The XXIV International Workshop
High Energy Physics
and
Quantum Field Theory

Micro alloying of SiC by radioisotope

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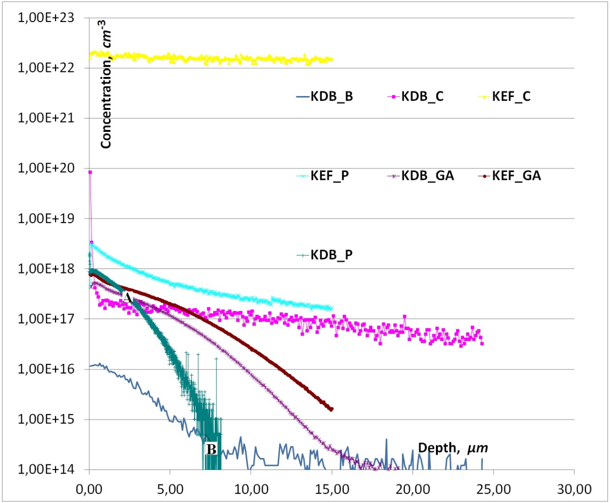
Betavoltaic battery or beta-converter – device for transforming beta-decay energy in DC.

HighLights

direct energy convertion of radiochemical transformations through semiconductor structures
optimal parameters:
- the geometry of the structure,
- the thickness of the deposition of the radioisotope layer,
- the depth and the width of the p-n junction

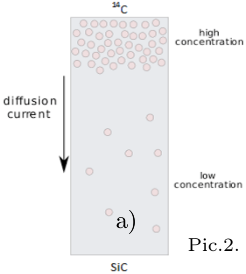
influence factors on energy conversion
optimal technology process of growth,
self-diffusion, radioactive Carbon isotope phase, the mobility of the radionuclide.
theoretical modeling of beta converters
Dark currents from 16 to 90 nA were observed in the external circuit. Idling voltage was amounted to 1.6 mV. The thickness of the activated n-SiC film in the heterostructure is $1 \div 5$ μm.

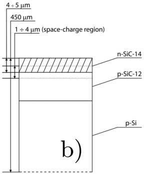
Self-organizing mono 3C-SiC endotaxy technology



Pic.1. Diagram of concentrations dependencies on depth. The analyzed depth ranges from $5.3 \cdot 10^{-8}$ to $24.3 \cdot 10^{-6}$ m. The concentration of C^{12} atoms (KDB_C curve), depending on the analyzed depth, ranges from $8.4 \cdot 10^{19}$ to $3.2 \cdot 10^{16}$ particles/cm^3.

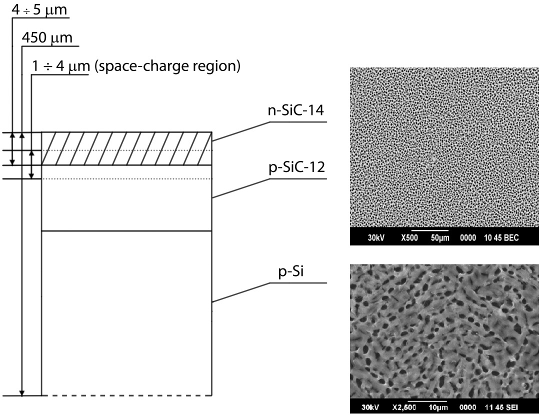
Diffusion and structures





Pic.2. Structures SiC/Si.

Beta-converter



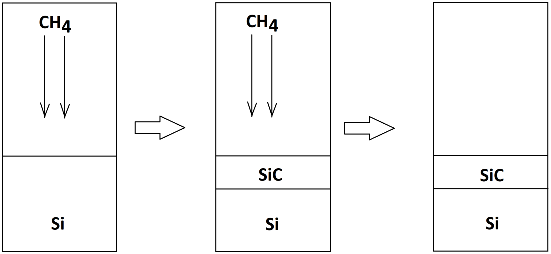
Pic.3. The structure of beta-converter.

Goals

- Solve the diffusion equation with the initial and boundary conditions for the process of carbon diffusion in silicon
- Using the Wolfram Mathematica analytical system, find the parameters at which the solution most accurately describes the experiment
- Compare the calculated diffusion coefficient with known values

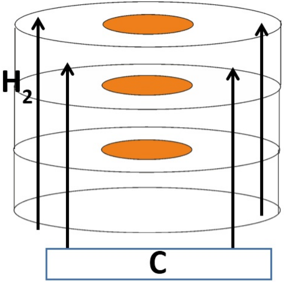
The process of endotoxy of carbon in silicon

$$CH_4 + Si \rightarrow SiC + 2H_2 \tag{1}$$



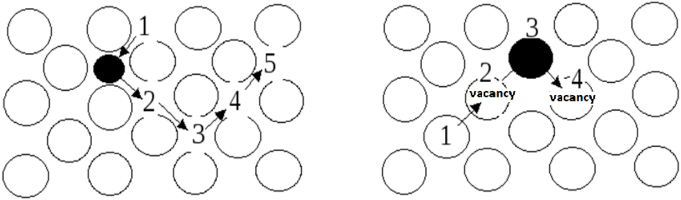
Pic.4. The endotoxy scheme.

The microalloying process in the gas chamber



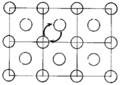
Pic.5. Schematic representation of chemical transport (experimental silicon substrates are indicated in orange); to the right: CVD endotaxy reactor of the SiC / Si family of heterostructures.

Carbon diffusion process in silicon



Pic.5. a)Interstitial diffusion mechanism; b) Vacancy diffusion mechanism.

The diffusion coefficient via the vacancy mechanism



Pic.6. The reverse motion of an impurity atom, the possibility of which is taken into account in the vacancy diffusion mechanism.[1]

$$D_{vac} = \frac{b^2\Gamma}{2} \lim_{n\to\infty} (1 + \frac{2}{n} \sum_{j=1}^{n-1} \sum_{i=1}^{n-j} \frac{< x_i x_{i+j} >}{b^2}), \ \ \Gamma = \lim_{n\to\infty} \frac{n}{t_n} \qquad (2)$$

[1] Stark, J.P. Solid State diffusion. M .: "Energy 1980.

Solution of the Neumann problem

Neumann problem:

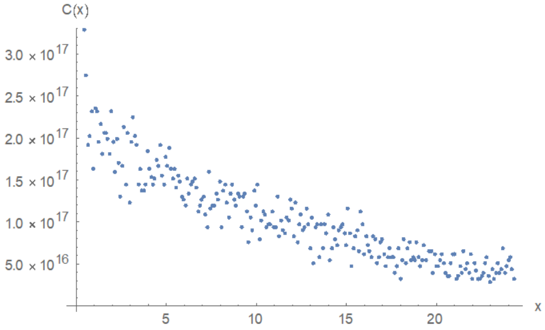
$$\frac{\partial}{\partial t}c(x,t) = D_{eff}\frac{\partial^2}{\partial x^2}c(x,t)$$

$$-D_{eff}\frac{\partial c(0,t)}{\partial x} = J, \;\; c(x,0) = 0 \tag{3}$$

Solution:

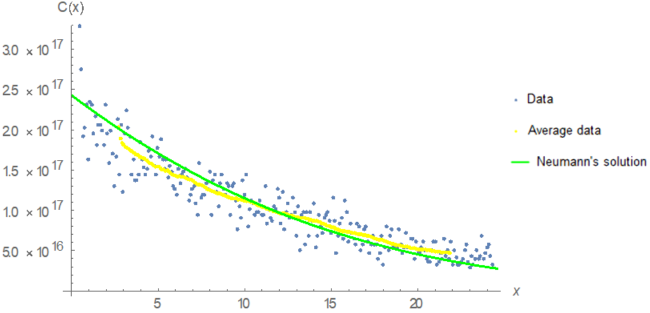
$$c(x,t) = J\frac{2e^{-\left(\frac{x^2}{4D_{eff}t}\right)}\sqrt{t}}{\sqrt{\pi D_{eff}}} - \frac{Jx}{D_{eff}}Erfc\left(\frac{x}{2\sqrt{D_{eff}t}}\right) \tag{4}$$

SIMS results



Pic.7. The investigated depth varies from $5.3 \cdot 10^{-8}$ to $24.3 \cdot 10^{-6}$ m. The concentration of atoms depending on the studied depth varies from $8.4 \cdot 10^{19}$ to $3.2 \cdot 10^{16}$ particles/cm^3.

Calculation of model parameters



Pic.8. The experimental points according to the WIMS results are blue, the averaged curve of the experimental points is yellow, and the solution to the Neumann problem found with the parameters found by approximation is green.

$D_{eff} = 4.95 \cdot 10^{-10} cm^2/s,\ J = 7.98532 \cdot 10^{14} particles/cm^2 \cdot s,$
where J is stable carbon flux density at the boundary.

Analysis and comparison of results

$D_{int} = 9.79 \cdot 10^{-4} cm^2/s$ - diffusion coefficient for the interstitial diffusion mechanism;
$D_{vac} = 5.11 \cdot 10^{-10} cm^2/s$ is the diffusion coefficient for the substitution mechanism.[2]

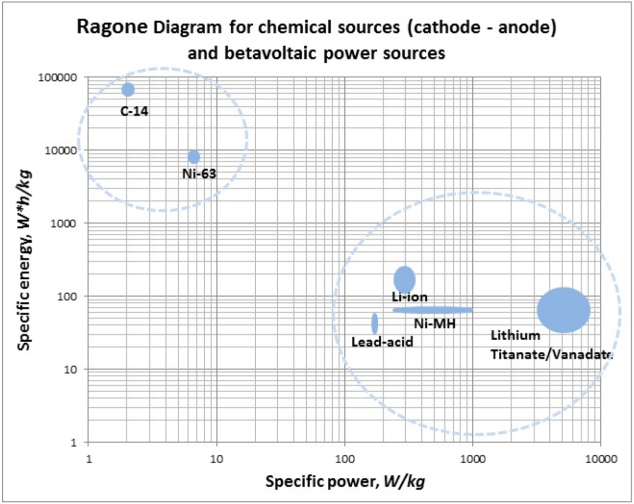
Our result is $D_{eff} = 4.95 \cdot 10^{-10} cm^2/s$

Under the given experimental conditions, during the diffusion process, the predominant mechanism is the substitution mechanism.

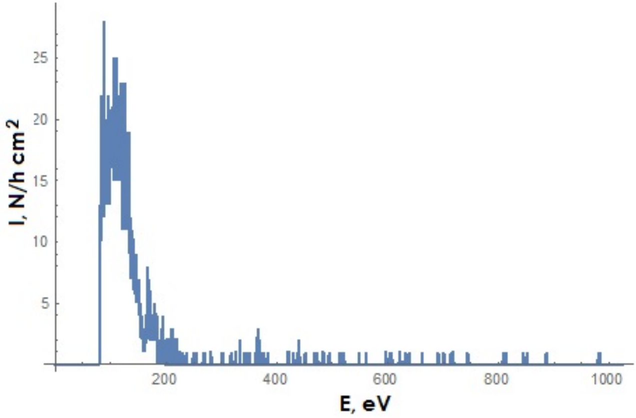
[2] P. Werner, H.-J. Gossmann's "Carbon diffusion in silicon"

Carbon-14 choice of as the fuel

1. Specific activity of C-14 is different from the Ni-63 about in 10 times per unit volume, due to the huge difference in half-life times.
2. Self-absorption of Ni-63 is larger by approximately three times, which leads to the maximum limit optimal thickness of the layer to 4 microns, and for C-14 this thickness may be up to 60 microns which is better suited. The total quantity of the isotope C-14 may be an order of magnitude greater, therefore, guaranteed more power for the same size of power converters.
3. The specific power of Ni-63 per gram of the substance 5 times (due to more activity) exceeds the power density of C -14. But the maximum and average energies of electrons in the C-14 decay is in 2, and even 3, times more than in the Ni-63 decay.

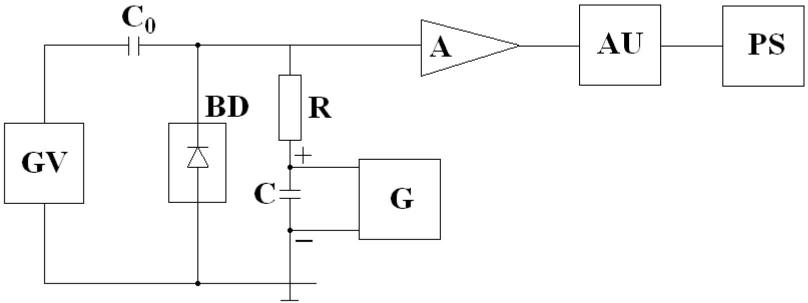


Pic.9. Ragone Diagram for chemical sources and betavoltaic power sources



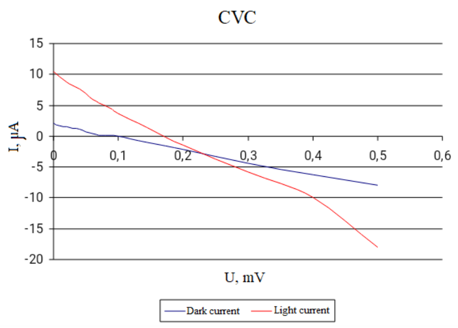
Pic.10. Spectrum of radioactive carbon in SiC structure.

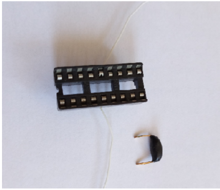
Electrical diagram of the measuring device



Pic.11. BD – detector, AU is the scale Converter, A – charge sensitive amplifier, PS – amplitude analyzer, G – source bias voltage, R – resistor leakage, C is a blocking condenser, GV – generator of voltage pulses, C0 – metering capacitor.

Current-voltage characteristic and samples





Pic.12. To the left: dark (blue) and light (red) current-voltage characteristics measured on the n-SiC / p-Sic / p-Si structure. To the right: example of the experimental structure with metallization

Sensor Example

Pic.13. These sensors were developed by the group of academician Muminov from Physical-Technical Institute of SPA "Physics-Sun" Tashkent, Uzbekistan.

Conclusions

At temperature $T = 1360 \div 1380$ °C and normal pressure $P = 10^5 Pa$, annealing time t = 60 minutes, the C^{12} carbon flux density at the boundary $J = 7.98532 \cdot 10^{14}$ $particles/cm^2 \cdot s$ and the effective diffusion coefficient of carbon C^{12} $D_{eff} = 0.0495984$ $\mu m^2/s$ were obtained. The results obtained are in good agreement with the known results.

$E_{Tr3,Ni63} < E < E_{defect}$

3C-SiC.

Thank you for attention!