8
 3   1 2 12 16
 4   2 16 8 22
 5   2 1 8 10
 8   4 2 5 22 10
10   5 8
12   3 16
16   12 22 3 2 4
22   8 16 4
```

Fig. 9. File of the recognition results (1)

As we see in this file, four rules out of ten are not met. According to the notation of substances (Fig. 2, Table 2), it is easy to find out that substance *C* (nickel) is not continuous and substance *F* (photo resist) is continuous, substances *C* and *D* (atmosphere) are not connected and substances *C* and *N+* (silicon n+ type) are not connected.

The result of a successful test is given in Fig. 10.




```
Testas SĖKMINGAS!

Rule: CON-1    101  RC: OK
Rule: CON-1    150  RC: OK
Rule: CON-2    140  RC: OK
Rule: EC  150    0  RC: OK
Rule: EC  150 105  RC: OK
Rule: EC  101 103  RC: OK
Rule: EC  101 105  RC: OK
Rule: DC    0 101  RC: OK
Rule: DC    0 105  RC: OK
Rule: DC    0 103  RC: OK

Regionai ir ryšiai tarp jų:

 1   2 11  9
 2   1  3 14  5 11  9
 3   2 14  5 20
 5   3  2 20  9
 9   1  5  2
11   1  2 14
14  11 20  2  3
20   5 14  3
```

Fig. 10. File of the recognition results (2)

As we see in Fig. 10 all the required rules are met. The test has passed with the verdict true.

The digits in the results file below the rules (Fig. 10) mean (from the left): the region number (not the substance notation) and identifiers of those regions connected with that region.

Recognition Experiments

The experiment was performed according to described features in section 2. In this experiment solar cells have been evaluated. The structure of semiconductor element is suitable if all the rules (13) are met. A total of 851 self-formed semiconductor elements have been analyzed while the experimental test was accomplished.

The test assigned 23 solar cells to class $\mathbf{\Omega_1}$. Results of the experiment are given in Table 3.

Table 3. Solar cells recognition results (I)

Total	Class $\mathbf{\Omega_1}$	Class $\mathbf{\Omega_2}$
851	23	828
100%	2,7%	97.3%

After the visual check of recognition results I stated that all good structures of the semiconductor elements where assigned to class $\mathbf{\Omega_1}$. But in practice 17 of them were bad because of the new further factor – non exposed photoresist (*nF*), which participates in self-formation process but cannot appear in the result.

Initial conditions were supplemented with a few new rules for testing the system flexibility. The algorithm wasn't changed, only the rules where renewed. The additional conditions – regions *D* and *F* cannot be connected with region *nF* (see Fig. 2) – should be satisfied. Then the connection rules are as follows:

$$CON(P) \wedge CON(C) \wedge \neg CON(F) \wedge EC\ (C,D) \wedge EC\ (C,N+) \wedge EC\ (P,N) \wedge EC\ (P,N+) \wedge DC(D,P) \wedge DC\ (D,N+) \wedge DC\ (D,N) \wedge DC\ (D,nF) \wedge DC\ (F,nF) \tag{15}$$

The recognitions test has assigned 6 solar cells to class $\mathbf{\Omega_1}$. The results of the experiment are summarized in Table 4.

Table 4. Solar cells recognition results (II)

Total	Class $\mathbf{\Omega_1}$	Class $\mathbf{\Omega_2}$
851	6	845
100%	0,71%	99.29%

This system is flexible for recognizing of any self-formed (and not only) two-dimensional structures if the suitability of the elements can be described by substances which participates within the structure and by connections between the substances. Thus, this system might be adapted to a particular case without algorithm changes.

The main steps of adapting the system for recognizing of particular set of semiconductor elements are:

1. Substance identification:
   a. Identification of colour for each substance;
   b. Identification of substances (notation assigning);
2. Description of the connections between the regions (rules are defined to describe the regions connections).

Results and Conclusions

Using the developed recognition system based on the proposed method and after performance of experimental research, the scientific conclusions are drawn:

1. Considering to special pattern specifics and depending on other authors works in pattern recognition area, the Regional Connections Calculus, the particular formalism for Qualitative Spatial Reasoning is the most appropriate approach for the recognition of self-formed semiconductor elements structures.
2. The method and algorithm of computer system in recognition of the self-formed semiconductor elements have been created.
3. The software application for the recognition of the self-formed semiconductor elements has been realized.
4. Experimental researches of the recognition of self-formed semiconductor elements were performed. The experimental results illustrate that software application is suitable for recognizing the self-formed semiconductor elements.
5. The developed system of semiconductor elements recognition could be flexible for recognizing any two-dimensional patterns if the suitability of pattern can be described by the participation of the substances within the structure and by connections between the substances.
6. Automation of self-formed semiconductor elements structure recognition can help to accelerate objects selection, reduce designers work volume and get higher selection results. The recognition system analyzes 10 – 20 structures per second.
7. Proposed recognition method, algorithm and computerized tool open new way of:
   a. accelerating recognition process of artificial objects,
   b. reaching higher selection quality of artificial objects.

List of Published Works on the Topic of the Dissertation

In the reviewed scientific periodical publications

1. Saulevičius, D.; Leonas, L. 2009. Semiconductor Elements Self-formation based on Qualitative Spatial Reasoning, *Electronics and Electrical Engineering* 89(1): 15–20.
2. Saulevičius, D.; Telksnys, L. 2009. Analysis of a Self-Formation Process of Semiconductor Elements, *Information Technology and Control* 38(1): 14–20.

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SAVAIMINGAI BESIFORMUOJANČIŲ PUSLAIDININKIŲ ELEMENTŲ ATPAŽINIMAS

Mokslo problemos aktualumas. Naudojantis savaimingo formavimosi pagrindais buvo sukurtos naujos puslaidininkių prietaisų ir integruotų schemų gamybos technologijos. Savaimingo formavimosi dirbtinės plokščios sistemos imitacijos rezultatas yra atsitiktiniai spalvoti dvimačiai paveikslėliai – šablonai. Tokie šablonai yra galimi efektyvesnių puslaidininkių prietaisų ar integruotų schemų modeliai. Būtina pabrėžti, kad savaimingo formavimosi plokščių sistemų rezultatų automatinio atpažinimo procesai smarkiai sumažintų darbo sąnaudas ir pagreitintų tokių sistemų modeliavimo procesus.

Taip pat svarbu yra tai, kad tokie procesai suteikia naujų galimybių tobulinti plokščių sistemų atrankos kokybę. Inžinierius gali skirti daugiau dėmesio detalesnei savaimingo formavimosi sistemos savybių analizei.

Darbe sprendžiama problema yra savaimingai besiformuojančių puslaidininkių elementų struktūrų atpažinimo automatizavimas.

Tyrimų objektas. Disertacijos tyrimų objektas – savaimingai besiformuojančių puslaidininkių elementų struktūros.

Darbo tikslas ir uždaviniai

Darbo tikslas – savaimingai besiformuojančių puslaidininkių elementų struktūrų atpažinimas. Tam, kad būtų pasiektas tikslas, sprendžiami tokie uždaviniai:

1. Sukurti savaimingai besiformuojančių puslaidininkių elementų struktūrų atpažinimo metodą ir algoritmą;
2. Sukurti savaimingai besiformuojančių puslaidininkių elementų struktūras atpažįstančią programinę įrangą;
3. Eksperimentiškai patikrinti programinės įrangos tinkamumą.

Mokslinis naujumas

1. Sukurtas savaimingo formavimosi sistemos koncepcija paremtas puslaidininkių elementų atpažinimo metodas, grindžiamas regionų-ryšių teorija (RCC).
2. Naudojantis suformuluota požymių sistema bei atpažinimo metodu, sukurtas savaimingai besiformuojančių puslaidininkinių elementų struktūrų atpažinimo sistemos algoritmas.
3. Sukurta savaimingai besiformuojančių puslaidininkių elementų struktūrų atpažinimo programinė įranga, vertinanti puslaidininkių elementų struktūrų tinkamumą.
4. Eksperimentiškai patikrinta savaimingai besiformuojančių puslaidininkių elementų struktūrų atpažinimo programinės įrangos praktinė nauda.

Tyrimų metodika. Disertacijos teoriniams tyrimams atlikti naudojami lyginamosios analizės, indukcijos ir eksperimentinio tyrimo metodai. Lyginamosios analizės metodai naudojami specifinių savybių dvimačių vaizdų atpažinimo metodų įvairovei analizuoti. Tokiu būdu pasirinktas metodas pritaikomas savaimingai besiformuojančių puslaidininkių elementų atpažinimui panaudojant dedukcijos ir indukcijos metodus. Atsižvelgiant į savaimingai besiformuojančių puslaidininkių elementų ypatumus, dedukcija naudojama metodui specializuoti, indukcija – konkretiems atpažinimo ir klasifikacijos metodams apibendrinti. Indukcijos metodas taip pat naudojamas ir autoriaus turimai bei literatūroje aprašytai konkrečių dvimačių vaizdų atpažinimo patirčiai apibendrinti.

Eksperimentiniams tyrimams atlikti buvo naudojama paties sukurta eksperimentiniams tyrimams skirta kompiuterinė atpažinimo sistema, kuri realizuota C++ kalba, naudojant Visual Studio .NET 2003 aplinką.

Praktinė vertė. Sukurtas savaimingai besiformuojančių puslaidininkių elementų struktūrų analizės metodas leidžia formuloti bet kokių savaimingai besiformuojančių dvimačių paveikslėlių atpažinimo uždavinį. Šis rezultatas ypač naudingas kuriant įvairių gamybai skirtų puslaidininkių elementų struktūrų atpažinimo sistemas. Automatizuotas puslaidininkių elementų struktūrų atpažinimas gali padėti:

- pagreitinti puslaidininkinių elementų atrinkimą;
- sumažinti inžinierių darbo sąnaudas;
- gauti aukštesnės kokybės atrankos rezultatus.

Šiame darbe aprašytas metodas yra nepriklausomas nuo generuojamojo elemento paskirties, todėl ateityje jis gali būti pritaikomas ir kitokių elementų struktūrų atpažinimo sistemų kūrimui.

Ginamieji teiginiai

1. Savaimingai besiformuojančių puslaidininkių elementų požymių aibę sudaro tų elementų struktūroje dalyvaujančios medžiagos (regionai) ir ryšiai tarp jų.
2. Savaimingai besiformuojančių puslaidininkių elementų struktūrų analizei vykdyti naudotinos ne tradiciškai paplitusios analizės iš taško perspektyvos, bet elementų struktūrą sudarančių erdvinių primityvų – regionų kokybinė analizė.
3. Pasiūlyta kokybinės analizės teorija ir sukurtas atpažinimo sistemos metodas yra tinkamas savaimingai besiformuojančių puslaidininkių elementų struktūrų atpažinimui.
4. Sukurta savaimingai besiformuojančių puslaidininkių elementų struktūrų atpažinimo sistema gali būti pritaikoma bet kokioms savaimingai besiformuojančioms dvimatėms struktūroms atpažinti, jei elementų kokybę galima vertinti pagal jų struktūras sudarančias medžiagas ir tų medžiagų tarpusavio ryšius.

Darbo apimtis. Disertaciją sudaro įvadas, keturi skyriai ir literatūros sąrašas. Disertacijos skyriai: Analitinė vaizdų atpažinimo metodų apžvalga, Kokybinė struktūros analizė puslaidininkių elementų atpažinimui, Puslaidininkių elementų struktūrų atpažinimo sistema, Atpažinimo sistemos eksperimentiniai tyrimai. Disertacijos apimtis 116 puslapių, 42 paveikslai ir 8 lentelės.

Įvade išdėstytas disertacijos tyrimo objektas, temos aktualumas, suformuluotas darbo tikslas, aprašyti tyrimo metodai, mokslinis naujumas, praktinė reikšmė, darbo rezultatų aprobavimas, aprašyta darbo struktūra bei turinys.

Pirmajame skyriuje pateikiama dvimačių paveikslų (šablonų) apdorojimo metodų analitinė apžvalga, apžvelgiant vaizdų apdorojimo ir atpažinimo metodus. Taip pat detaliai aptariama regionų erdvinių ryšių samprata ir konkretus jos taikymo formalizmas – RCC.

Antrajame skyriuje išsamiai aprašytas savaimingo formavimosi sistemos koncepcija paremtas puslaidininkių elementų atpažinimo metodas naudojant RCC taisykles. Taip pat suformuluota puslaidininkių elementų požymių sistema.

Trečiajame skyriuje aprašomas sukurtas savaimingai besiformuojančių puslaidininkinių elementų struktūrų atpažinimo sistemos algoritmas.

Ketvirtajame skyriuje aprašomas savaimingai besiformuojančių puslaidininkių elementų struktūrų atpažinimo sistemos veikimas, atskiri eksperimentiniai tyrimai, bei pateikiami kiekvieno jų rezultatai ir išvados.

Išvadose pateiktos disertacijos darbo išvados.

Prieduose pateikiami programinės įrangos algoritmai C++ programavimo kalba ir paveikslai.

Bendrosios išvados

Sukūrus savaimingai besiformuojančių puslaidininkių elementų atpažinimo programinę įrangą ir atlikus eksperimentinius tyrimus, suformuluotos šios mokslinės ir praktinės išvados:

1. Atsižvelgiant į analizuojamų savaimingai besiformuojančių puslaidininkių elementų struktūrų specifiką ir apžvelgus kitų autorių darbus, daroma išvada, kad tinkamiausias būdas puslaidininkių elementų struktūroms atpažinti yra formali sistema kokybiniams erdviniams skaičiavimams – regionų-ryšių teorija (RCC).
2. Sukurtas savaimingai besiformuojančių puslaidininkių elementų struktūrų atpažinimo metodas, leidžiantis kokybiškai analizuoti puslaidininkių elementų struktūras.
3. Naudojantis puslaidininkių elementų atpažinimo metodu ir algoritmu buvo sukurta savaimingai besiformuojančių puslaidininkinių elementų struktūrų atpažinimo kompiuterinė programa.
4. Atlikti savaimingai besiformuojančių puslaidininkių elementų struktūrų atpažinimo eksperimentiniai tyrimai. Eksperimentiškai patikrinus metodo (programinės įrangos) veiksmingumą galima daryti išvadą, kad disertacijoje aprašytas metodas yra tinkamas savaimingai besiformuojančių puslaidininkių elementų struktūrų atpažinimui.
5. Sukurta programinė įranga pritaikoma bet kokiems dvimačiams

šablonams atpažinti, jei šablonų kokybę galima vertinti pagal jų struktūras sudarančias medžiagas ir tų medžiagų tarpusavio ryšius.

6. Puslaidininkių elementų struktūrų atpažinimo metodas ir jo pagrindu sukurta programinė įranga leidžia sumažinti inžinierių darbo laiko sanaudas ir pagreitinti savaimingo formavimosi sistemų atpažinimo darbus. Kompiuterinė programa per 1 sekundę apdoroja 10 – 20 puslaidininkių elementų struktūrų.
7. Savaimingai besiformuojančių puslaidininkių elementų struktūrų atpažinimo metodas ir jo pagrindu realizuota programinė įranga gali atverti naujas galimybes:
   a. pagreitinant savaiminio formavimosi sistemų atpažinimo darbus;
   b. gaunant aukštesnės kokybės atrankos rezultatus.

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