Betavoltaic device in por-SiC/Si

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& *Oleg Surnin* LLC open {code;} *Investor*

The product on which the proposed project is focused

“Nuclear” battery

The purpose of the proposed product to manufacture

- Independent power source for MEMS / NEMS various applications: pacemakers (in medicine), sensors monitoring and control (construction, pipeline oil transportation, military equipment) etc.
- To increase the lifetime of MEMS sensors, improve their smooth operation and low-energy consumption

“Nuclear” battery converts the energy of the beta decay of Carbon-14 into electric power by means of converters based on porous heterostructures “por-SiC/Si”

Smart ^{14}C ß-Converters with unlimited resource for MEMS and NEMS

Solution for the problem

Problem to be solved

Proposed customer values

Nuclear Battery

Betavoltaic power source

FUEL: isotope ^{14}C

ß-CONVERTER: por-SiC/Si heterostructure

WORKING LIFE: 100 years

Performances:

Voltage range: ~ 2 mV

Size of the device: ~ 10 mm × 10 mm × 0,01 mm

Mass of the device: < 100 mg

Working current range: 0,1 μA

Working temperature range: -50° ÷ 350° C

The Advantages

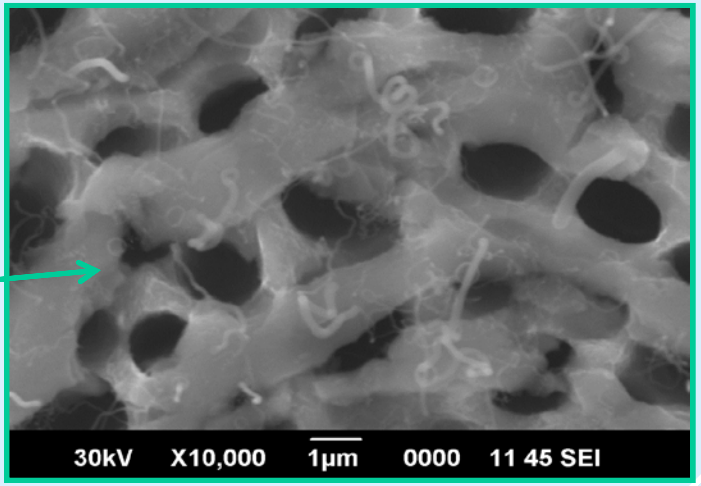
- Clean fuel, harmless for human health and the environment
- Reduction of the size of the instruments and the chance of their implementation into out-of-the-reach application locations
- The possibility of autonomous work seamlessly for over dozens of years
- Quiet operation, ease of use, reliability
- Pulsed neutron source to generate the carbon-14 ion target nitrogen-14

The Technology

^{14}C β-decay

Energy converter of β-decay on the basis of heterostructures porous-SiC/Si

Electric current

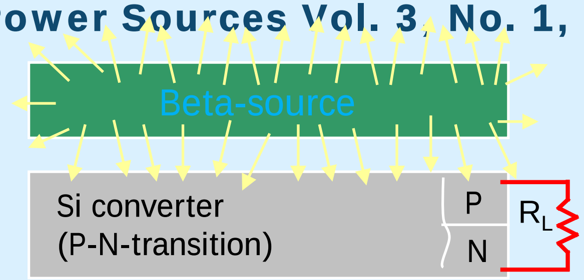


The wall thickness between the pores is 10-50 nm

And the possibility of obtaining C-14 and the installation with further application of SiC/ Si substrate

КГУ
SiC
В
50
40
30
20
10
300 500 700 900 1100
T, K

- Goal: **criterial parameters determining for the efficiency of the semiconductor betaConverter *C*-14 in the molecule *SiC* based on the effectiveness of the basic parameters of the system. The main variable parameters in a mathematical model: the depth of *p-n*-junction, the thickness of the layer *SiC*-14, the width of the space charge region (SCR).**
- **[Tariq R. Alam and Mark A. Pierson J. Energy Power Sources Vol. 3, No. 1, 2016, pp. 11-41]**



- **1.** *Compare* **technology implementation for Betavoltaic converters**
- **(***fuel and semiconductor selection***).**
- **2. Develop** *model* **processes and increase the efficiency of betaConverter *C*-14 in the molecule *SiC*.**
- **3. Conduct** *theoretical analysis* **calculation methods depending on the thickness of the surface activity (*maximum layer*) of Isotope to determine the optimal layer thickness (*the depth of immersion in the SCR*) *SiC*-14 versus *Ni*-63.**
- **4.** Installation of the carbon-14 synthesis by neutron source in ion nitrogen-14 target

Choosing the isotope material

Isotope	Beta Decay Maximal Energy, MeV	Half-life, years
Sr-90	0,546	28,8
Pm-147	0,224	2,63
H-3	0,019	12,3
Os-194	0,087	6
Ni-63	0,067	100,1
Ar-42	0,600	33
Kr-85	0,687	10,6
S-35	0,167	0,24
P-33	0,249	0,07
C-14	0,156	5730

Selection of the semiconductor material for the carrier separating

Si	GaAs	SiC	(SiC / Si) *
↓	↓	↓	↓

PolikarpovMA,YakimovEB Investigation of properties of semiconductor silicon-based transducers for beta betavoltaic elements

MISA
UlGU
NRC
"Kurchatov Institute"

Tomsk State University

Swiss uni-t

Mayntsinga.

source of energy S-35.

Cornel University.

Florida University

New Mexico

energy H-3 and Ni-63

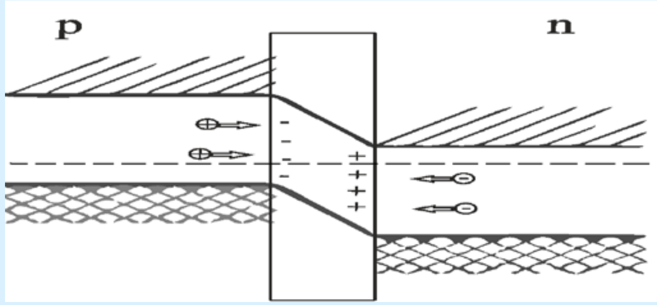
SityLab

Wideronix

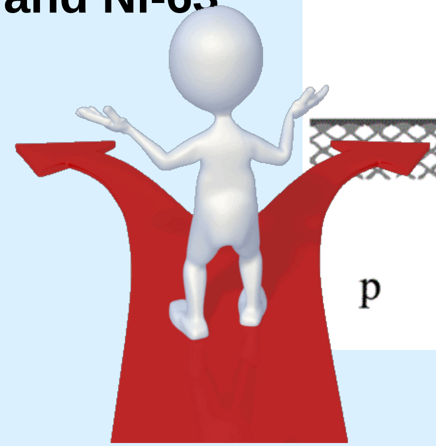
Ultrateh

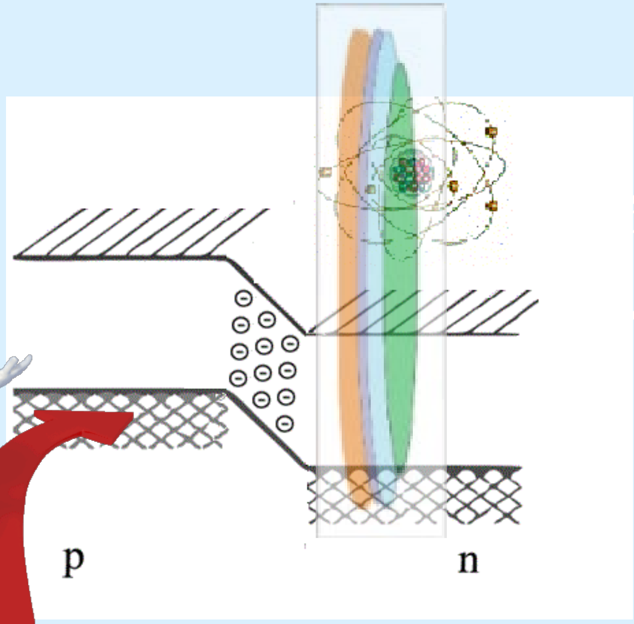
BetaBatt

Patent №02370851 C2 endotaksy method self-assembled mono 3c-SiC on Si substrate / Chepurnov VI, valid from 15.12.2005



Физика и техника полупроводников, 2015, том 49, вып. 6
М.А. Поликарпов, Е.Б. Якимов
NRC «Kurchatov Institute»
The experimental investigation of silicon based p−i−n diodes in a scanning electron microscope in the conditions imitating beta-radiation from radiation source Ni63 with an activity of 10mCi/cm2 were carried out.

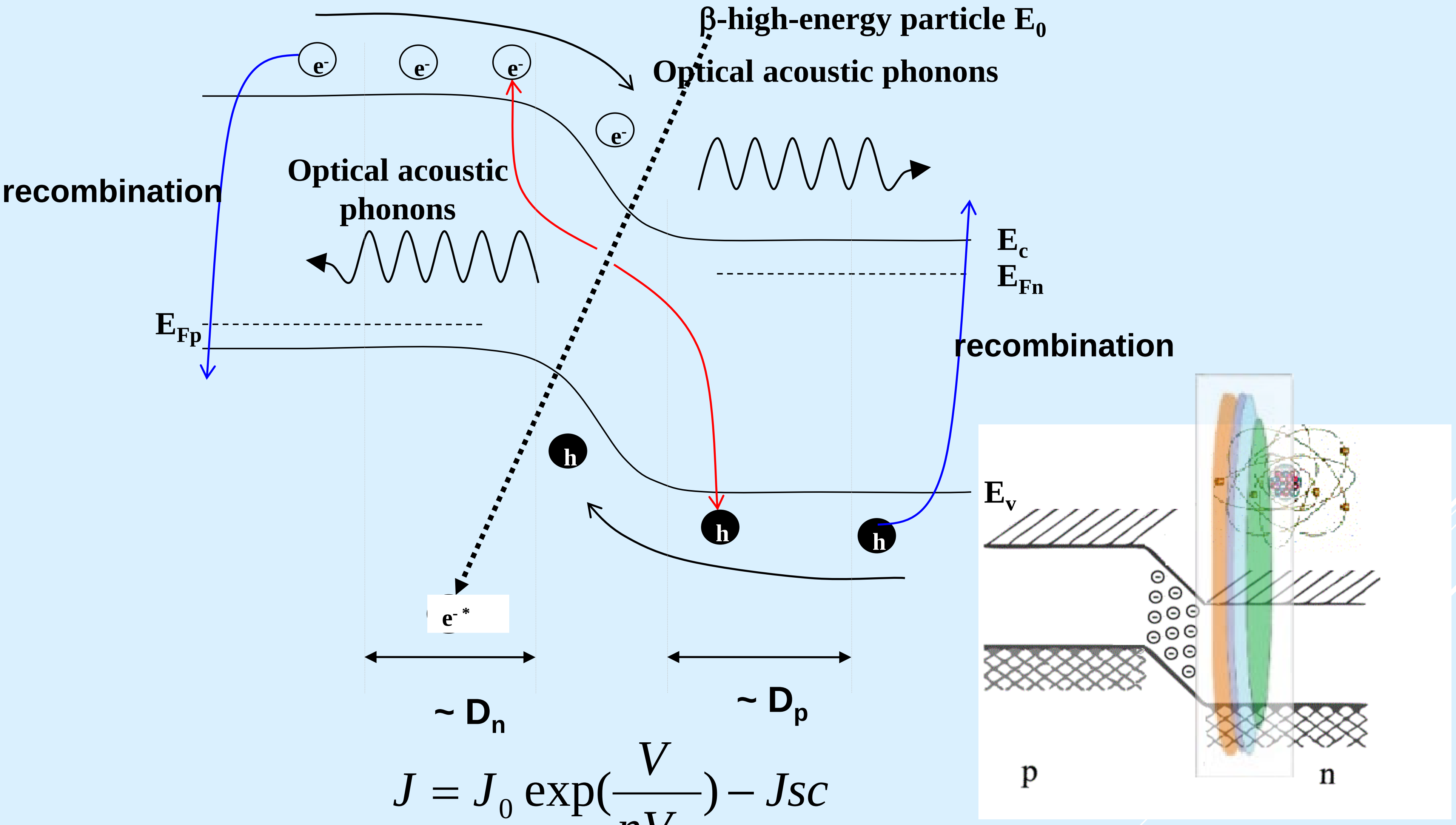




Why SiC ?

- *SiC*-structure resistant to radiation and temperature. Additional radiation passivity gives developed mesoporous surface por-SiC.
- The presence of pores increases the area of the perceived light. Increased stability of physico-chemical properties in conditions ßirradiation (electron flow).
- At the expense of long diffuse radiation defects to the surface and are derived from a crystal
  => increased efficiency converter.
- efficiently produce SiC film on the substrate Si.
  because the cost of finished substrates:
  si ~ $ 10. SiC ~ 1000$.

How does it work



$$J = J_0 \exp\left(\frac{V}{nV_{th}}\right) - Jsc$$

MODEL

$$\eta = \frac{I_{K3} U_{XX} F F}{P_{\beta}}$$

emitted by the radioisotope power

$$R_{KO} = \frac{0.0276 A E_0^{1.67}}{Z^{0.89} \rho}$$

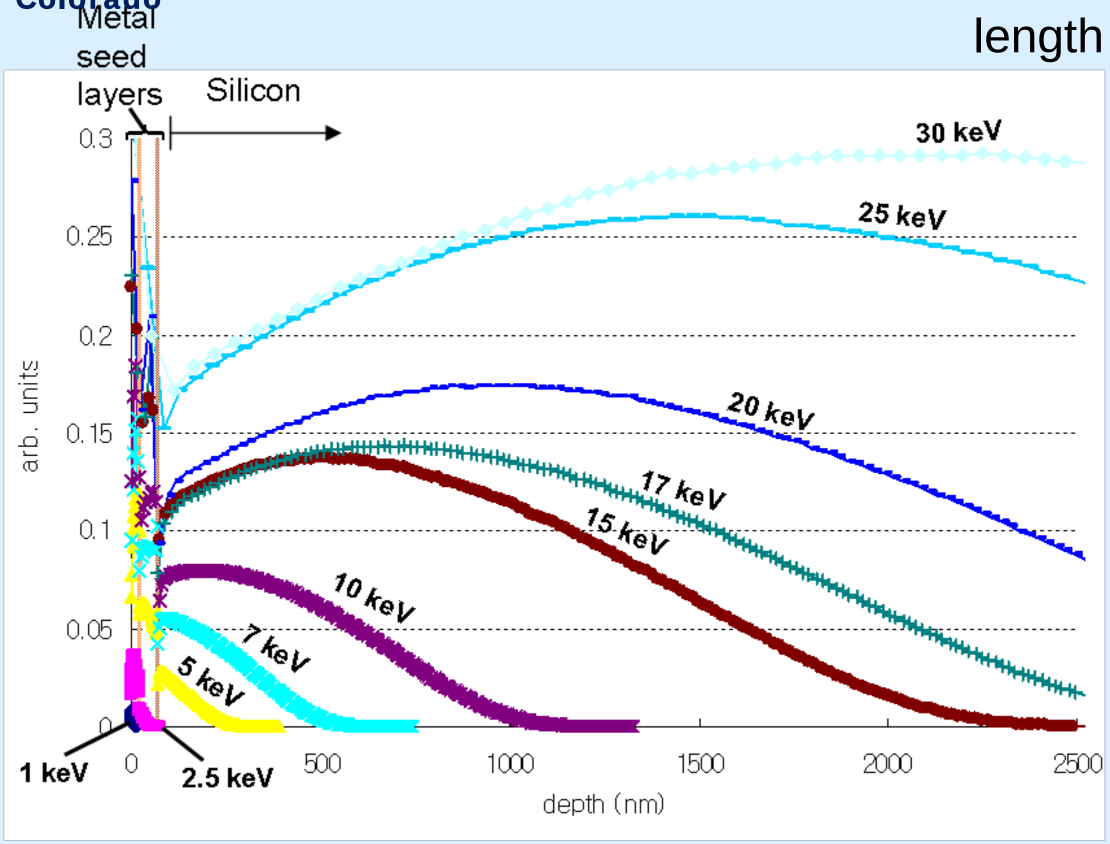
the equation Kanaya-Okayama

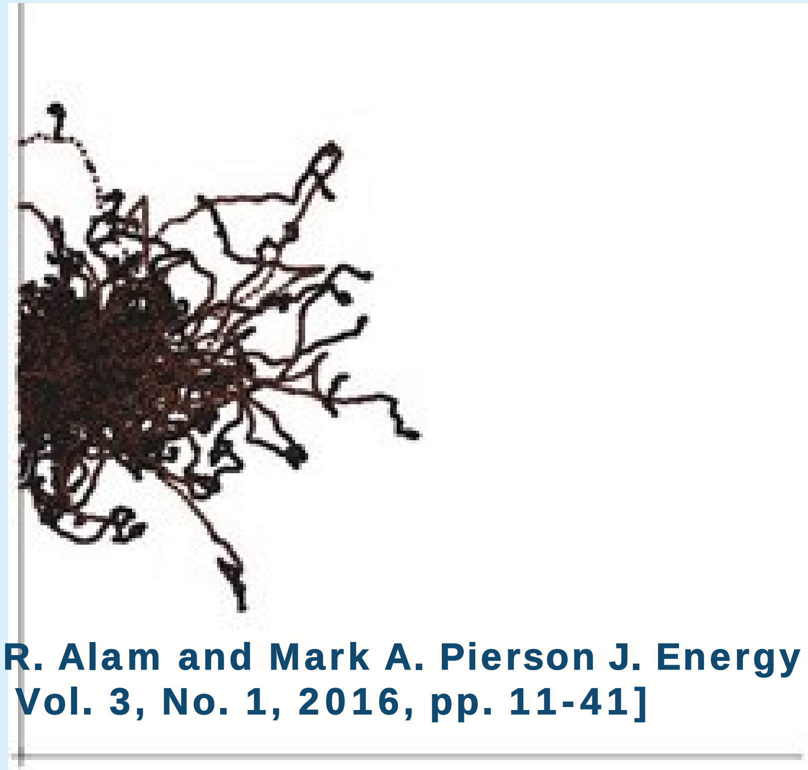
$$h(x) = 0.60 + 6.21x - 12.04x^2 + 5.23x^3.$$

$$x = \frac{z}{R(E)}$$

George Miley, University of Illinois; Rich Masel, University of Illinois; Saeed Moghaddam, University of Illinois; Priya Desai, University of Illinois; Ben Ulmen, University of Illinois

7th International Energy Conversion Engineering Conference Denver, Colorado





- **[Tariq R. Alam and Mark A. Pierson J. Energy Power Sources Vol. 3, No. 1, 2016, pp. 11-41]**

The optimum thickness of the layer C-14.

Approximation calculations by the Monte Carlo method:

$$h(x) = 0{,}60 + 6{,}21x - 12{,}04x^2 + 5{,}23x^3; \quad x = \frac{z}{R(E)}$$

Where *z* - the average depth of penetration of the electrons in the material,

***R (E)* - the maximum length of an electron with an electron with energy *E*in a given substance. Function*h (x)* It has the meaning of probability of detection particles, emitted with an energy of *E* at a depth *z*.**

[Абанин И. Е. Выбор активных слоев источника питания с p—n-переходом, возбуждаемым β-излучением **НАНО- И МИКРОСИСТЕМНАЯ ТЕХНИКА, № 10, 2015**]

The optimum thickness of the layer C-14

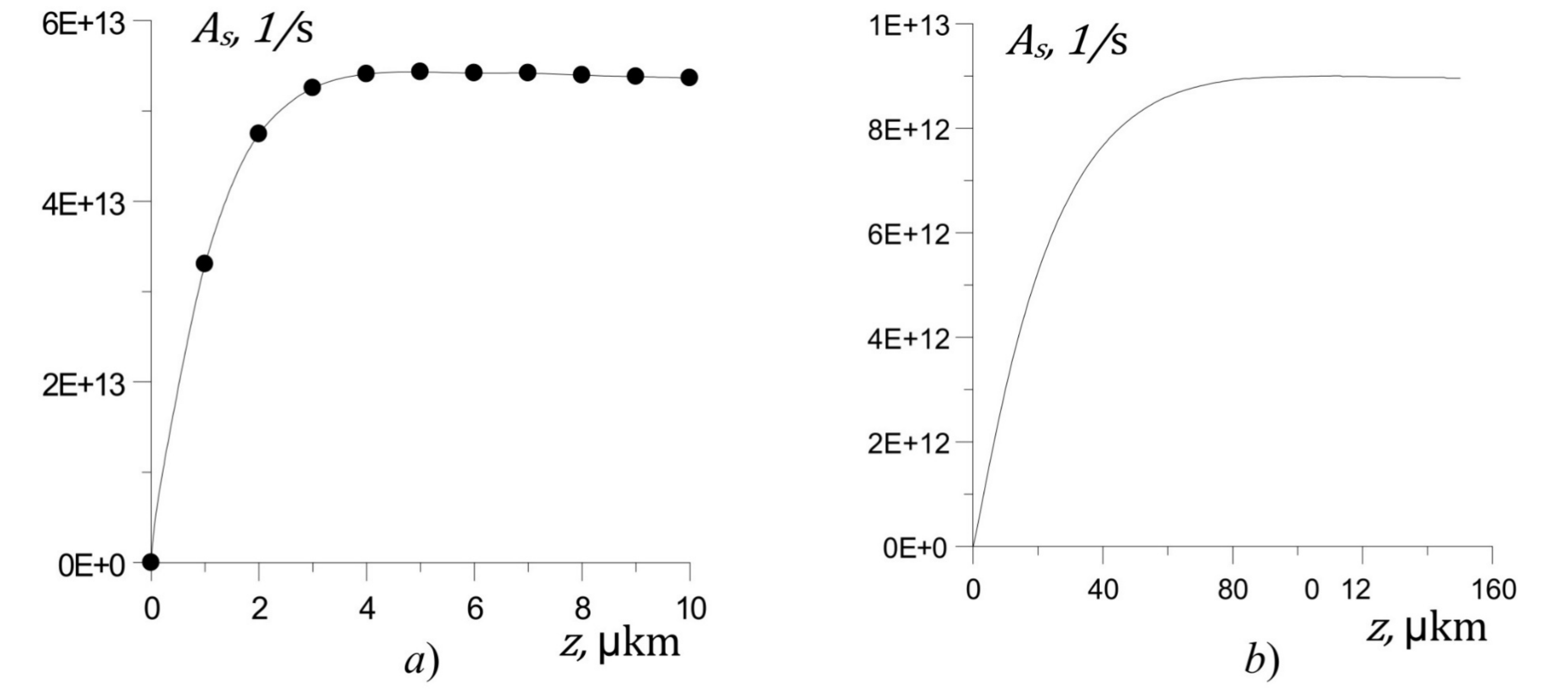
The probability that an electron of any energy generated at a depth of *z*. reaches the surface:

$$W_S(E) = \int_0^{E_{max}} W_c(E) h\left(\frac{z}{R(E)}\right) dE.$$

Then the expression for the surface activity:

$$A_S = A_{Vo} S \int_0^d dz \int_0^{E_{max}} W_c(E) h\left(\frac{z}{R(E)}\right) dE \ .$$

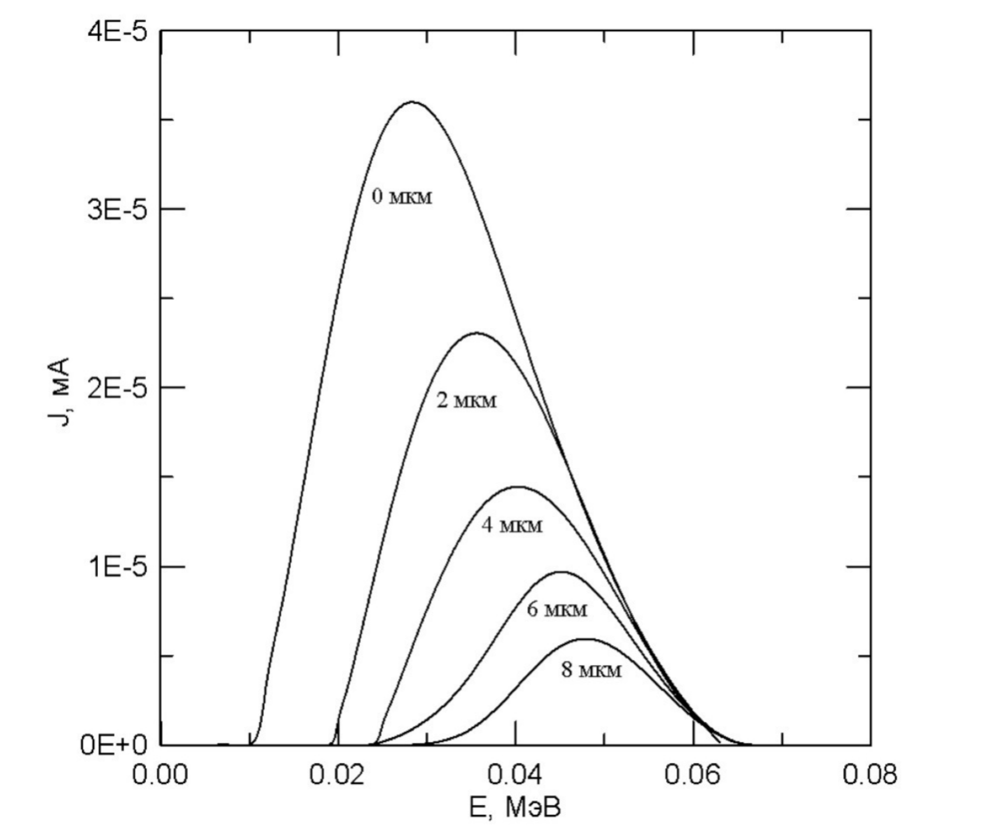
The optimum thickness of the layer *C*-14



Dependence of the activity on the surface layer of the isotope.

***a*) - Ni-63. *b*) - C14.**

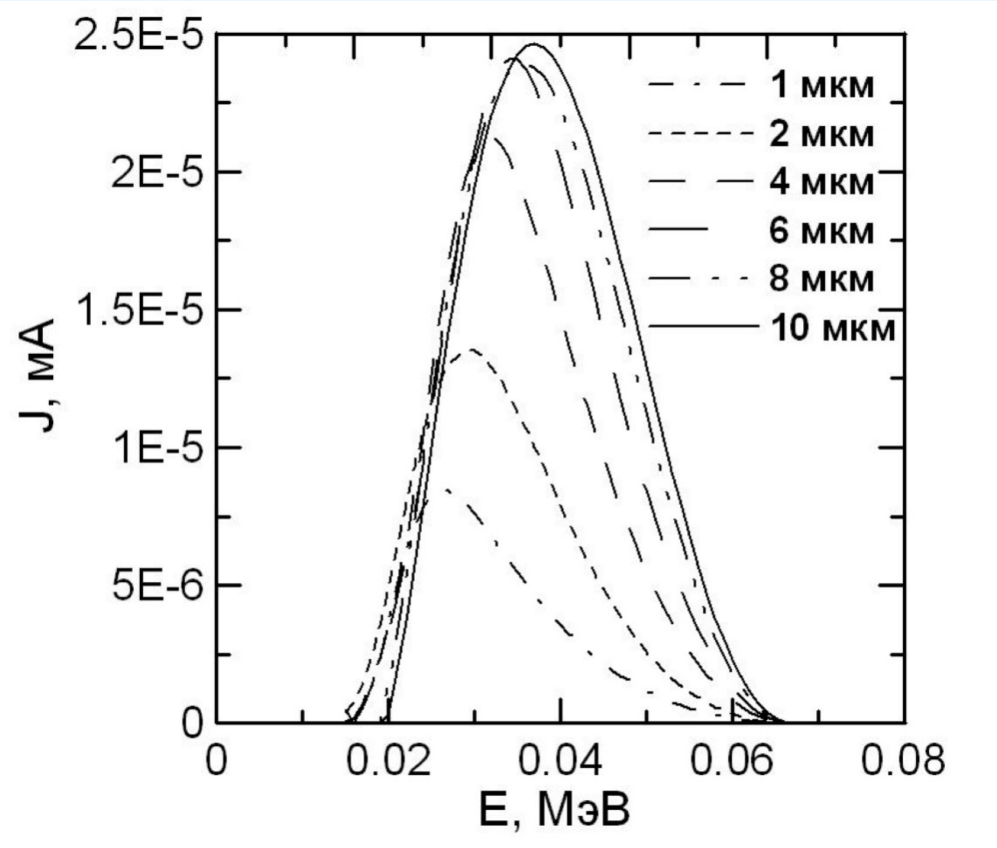
The depth of *p-n*-junction



Spectrum generation current of depth p-n-transition to SCR width 8 microns using the isotope Ni-63 with activity 20 mCi.

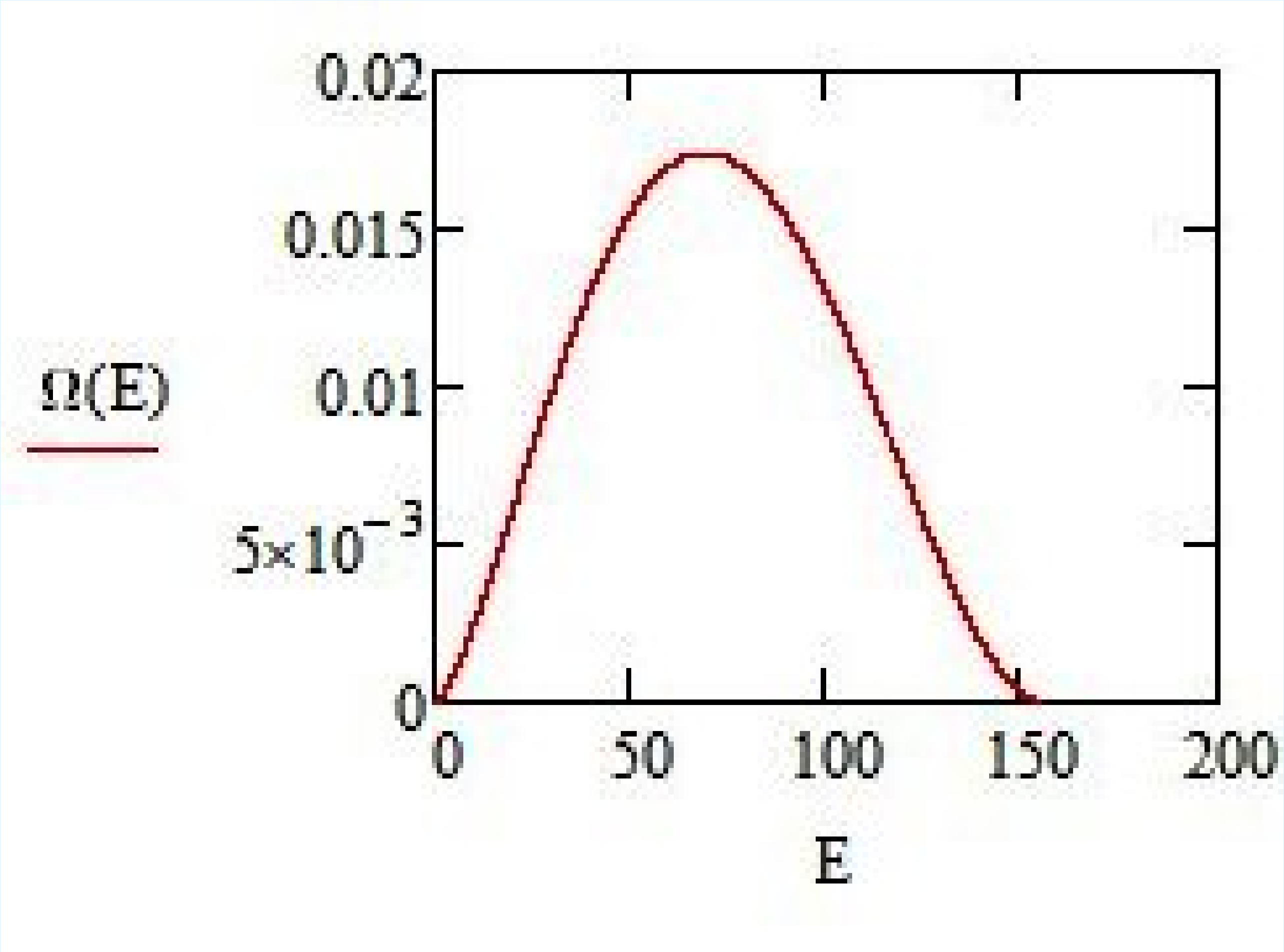
Нагорнов Ю.С. Современные аспекты применения бетавольтаического эффекта Ульяновск: УлГПУ, 2012. — 113 с.

The width of the SCR



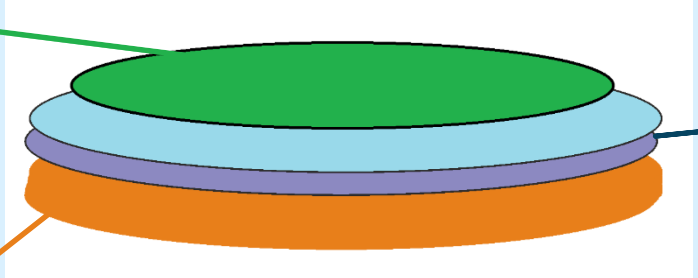
Current generating from the SCR spectrum width to depth *p-n*-transition using isotope Ni-63 with an activity of 20 mCi.

Si C-14

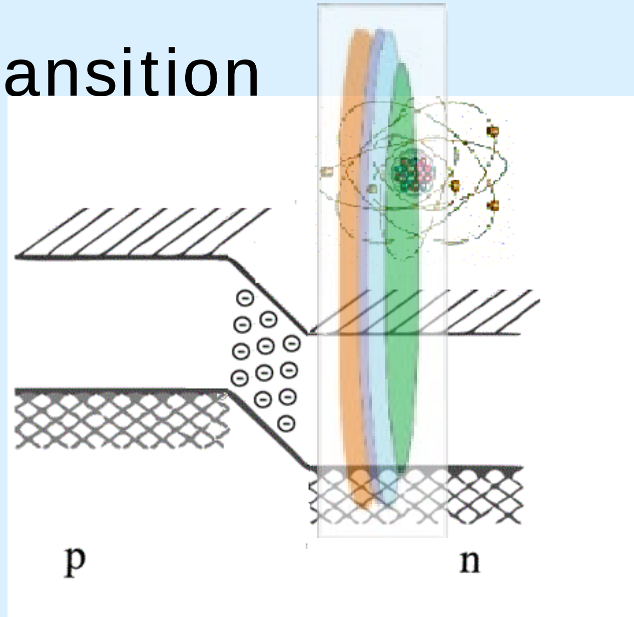


Our and general schemes for ß-converters

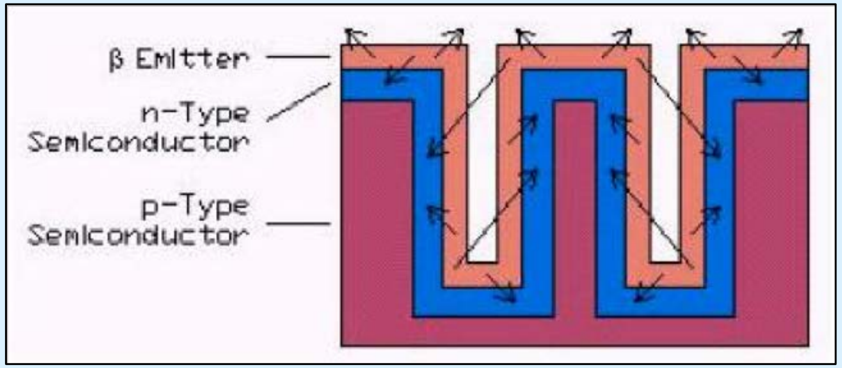
Contact Conclusion *Ni*

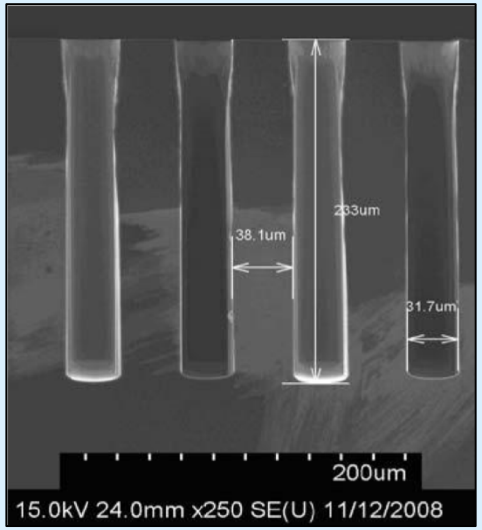


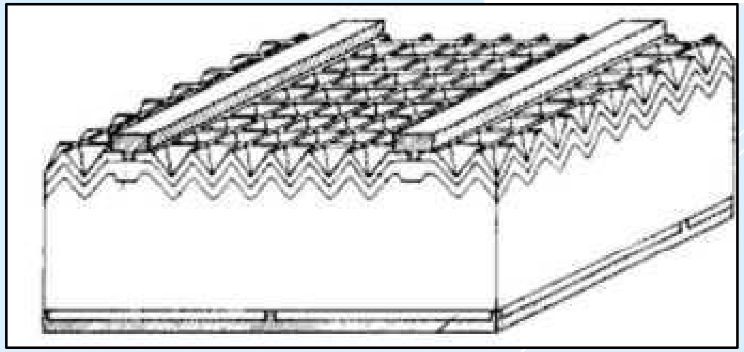
p-*n*-transition



Structure por-*SiC*/*Si*-podlozhke

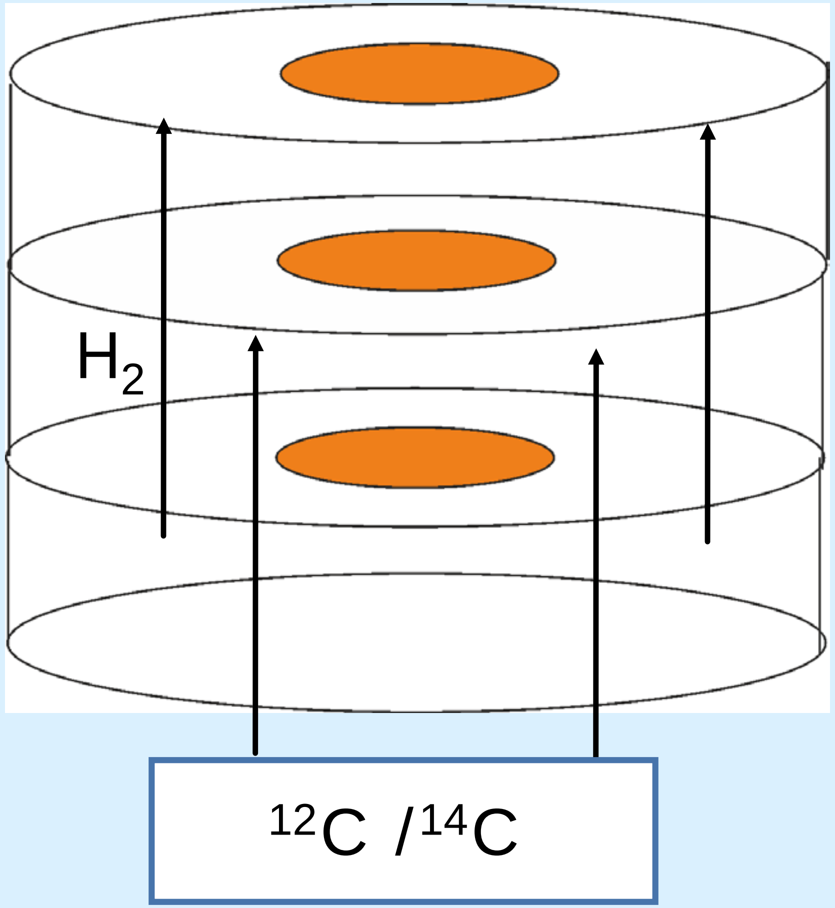


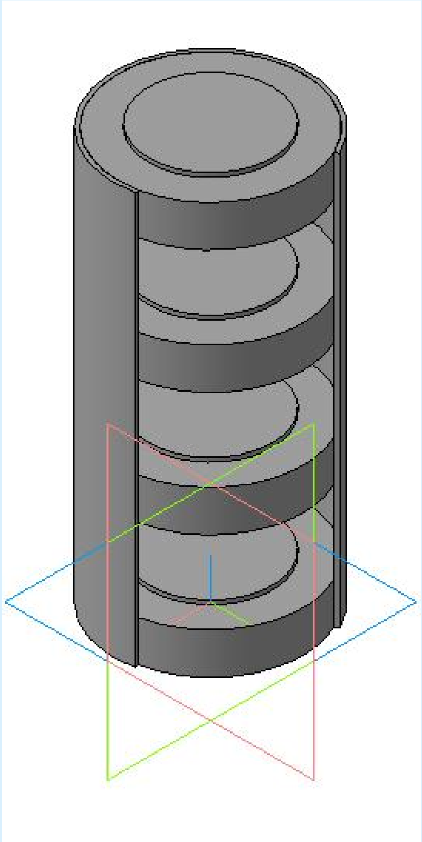


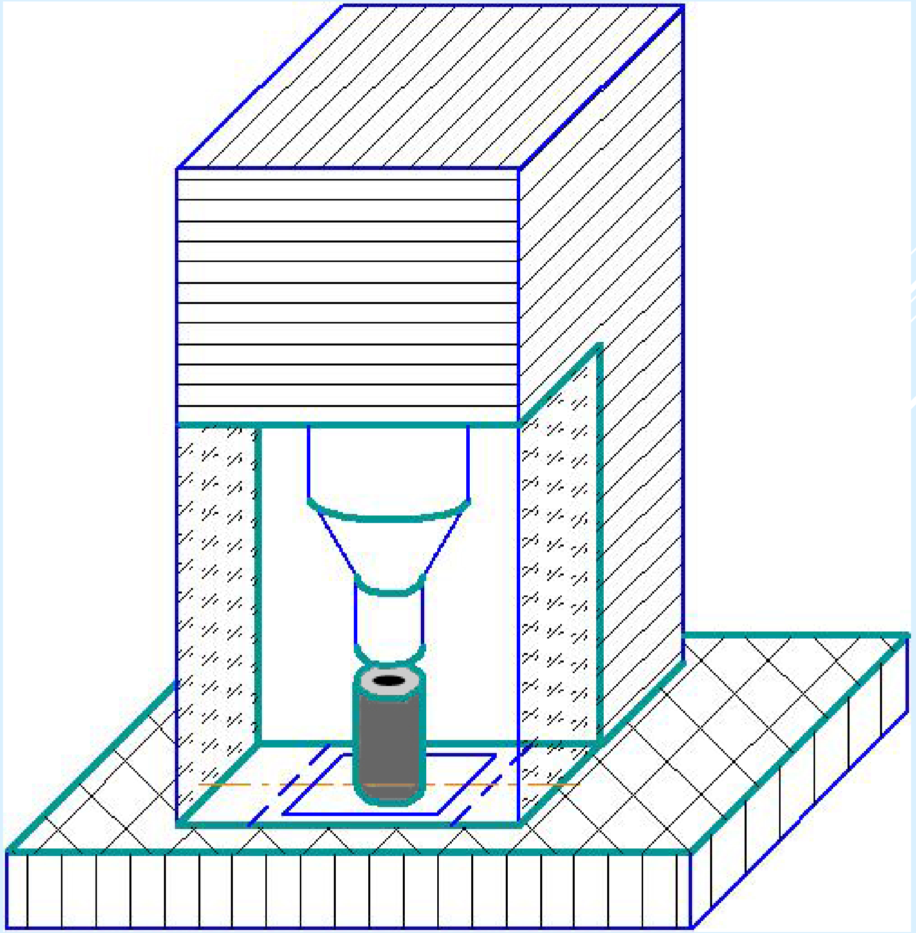


SiC / Si Production Endotaksy method

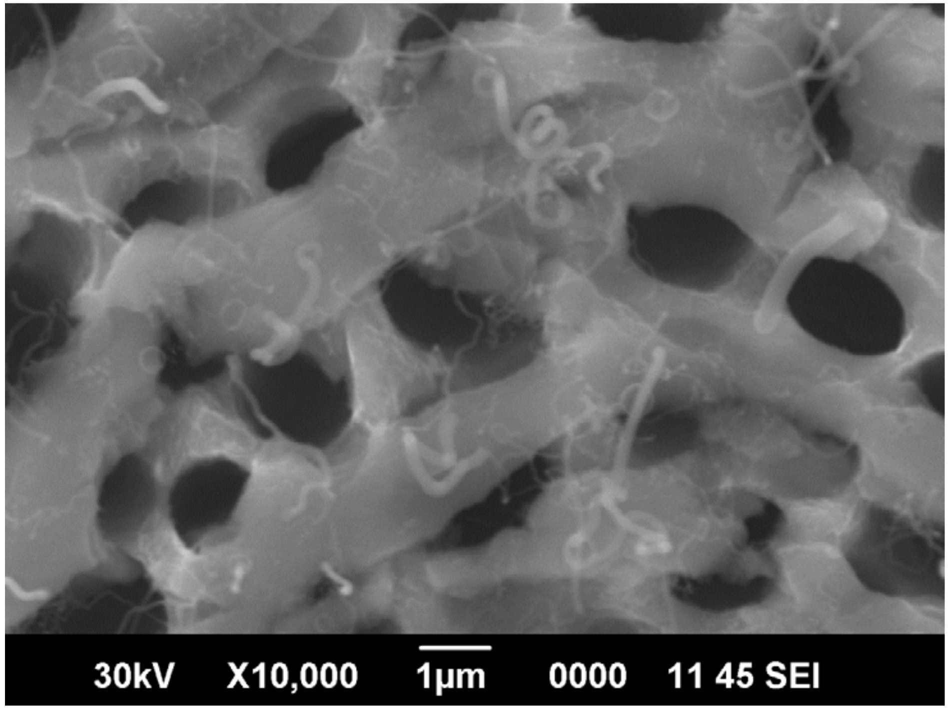
Monocrystalline Silicon Substrates are placed in the section installed in tiers in a container and subjected to a stream of processing hydrocarbons from the bottom of the chamber.



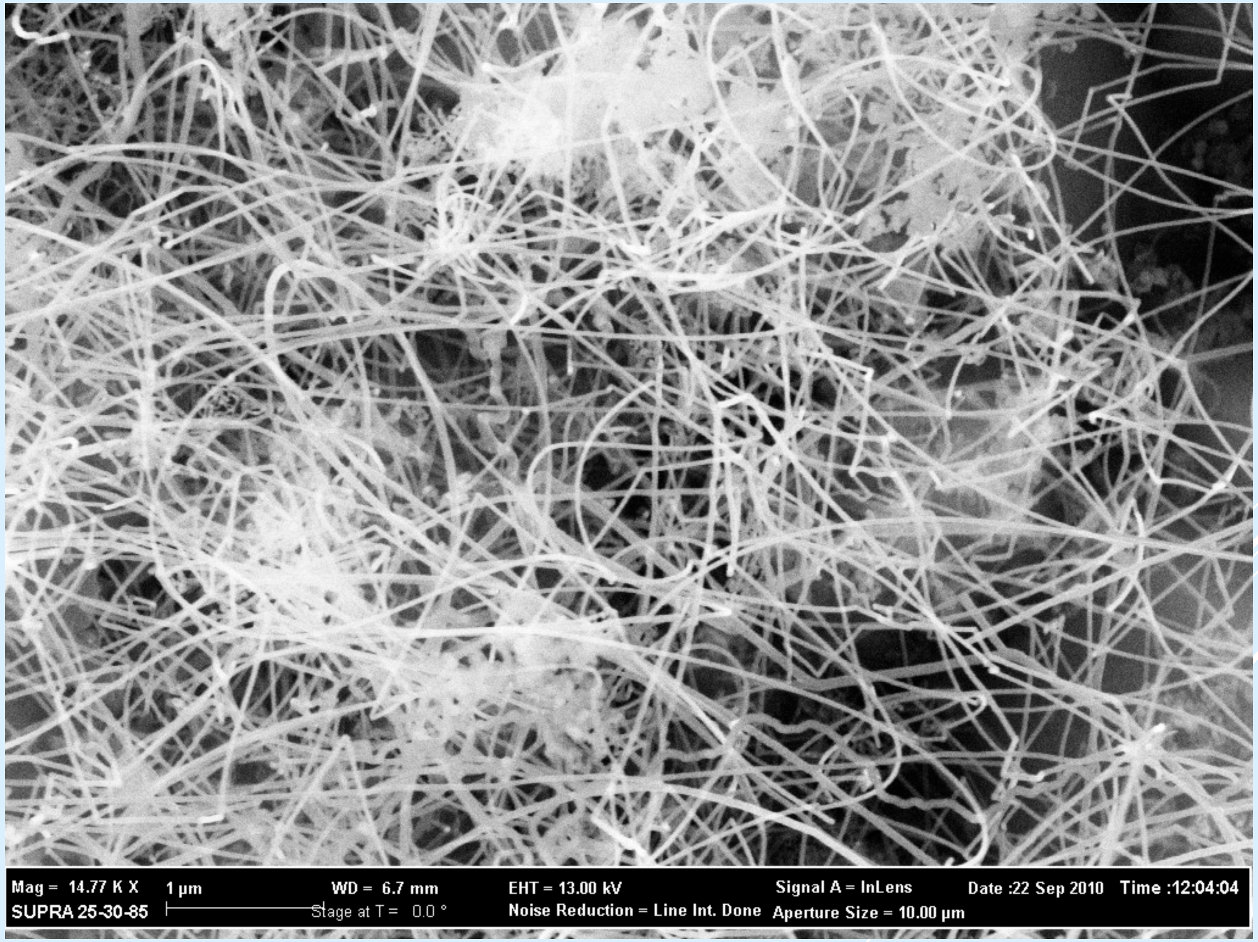




Structure SiC / Si obtained by endotaksy



The porous structure SiC / Si.
Pore sizes: 1-2μm.



Silicon carbide nanowires on the porous structure surface

Generator controlled ion as a source of neutrons for the synthesis of C-14

Generation proton flux for the synthesis of neutrons by lithium ion target as a result of compaction of the primary flux of protons and sampling of parameters specify the density and average energy of the flow. Electronically controllable streams are formed in parameters repetition period Tsl and frequency discrete streams ωsl. Accelerator provides change of energy of the primary ion fluxes from 150 keV to 1200 keV.

Generation dense proton flux for the synthesis of neutrons by lithium ion targets:

$$D + Li^6 \rightleftarrows Be^7 + n^0$$

$$D + Li^7 \rightleftarrows 2He^4 + n^0$$

The synthesis reaction at the target dense nitrogen ions:

$$n^0 + N^{14} \rightleftarrows C^{14} + p^+$$

1) The total energy of the incident particle and the target above the Coulomb repulsion energy
2) Density ni impinging stream for pulsed operation is equal to or above $ni \geq 10^{22}$ cm-3.
3) Retention time in a magnetooptical chamber with τ≥1.
4) The energy of the ions in the incoming stream W_i> 200 keV.

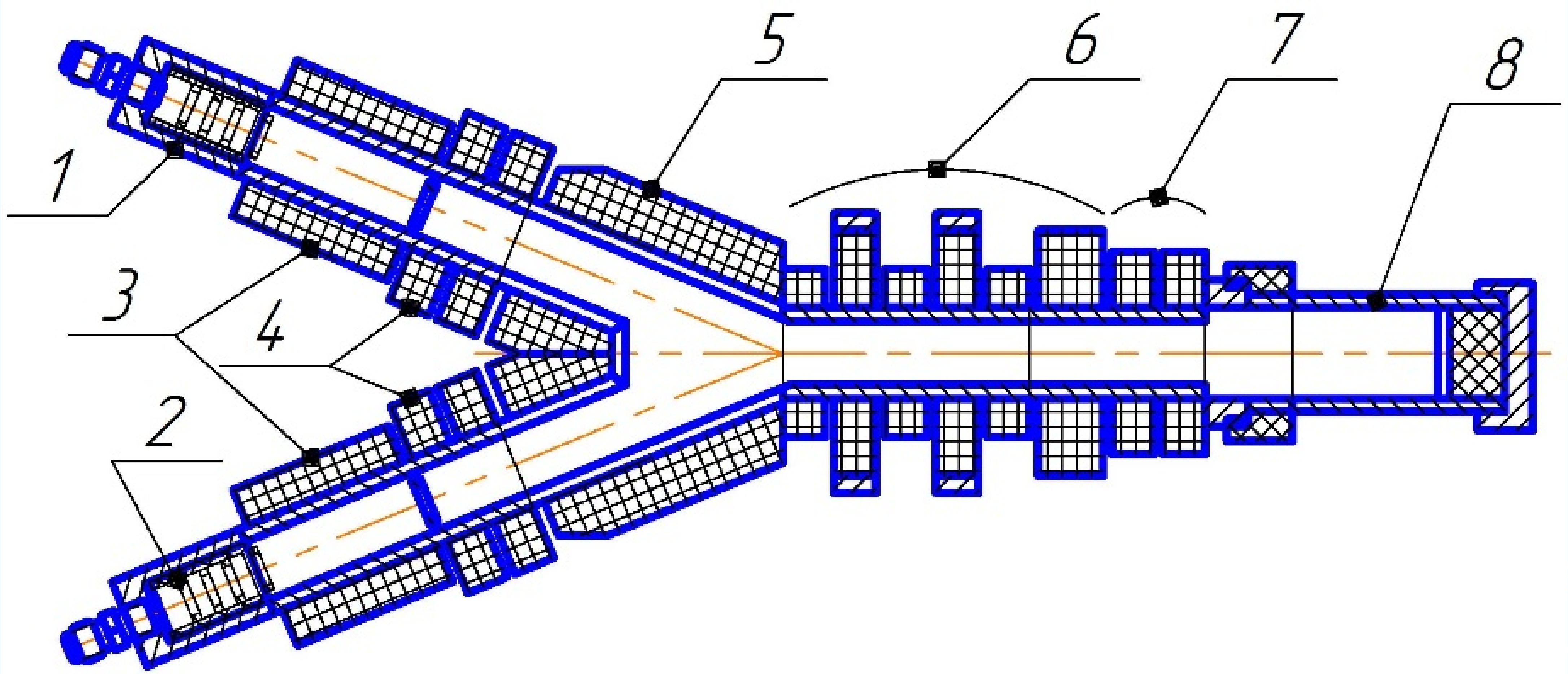
[a) G.A.Mesyats Pulsed Power end Electronics 2004]
[b) S.Y.Luk'yanov Hot plasma and controlled nuclear fusion 1975]

Generator controlled ion as a source of neutrons for the synthesis of C-14

DESCRIPTION STRUCTURE GENERATOR

number	node name	the destination node
1	ionizers hydrogen, nitrogen, lithium	Ionization of the hydrogen, nitrogen, lithium
2	Injector hydrogen ions, nitrogen, lithium	Injector energy of 25 keV
3	Magneto-optical storage device, the ion generator ^{1}H. ^{7}Li.^{14}N	Ensure the formation of discrete ion flows accelerator
4	Accelerator-shaper protons linear	Energy from 200 keV to 600 keV with an electrostatic scanning ions
5	Accelerator-shaper nitrogen ions linear	Energy from 200 keV to 400 keV with an electrostatic scanning ions
6	Accelerator-linear ion generator ^{7}Li	Energy from 200 keV to 300 keV with an electrostatic scanning ions
7	First output magnetodynamic two or four cyclic camera two injector	Synthesis ^{7}li c ^{1}H
8	The magneto-optical drive limiter	Delays the charged ions
9	Second output magnetodynamic two cyclic two chamber injector	Synthesis ^{14}N and n
	drainage system ^{14}FROM	

Ability to generate an 8-cycle synthesis of particles of different grades. Support deuterium-lithium reactions synthesis with a retention time in the system above the magnetooptic c a single cycle of 5 seconds.



1- ionization lithium hydride LiH 2- ionization nitrogen 3 – injector 4 - Magneto-optical drive - driver 5 - Accelerator-driver
6 - magneto dynamic eight cyclic camera 7 - Magneto-optical drive-limiter 8 - The drainage system ^{14}C

The density of neutron flux n=7.477E+18 cm-3
The energy of the neutrons is 1: 2.72 E+6 MeV
The energy of the neutrons is 1: 12.0 E+6 MeV

Results and Prospects

- The suitability of *C*-14 as a source of beta-cells.

- Highlights the key parameters affecting the efficiency of beta-cells and conducted a qualitative analysis of the ways to increase the effectiveness of beta-source *C*-14 in the molecule *SiC*.

- Separately it is necessary to solve the problem of isotope enrichment ^{14}C.

- We need to develop and conduct a series of experiments to verify the theoretical calculations and hypotheses.

Results and Prospects

- The production of carbon-14 at a cost lower than traditional production.
- The source of the neutron fluxes for the synthesis of radioactive isotopes for medical purposes.
- Modification device to vacuum ion-plasma deposition of carbon on the SiC substrate 14.
- We need to develop and conduct a series of experiments to verify the theoretical calculations and hypotheses.

Results and Prospects

- A method of implantation ^{14}C in molecule por-SiC in step preparation heterostructures of p-n-transition

- Technology has been developed and a mathematical model of the converter manufacturing: technological (route maps, physical parameters, tools) and design (assembly devices, housing, terminals, electrical insulation, recycling methods) documentation.

- Separately it is necessary to solve the problem of isotope enrichment ^{14}C

THANK YOU FOR ATTENTION!

Authors thank Victor Ivanovich Chepurnov
for numerous comments and advice on the technological process of manufacturing and properties of SiC semiconductor structures.