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WORLD TENDENCIES OF THE MICROELECTRONICS DEVELOPMENT AND THE STANCE OF THE REPUBLIC OF BELARUS IN THIS PROCESS

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The review provides an analysis of the microelectronics development in the economically advanced countries for a period of 7—10 years until 2008, when the influence of the economic crisis started to manifest in the world economy. In the article were used the data of Stat World Fab Watch. Under the review were also the achievements and potential capabilities of JSC "Integral" — leading organization, responsible for the microelectronic branch in Belarus.

The contemporary development of the industrial countries is based on the ever wider application of the devices of the electronic equipment in all spheres of life — industry, transport, communications, telecommunications, health care, banking and social spheres, military hardware, etc. Not a single branch of the national economy, not a single enterprise can operate productively, if they are not furnished with the high technology electronic equipment and electronic control system.

From the midst of the XX century the electronic industry is the key component of the electronic branch, ensuring the common wealth of any state, the unconditional leader in the world division of labor, volumes of its production are undeviatingly on the increase, determining progress in all other spheres of life. This is the most rapidly advancing branch, which produces more additional cost, than any other industrial branch.

The major place in the electronic industry is occupied by the microelectronics, whose development is based on the achievements of the microelectronic element-component base and determines the development level of the radio-electronic branch of industry as a whole.

The microelectronic element-component base is a wide nomenclature of the devices and instruments, determining the technical and consumer characteristics of the final products, fabricated in all branches of industry (machine-building, transport, power engineering, medical instrument-making industry, etc.)

The experience of the world leading countries shows, that realization of the technical and socio-economic programs of the microelectronics development results in the integral effect, far exceeding the frameworks of the microelectronic branch, including the market growth of the science intensive products, elevation of the technical level and competitiveness in the adjacent branches — communications and telecommunications, computing equipment, missile-space, aviation, machine-building, auto-transport, machine-building and others.

The output volume of products of the world radio-electronic branch of industry almost 4.5 times surpasses the output volume of oil, petrol and mineral raw materials, almost 3 times — output of chemical products and plastics, 2.5 times — volumes of cargo transportation and over 2 times – power generation and gas production.

It is worthwhile noting, that in the advanced foreign countries specifically science intensive product is the main source of replenishing the budget. If the sale of one ton of crude oil may bring up to $20 of profits, a mere one kilogram of the industrial products in the sophisticated radio-electronic consumer equipment bring up a profit of up to $50, in aviation — up to 500—600 US dollars, in electronics — up to $3000 (1 kg of chips of the contemporary VLSIs is 2.4 times more expensive, than gold).

The economic efficiency of electronics in the given countries is vividly demonstrated by the following facts:

— $1 of investments brings up to $100 in the finished product;
— the average world recoupment term of investments constitutes two-three years;
— the growth rates of the branch are three times higher, than the growth rates of the internal gross produce;
— one working place in the electronic industry makes it possible to create up to four working places in other branches;
— 1 kg of devices of microelectronics by cost corresponds to 110 tons of oil.

But the matter is not confined to the economic efficiency alone. The informational technologies and microelectronics, having received the widest development in the advanced countries of the world, ensued the radical changes of their social structure, ever more increased the break-away of these countries from the remaining mankind. An example to this — the specific production of the electronic equipment, indicated in **Fig. 1**.

The fact is indicative, that the cost share of the electronic equipment devices in the cost of the contemporary industrial, consumer and military radio-electronic devices and systems constitutes from 30 to 80% and annually is on the increase. The sales volume of the electronic devices on the world market has the absolute leadership (a greater share, than automotive industry, metallurgy, petrochemical industry, etc.). The electronic branch is the undisputable leader in the world separation of labor, volumes of its production are steadily on the rise, determining progress in all other spheres, such as air-space and radio-electronic industry, robot-construction, production of the computing and optical fiber equipment, office equipment, development of software. The electronics as such is based on development and achievements of the microelectronic branch. Therefore the leading countries of the world attribute the priority attention to the microelectronics as “a point of growth” of economy and national security. The experience of these countries shows, that realization of the technical and socio-economic targets and tasks of the microelectronics development results in emergence of the integral effect, far reaching beyond the frameworks of the microelectronic branch, including the market growth of the science intensive products, enhancement of the technical level and competitiveness in the adjacent branches – radio-electronic, communications and telecommunications, computing equipment, auto-transport, machine building, etc.

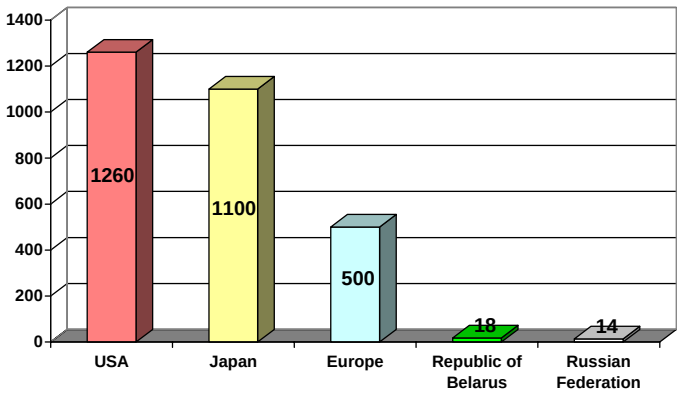

Fig. 1. Specific production of the electronic equipment (per capita of population)

The main tendency of the microelectronics development is the steady integration growth of many functions in composition of one microelectronic device – combination of functions of reception, storage, processing and transfer of data. This makes it possible to create the new element base for the radio-electronic systems, ensuring an abrupt reduction of expenses on its production and operation,

enhancement of reliability and broadening the functional capacities. Most vividly it is displayed on the examples of television (a single chip TV-set) and communications (mobile telephones with exit to the Internet).

It is worthwhile noting the important peculiarity in development of microelectronics — the extensive growth of production at the time of the sales growth and the technological growth (development and implementation of the new technologies and prospective devices) with the narrowing of the market. Meanwhile, aggravation of competitiveness causes the accelerated transition to the smaller design rules and production transition to the "deep submicron". Thus, transition, for instance, from 1.0 to 0.035 μm ensures reduction of the LSI 8—9 times owing to reduction of the chip area with the simultaneous growth of profitability 3—4 times because of enhancement of the functional complexity of the integrated circuits.

However, transition to the new design rules requires huge financial expenses on the capital construction, equipment, new technologies. **Fig. 2** shows, as a typical example, the information, characterizing the level of the financial expenses on creation of their productions with the design rules less than 0.1 μm. Thus, the cost of creation of a plant (a factory) with a single base technological process in dependence on its capacity for the design rules of 90…65 nm constitutes (for the wafers of dia 300 mm) from 2.5 to 3.0 bln. $; for 45…32 nm — from 3.5 to 4.0 bln. $; from 22…12 nm — from 4.5 to 6.0 bln. $. And this is only the cost of construction and equipment without the design cost (or the license purchase) of the technological process.

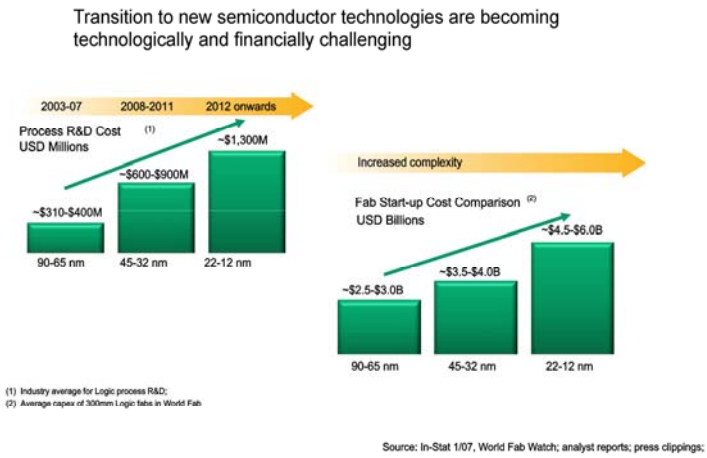

Fig. 2. Level of financial expenses on creation of productions with the design rules less, than 0.1 um (source: In-Stat 1/07, World Fab Watch; analyst reports)

The design cost of the base CMOS-process of the LSI fabrication with the design rules of 90 nm at AMD constituted 310 mln $ and 400 mln $ for 65 nm. The design cost of the 45 nm and 32 nm technologies is evaluated, appropriately, in 600 and 900 mln $, and development of the 22 nm process – over 1.3 bln $. It is worthwhile noting, that the number of companies, which can afford such expenses is very small, thus, the technology with the design rules of 22 nm is mastered by only four companies.

Fig. 3 (source — SICAS/Future Horizons) represents the distribution dynamics of the wafers production for the period of 1999 – 2007 for the various design rules. By the vertical axis the volumes are represented of the weekly start (thousands of wafers) in calculation for the equivalent 200 mm wafers, and by the horizontal axis – the quarter and the year of fabrication.

Digressing from the quantitative characteristics, i. e. from the production volumes one should note the main thing — each two years the next generation of the microcircuits emerges on the market. Thus, in the first quarter of 2000 the production peak was on the devices with the 0.25 μm rules, and at

this time the 0.18 um devices emerge on the market, whose production reaches a peak in the second quarter of 2002. In the third quarter of 2002 the production of the 0.18 μm LSIs starts to drop, because the 0.13 μm devices start to emerge on the market, which attain the production peak after two years, etc.

However, meanwhile one should note such an important fact — although the production volumes of devices with the "old" design rules significantly dropped, they still remained on the market. At fist glance, one observes a paradoxical picture — at the beginning of the "crisis" 2008 in the world the weekly start of the wafers with the 0.8 μm norms was two times more, than with 0.25 μm, and more, than with 0.35 and 0.18 um. Meanwhile, within seven previous years (2001—2007) the volumes of the wafers starts with these norms did not reduce, consequently, they are in demand on the market.

Note should be taken, that the most stable niche is that of the devices with the design rules of 0.35 μm and above, meanwhile the production volume of such devices constitutes about 20% of the market volume. Once again this fact confirms the conclusion, that the given segment of the semiconductor branch may be used for design of such devices and their promotion to the world market.

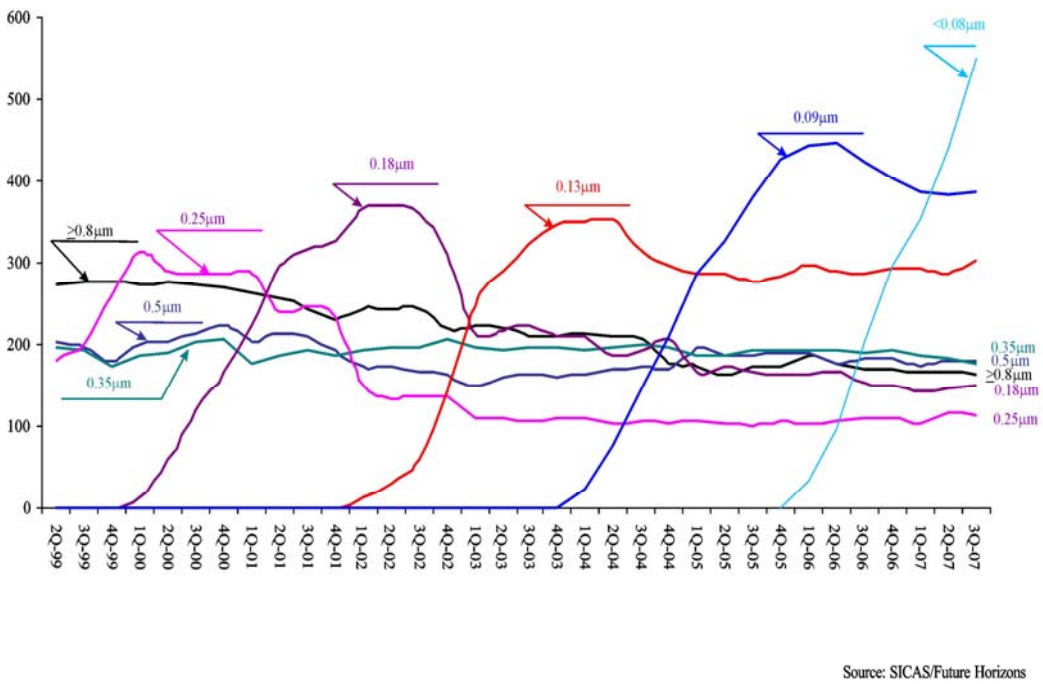

Fig. 3. Distribution dynamics of the world production of wafers for the various design rules (source: SICAS/Future Horizons)

As for creation of the microelectronic devices except the two components (technology + equipment) it is required to have expensive software and hardware design means, the cause becomes obvious of the rapid development of the fabless business model in the microelectronic production.

Today the fabless model is the most dynamically developing and the most efficient in the semiconductor business, because the cost of any contemporary production line is by several orders more than the size of the investments required for arrangement of the standard design-center and acquisition of the automated design means and the design libraries for it. It is no accident that the increase in sales, demonstrated by the fabless companies, for the last years is significantly higher, than that of the average branch one. Thus, the sales volume of the TOP-10 best fabless companies (design-centers), for 2007 constituted 28.015 bln US dollars, which is only 4 times less than the sales volumes of the TOP-10 companies with their own production lines.

The major organization, responsible for development of the microelectronic branch in Belarus, is JSC “Integral” [1—5]. By the generally accepted world classification the enterprise is classified as IDM, i. e. a company, which produces the microelectronic components of its own design only. At JSC “Integral” the entire complex of works is realized, including design and production of the wide range of the microelectronic devices and finished goods (medical devices, electronic panels, control blocks of the household, industrial, automotive and agricultural equipment, etc. There are about several dozens of such large companies in the world, amongst them are Intel, Motorola, Siemens, Texas Instruments (TI), NEC, Toshiba.

In contrast to the majority of the foreign companies, JSC “Integral” possesses a wide spectrum of the technological processes: base CMOS, CMOS with the built-in EEPROM block, CMOS with the built-in high voltage (100V and above) blocks, special radiation resistant CMOS-process, various versions of the bipolar processes, including the radiation resistant, combined bipolar-field (BiCMOS); SOI technology for the special applications, MOSFET processes for fabrication of the power rapid-response and high-voltage transistors and others.

For the entire history of its existence the enterprise has never bought a single license, which is undoubtedly indicative of the high qualification level of both designers and line production engineers.

The constant range renewal of the produced microelectronic products (over 2000 types of integrated microcircuits, 500 types of semiconductor devices, 200 types of liquid crystal indicators, about 150 types of devices of the electronic technology) makes it possible for the JSC “Integral” to preserve the gained world market niches and to satisfy to a considerable extent the microelectronic components requirement of the national structure forming enterprises of radio electronics under the conditions of the fierce competition.

The **Table** lists the data for comparison of quantities of device types and volumes of output of the integrated microcircuits and the semiconductor devices in Russia and JSC “Integral” for 2007.

Quantitative Indicators	Russia	JSC “Integral”
Number of IC types	1500	2000
Number of types of semiconductor devices	2000	500
Production volume of microcircuits, blns of pcs	1.7	1.2
Production volume of discrete semiconductor devices, blns of pcs	2.2	2.1

A greater part in the microelectronic product range of JSC “Integral” is occupied by the special- and dual-purpose microelectronic elementary components (“MA” and “ERM” quality categories). At present over 250 types of special-purpose integrated microcircuits and discrete semiconductor devices are in production, half of them has been created during the past five years. These products are in demand on the external market (predominantly in the Russian Federation) owing to the high quality and reliability. The Ministry of Defense of the Russian Federation certified the JSC “Integral” for design and batch production of the devices for the enterprises of the military-industrial complex of the Russian Federation.

The major advantage of elementary components of JSC “Integral” unconditionally recognized by the enterprises of Russian military-industrial complex and their competitors lies in new design and technology solutions and IC layouts, ensuring the high reliability and serviceability of the devices under the influence conditions of the higher radiation, neutron irradiation, gamma-irradiation, electromagnetic impulse. Such technical characteristics and parameters are exceptionally important for the armament systems, electronic control systems of the military and space equipment, control and security enforcement systems of the nuclear power stations. In the post-Soviet space JSC “Integral” is the sole

actually recognized supplier of such devices to the nuclear power engineering and to a number of enterprises of "Roscosmos".

In the outer space the semiconductor devices must function under the conditions of hard radiation, caused by the ion irradiation, present in the space beams and the solar wind, as well as captured in the radiation belts around the Earth. For a number of years JSC "Integral" participates in the works for the near and deep space, in particular, creation of production of the unique integrated micro-assemblies of the charge couple devices for the earth remote sensing spacecraft which has no world analogues (spacecraft "BelKA" and mini-satellite "BKL" (Belarus"; satellite "Kanopus" (Russia"; spacecraft "BKVR" of high resolution, systems of cartography and meteorological observations ("Flying electronic eye") (Russia).

The most advanced samples of the strategic armaments systems, such as "Topol-M", "Bulava", "Sineva", antiaircraft-missile complexes C-400, 500, fighters of the fifth generation Su-35, MiG-35, helicopters MI-28, "Shark", "Alligator" (KA-50, 52), submarines of the fourth generation of the type "Yury Dolgoruky' of the Project 955 "Borei", etc., are being created in Russia with the use of microelectronic products of JSC "Integral".

The electronic component base created at JSC "Integral" is used in the scientific projects of different countries, which vividly demonstrates the potentialities of Belarussian science and microelectronic industry. A number of the integrated circuits, designed and fabricated at JSC "Integral", passed a successful approbation and faultlessly operate in such projects as GEM (superconducting super collider, USA) DO (Tevatron collider of the Fermi National Accelerator Laboratory, USA), CMS (Large Hadron Collider, European Organization for Nuclear Research), PiBeta (Switzerland), PANDA (Facility for Antiproton and Ion Research, Germany), in the multi-particle spectrometer and universal calorimetric detector in Dubna, in the program SVD-2 on the spectrometer with the apex detector and the unit OKA on the accelerator Y-70 (Russia). Success of such activity is determined by the lower development cost, as compared with the foreign ones, their high reliability, stable technical parameters, acceptable price, well arranged commercial cooperation.

The efficient concentration of efforts of scientists of the National Academy of Sciences of Belarus, higher educational institutions, branch research institutes and design bureaus and mass production plants made it possible to a considerable extent to solve the task of saturating the market of the Republic of Belarus and the CIS countries with the competitive element base for the priority branches of the national economy and the national defense, ensured enhancement of the export potential of the Republic of Belarus, development of the new power and resources saving import-substituting science intensive technologies and devices.

At the present time in electronics and its application the researches and design developments are being conducted in the Republic of Belarus under the various programs. Within the framework of the "Union TV-set" program an entire spectrum of the sophisticated functional microcircuits and semiconductor devices has already been developed and implemented into the mass production for the receivers of the color image, which are used both by national ("Horizont", "Vityaz") and Russian manufacturers of TV-sets.

Within the framework of the "Base" subprogram JSC "Integral" designs over 70 types of new microcircuits, intended in the first place for the armament systems and military equipment, as well as for the products of the national economy purpose.

Within the framework of the "Supercomputer" program JSC "Integral" designed and delivered to the Customer VLSI of the stream hyper-processor "Mini-Tera", where the chip with the size of 10.6×11.0 mm^2 accommodates over a million transistors under the 0.5 μm design rules. Owing to application of the original architecture of VLSI in the 10-pin package with E_{supply}=3.0 V made it possible to ensure the throughput of the supercomputer up to 1.2 Gigaflop at the fist stage and up to 20 Gigaflop at the second stage.

JSC “Integral” together with the material engineers of the Republic of Belarus develops the advancing activities on the market of semiconductors, which is denoted quite widely: devices of the military application, sets of circuits for the automotive electronics, television equipment, means of communication and telecommunications, devices and their control means in the kind of converters, intellectual keys, etc.

Already created are the integrated circuits on the wafers of the diameter 200 mm with the design rules 0.35 um within the frameworks of the investment project “Organization of the submicron production at JSC “Integral”. This project will make it possible to solve many problems of the joint radio-electronic complex of Belarus and Russia, including fabrication of microcircuits with the informational capacity of 1 – 4 Mbit, resistant to the external influences. In future it is envisaged to design the high voltage elements, microcircuits of the RF-range, chips with the possibility of the FM-range radio-reception, new competitive items: special purpose radiation resistant microcircuits for the armament systems and military equipment, super-large integrated circuits of the signals digital processing, microcircuits for the communication means and telecommunications, etc. The dual purpose items will find their application in creation of the armament systems and military equipment, including in Russia. The existent in Belarus quite powerful complex of tractor and motor-car construction presupposes the enhanced attention to electronics, comprising up to 30% of the car cost. Meanwhile, the sets of circuits are used, based on the new standards of the on-board automotive equipment.

Prospective is development of power devices and their control means, so-called intellectual key, control circuits of pulse supply sources. Production is planned of the new generations of DC/DC and AC/DC converters, being of huge demand on the market. The first ones are used in each cell phone, the second ones — in each charging device for it. Mastering this direction will satisfy the requirements of the internal market and will make it possible to gain a part of the foreign one, including Russian, despite presence of the Western giants in this sector.

From the performed analysis and prospects of the microelectronics development it ensues, that the Republic of Belarus should use its great scientific and practical experience for development of the new technologies, which are applied at the major microelectronic companies of the world. Such technologies include the following:

— fabrication technology of the structures silicon on insulator (SOI), including development of IC design system on the SOI substrates and development of the technological processes for fabrication of CMOS-IC on the SOI wafers. This will make it possible to create the radiation, heat- and interference resistant ICs, high temperature ICs (up to 350°C), power electronics ICs and also will open the principle potentialities of designing the circuits with the tri-dimensional integration;
— formation technology of Si/Ge-structures for the high speed electronics devices, including designing the high efficiency devices. For development of such technology it is required to perform the preliminary researches of the growth peculiarities of the sub-thin (50 nm on 10 layers) nano-size films and nano-clusters of Si_xGe_y alloy on the semiconductor and dielectric substrates. On the basis of these researches there will be developed processes of creation of micro-wave transistors of the new generation, light diodes and elements of the nonvolatile memory;
— fabrication technology of the nonvolatile memory systems on transistors with the floating gate with the Germanium quantum points in tunnel dielectric and on the basis of ferroelectrics (FRAM-technology);
— fabrication technology of the radiation resistant ICs (Bipolar, CMOS, Bi-CMOS), including the system of their designing.

The main consumers of the electronic element base, made by JSC “Integral” are practically all large structure forming enterprises in Belarus, Russia and other CIS countries, as well as the South-East Asia, Europe and Northern America. Only application of the modern element base will make it possible to solve the task of ensuring competitiveness of their products on the national and world markets. Specifically because of this the development of the national microelectronics is a priority task for our state and deserves a special attention.

REFERENCES

1. Турцевич А.С., Гуминский В.В., Перец А.Ф. Наращивание, заимствование, преемственность — постулаты инновационного развития ОАО «ИНТЕГРАЛ» // Наука и инновации.— № 3.— 2012.— С. 9—12.
2. Богатырев Ю.В., Шведов С.В. Радиационно стойкие интегральные схемы // Наука и инновации.— № 3.— 2012.— С. 13—14.