SOME ASPECTS OF PHOTONUCLEAR REACTION APPLICATIONS IN RADIATION TECHNOLOGIES

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Abstract

The experience of photonuclear reaction applications on electron linear accelerator "Fakel" is presented. The technology of photo-nuclear doping and modification of semiconductors properties and the technology of medical isotopes manufacturing are described.

1. Introduction

Relation to radiation technologies, that may be devised on the basis of photonuclear reactions, is sometimes very cautious. The reason of such relation is in the fact,that in nuclear processes with leptons cross-sections are smaller by a factor of hundreds and thousands than in nuclear processes with hadrons. However, in modern several dozens MeV electron accelerators the beam intensities are more, than in proton accelerators. This circumstance results in the fact, that radiation technologies on the basis of photonuclear reaction become competitive and aquire commercial interest. In this case we want to pay attention of state and business structures to some technologies, devised on linear electron accelerator "Fakel"/1/.

Accelerator "Fakel" is multi-section travelling wave accelerator with following parameters of beams: electrons energy may be smoothly changed from 3 to 50 MeV; pulse length have two ranges - (25-300) ns and 5 mks; beam power in microsecond pulse length range is up to 50 kW.

Accelerator has ramified electron-optical channels system and optimised converters. Gamma-convertors are manufactured from heavy metal (tantalum, wolfram) - separate thin sections, cooling by the water; its common thickness is defined from the condition of maximum radionuclide output when energy of incoming electron is chosen.When electron energy is 30-40 MeV and common convertor thickness, is, for example, 2,5 g/sm, part of gamma in spectrum under reaction energy threshold, used in technology reaches up to 20%. We must notice, that neutrons, borned in gamma-convertor material, doesn't exert any influence in all considering technologies (little thickness, isotropic direction of neutron fly, neutron borning is secondary process with respect to gamma-quantums borning).

Neutron convertors are thick targets, also manufactured from heavy metals and cooling by water. Presence of cooling water can allay neutron energetic spectrum a little, average neutron energy is near 1.1 MeV. Neutron output from tantalum target, normalised on the basis of 1 kW of electron beam power, is 10^{12} n/s. Neutron out put from uranium target is 2.5 times as many as tantalum one.

On our accelerator we also have possibilities for work with electrons with energy range from 100 to 300 keV and with moderated neutrons.

Accelerator "Fakel" as a source of high energy gamma-quantums is superior by all its parameters in comparison with all known in Russia such radiation sources, and, besides that,it may be of great interest of some radiatiom technologies development on the basis of neutron radiation and low energy electrons.

2. Photonuclear doping and modification of semiconductors properties

Doping and modification of semiconducting properties of silicon - basic material of modern electronics - are of great interest. Proposal about photonuclear doping first appeared in work /2/. It is based on the reaction:

$$^{28}Si\ (\gamma,n)\ ^{27}Si\ \rightarrow\ ^{27}Al$$

We must notice, that aluminium is acceptor impurity.

The technology of photonuclear doping in general is the following /3/. Electron beam is directed to the convertor, after which purufying magnet is installed, and after it - silicon ingots assembly. Assembly is scaned relatively to gamma-quantum beam in vertical and horizontal planes, and after irradiation to half a dose it is rotated perpendicular to direction of ingots axes. Such technology has no restrictions on ingots diameter and quantity in assembly, but the length of ingots must be not more than 150 mm. In such conditions volume unhomogeneity will be not more than 5%. Values of energy and general convertor thickness are selected from the condition of aluminium maximum output from the reaction. However, energy more than 3,5 MeV is inexpedient because of undesirable admixtures appearance owing to possibility of reactions (γ, 2n), (γ ,np) and so on appearance.

Our technology, besides obtaining p-silicon with specific resistance range from 10 Ohm/sm to 10 kOhm/sm, allows to modify n-silicon properties.

Output of silicon with specific resistance higher than 8 kOhm/sm in zone smelting technology is not more than 10% /4/. Our technology allows to modify initial silicon with specific resistance near 1 kOhm/sm (its output with zone smelting technology is near 100%) to n-silicon with specific resistance from 1 to 40 kOhm/sm and higher, and to transfer n-silicon to p-silicon with specific resistance up to several hundreds kOhm/sm. It also allows to decrease specific resistance unhomogeneity along the ingot edges.

Output of photonuclear doping installation is determined in general by given specific resistance values, electrons intensity, correct choise of gamma-convertor thickness and accelerated electrons energy. On the accelerator "Fakel", when average current is 400 mkA and energy is 35 MeV, output (according to experimental data) was from several hundreds kg (p-silicon with specific resistance near several dozens Ohm sm) to several dozens tons per year (n-silicon with specific resistance near 5 kOhm sm).

Obtained knowledge and experience in the field of gamma-doping of silicon allows us to formulate the semiconducting diamond obtaining problem on the basis of reaction:

$$^{12}C\ (\gamma,n)\ ^{11}C \rightarrow\ ^{11}B \quad \text{and} \quad ^{12}C\ (\gamma,p)\ ^{11}B$$

Attitude to diamond is conditioned by its unique physical properties: diamond is wide-range semiconductor with unique heat conduction, it has hundred times as many as other semiconductors stability to radiation, it is stable to agressive media and can work when temperature is up to 1500 C /5-6/. Scientific opinion is that now all elements of modern electronics can be manufactured from diamonds. Espesially important is diamond application in nuclear physics and atomic energetics, in aircraft and rocket industry, in chemistry and so on. Natural and synthetic semiconducting diamonds have large unhomogeneity of electrophysical parameters, their characteristics cannot be purposefully controlled. Scientific research work may allow to devise technology of semiconducting diamonds obtaining with uniform properties on the whole volume. Technology will not have restrictions on crystal size and their origination.

Nuclear doping of semiconductors, in our opinion, is now on the primary stage of its development.

3. Medical isotopes manufacturing

Technology of I-123 obtaining, used now all over the world, is based on special cyclotrons and targets usage. Our technology is based on photonuclear reaction [7,8]:

$$^{124}Xe\ (\gamma,n)\ ^{123}Xe \rightarrow\ ^{123}I\ .$$

More simple and cheap targets are used in our technology and it is almost completely analogous to one, described before. Its picualiarities are, in general, in process of xenon and iodine separation: by defined temperature iodine is freezing on the ampoule walls, xenon is pumped out from the ampoule into the balloon for initial gas storage and only after this iodine is removed from the ampoule by washing out with the alkali. Solution NaOH (0,01 M) is used later on for organic preparations synthesis (gippurin, albumin, rich acidities). We must note very high radionuclide purity of obtained iodine, which cannot be reached by another method, also by reaction:

$$^{124}Xe\ (p,2n)\ ^{123}Cs \rightarrow\ ^{123}I\ .$$

Obtained experimental data give us possibility to scientific prognostication of iodine output on accelerator with "Fakel" parameters - 5 Ki/day. Ultrashortlived oxigen-15 radionuclide (half-life period - 123 s) is used in medicine for dynamics of human metabolism investigation. Technology of oxygen-15 obtaining is the following. On some distance from gamma-convertor (in our case its whole thickness is 1,5 mm) container with the water is placed. Water is irradiated by gamma-quantums and oxygen lancing is done. Radioactive oxygen is carried away, and gas radioactivity becomes smaller. When container with water is irradiated by gamma-quantums, ozone and carbon-11 are generated because of reaction:

$$^{16}O\ (\gamma,\alpha p)\ ^{11}C \rightarrow\ ^{11}B\ .$$

That is why, in order to decrease carbon admixture, it is necessary to decrease accelerated electrons energy. When electrons energy is 25 MeV, carbon admixture is not more than 10%, it is enough for full information about radioactive oxygen behaviour in organism. Cleaning from ozone is carried out by gas passing through water. Oxygen special activity in given before conditions and accelerated electrons average current 250 mkA is up to 70 mKi/l. Advantage of such method of oxygen-15 obtaining is the fact, that it gives possibility of oxygen transporting by continious stream through pipelines with controlled activity. Photonuclear method is perspective and competitive for obtaining another ultrashortlived isotopes,in particular nitrogen, carbon,fluorine and so on. But in this direction, in our opinion, there are needed joint efforts of physicists, biologists and physitians for actual radionuclides definition.

4. References

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