PROCEEDINGS OF THE INTERNATIONAL CONFERENCE NANOMATERIALS: APPLICATIONS AND PROPERTIES
Vol. **2** No 3, 03AET06 (3pp) (2013)

Properties of Zirconia Nanoceramics under High-Energy Electrons Irradiation

N.I. Aizatsky[1], N.P. Dikiy[1,*], A.N. Dovbnya[1], I.D. Fedorets[2], V.A. Kushnir[1], Yu.V. Lyashko[1], D.V. Medvedev[1], V.V. Mytrochenko[1], I.N. Onishchenko[1], S.A. Perezhogin[1], I.A. Danilenko[3], T.E. Konstantinova[3]

[1] *NSC "Kharkiv Institute Physics and Technology", 1, Akademicheskaya Str., 61108 Kharkiv, Ukraine*
[2] *V.N. Karazin Kharkiv National University, 4, Svobody Sq., 61022, Kharkiv, Ukraine*
[3] *O.O. Galkin Donetsk Institute for Physics and Engineering, 72, Luxemburg Str., 83114, Donetsk, Ukraine*

(Received 20 May 2013; published online 31 August 2013)

Formation of radioactive isotopes is investigated under irradiation by relativistic electrons with energy up to 100 MeV. Radioactive isotopes ^{87,88}Y, ^{88,89,95}Zr, ^{95}Nb, ^{175}Hf are registered after irradiation by relativistic electrons with energy 47.2 MeV. The present data are necessary for the choice of a material for a dielectric wakefield accelerator. The greatest danger at operation of accelerators represents ^{88}Y. Formation of radiation defects in nanoceramics is investigated. The various types of radiation defects are found out at an irradiation by relativistic electrons with energy 47 MeV and 86 MeV. In UV–VIS spectra the absorption lines of radiation are registered at 402.2 nm and 635 nm, which correspond to the F and F' centers of monocline lattices of zirconia. It is revealed, that krypton atoms are the centers of segregation of point defects.

Keywords: Dielectric constant, zirconia, Wake-Field accelerators, Radiation damages, Nanoceramics, Color centers, Nuclear reaction.

PACS numbers: 61.46. + w, 61.80.Fe

1. INTRODUCTION

Dielectric resonator for wakefield accelerators should have high values of dielectric constant ($\varepsilon > 20$) and small dielectric losses ($tg\delta < 10^{-4}$) and to keep these parameters during acceleration of particles. Therefore influence of radiation damages on dielectric parameters flying relativistic electron bunches represents significant interest [1, 2].

One of possible materials for dielectric waveguides can be zirconia. It has good mechanical and ionic properties. It is used as a grinding medium and engineering ceramics. Therefore, the material properties, inducing optical properties, are of a high interest. The favorable properties of ZrO_2-based materials become especially pronounced if these materials were fabricated of powders of nanoscopic size. It is well known that the phase stabilization of zirconia can be achieved by an addition of a certain amount of the trivalent yttrium oxide (Y_2O_3, yttria) to form a solid solution in the ZrO_2 lattice.

2. RESULTS AND DICUSSION

ZrO_2-3 mol% Y_2O_3 nanopowders (3Y-TZP) were synthesized by a co-precipitation technique using $ZrOCl_2$*nH_2O salts. Calcinations temperature of dried zirconium hydroxides was chosen at 700 °C with dwelling time 2 hours. This calcinations temperature provide the formation of unagglomeratd nanopowders and sintering obtained nanopowders to density near theoretical at 1400-1500°C. The density was 6,0-6,02 g/cm^3 for ceramic materials, obtained by sintering of zirconia nanopowders obtained from $ZrOCl_2$*nH_2O.

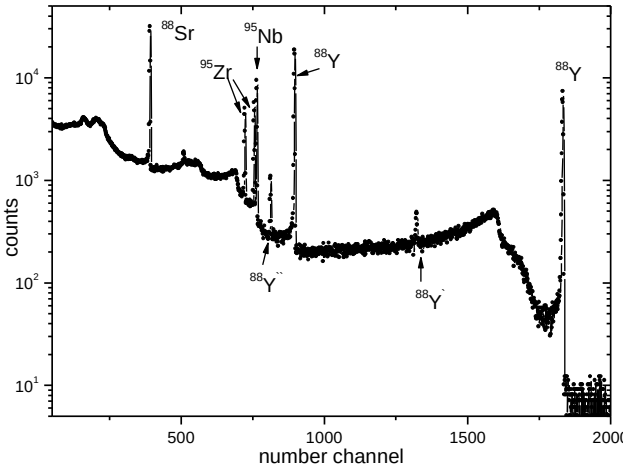

Fig. 1 – The spectrum of nanoceramics after irradiation at 47.2 MeV by dose 2.28 10^{14} electrons/cm^2

Radiation defects in nanoceramics zirconia were investigated after electron irradiation with energy 41–89 MeV up to a dose 2.28-5.7·10^{14} electrons/cm^2 (fig. 1,2). At an irradiation by electrons and bremsstrahlung of nanoceramics in Zr of natural isotopic content (^{90}Zr - 51.46%; ^{91}Zr - 11.23%; ^{92}Zr - 17.11%; ^{94}Zr - 17.40%; ^{96}Zr - 2.8%) the highest activity is realized from an isotope ^{89}Zr, received in reaction ^{90}Zr(γ,n)^{89}Zr [3]. The half-life period of ^{89}Zr equals to 79.3 hours and in long-term aspect it does not represent danger. Also activity and from an isotope ^{95}Zr from reaction ^{96}Zr(γ,n)^{95}Zr with a half-life period of 64.05 days can be realized. However on an isotope ^{94}Z can activity from ^{93}Zr with $T_{1/2}$=9.5·10^5 years is realized. During work of the ceramic resonator its irradiation by bremsstrahlung and neutrons, arising in accompanying reactions, can be realized. For example, ^{93}Zr can arise in reaction of radiation capture on ^{92}Zr. Therefore

* ndikiy@kipt.kharkov.ua

for significant activity of ^{93}Zr it is necessary to carry out its burial in geological structures. From the point of view of radiating safety at operation of wake-field accelerators the greatest danger represents ^{88}Y which is formed in reactions ^{89}Y(γ,n)^{88}Y or ^{89}Y(e,n)^{88}Y. The half-life period ^{88}Y amounts 106.65 days. Disintegration ^{88}Y is accompanied by radiation of two intensive lines with energy 898 and 1836 keV.

Activity of the isotopes generated by electron irradiation of samples of nanoceramics was measured by Ge(Li)-detector. Radioactive isotopes ^{87,88}Y, ^{88,89,95}Zr, ^{95}Nb, ^{175}Hf are registered after irradiation of electrons with energy 41 and 47.2 MeV (fig. 1).

The activity of ^{83}Rb was registered after irradiation by electrons with energy 86 and 88.9 MeV (fig. 2). Activity of ^{83}Rb can be formed in reactions (γ,6n) or (e,6n). The threshold of the given reactions equals to 59.4 MeV.

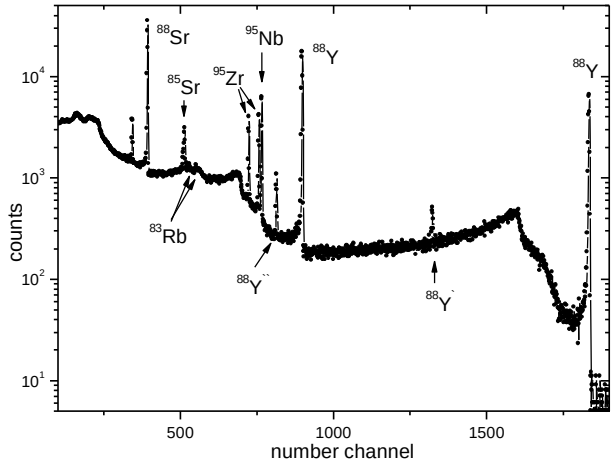

Fig. 2 – The spectrum of nanoceramics after irradiation at 86 MeV by dose 5.7 10^{14} electrons/cm^2

The maximal energy of recoil atoms E_{rec} of oxygen or zirconium in nanoceramics at irradiation by relativistic electrons equals:

$$E_{rec} = \frac{2E_1(E_1 + 2m_oc^2)}{M_2c^2}, \qquad (1)$$

where m_o, E_1 – weight and energy electrons, M_2 - weight of atoms of oxygen or zirconium. For energy electrons 47.2 MeV the maximal energy of recoil atoms of oxygen will amount 302 keV. For atoms of recoil zirconium the maximal energy of recoil atoms will amount 53 keV. For energy electrons 86 MeV the maximal energy of recoil atoms of oxygen will amount 998 keV. For atoms of recoil zirconium the maximal energy of recoil atoms will amount 175 keV. The number of the displaced atoms at braking recoil atoms with such energy can amount 6000, 1000 (47.2 MeV) and ≈2·10^4, 3500 (86 MeV), respectively. Recoil atoms with such energy can cause thermal spike. It in turn can result in transformation of initial structure of zirconia.

UV-VIS spectroscopy was used for measurement of spectra of absorption of the irradiated samples of zirconia nanoceramics before and after annealing during 2 hours at 500°C. Measurements of absorption spectra carried out concerning unirradiated sample of nanoceramics. Up to annealing samples of zirconia nanoceramics the wide peak of absorption in area of 500-700°nm is observed. Also are registered absorption lines of radiation at 402.2 and 635 nm which correspond to the F and F'-centres of monocline lattices of zirconia (fig. 3,4) [4].

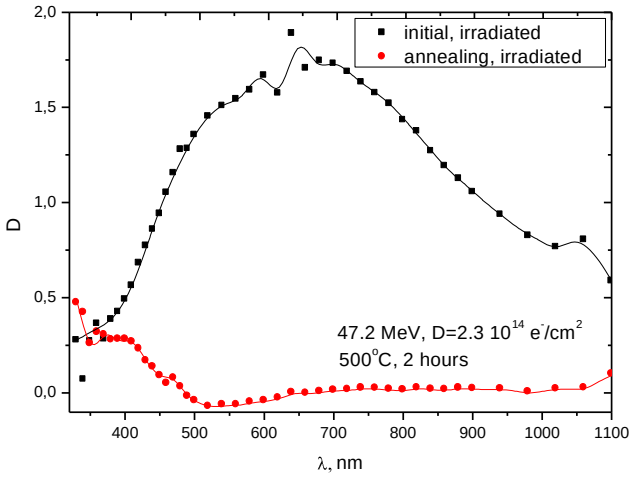

Fig. 3 – UV-VIS spectra of zirconia samples of nanoceramics irradiated by relativistic electrons with energy 47.2 MeV before and after annealing

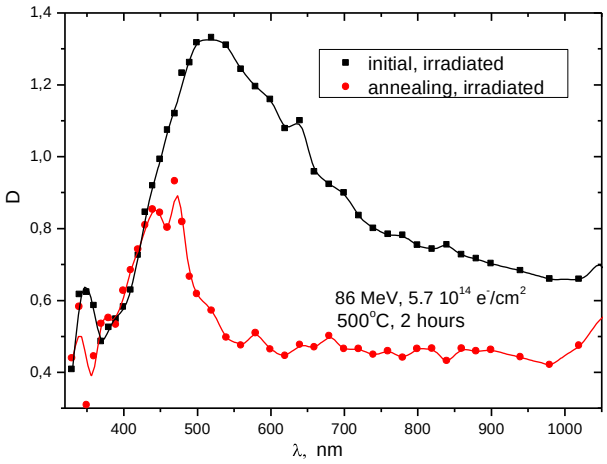

Fig. 4 – UV-VIS spectra of zirconia samples of nanoceramics irradiated by relativistic electrons with energy 86 MeV before and after annealing

Different process of annealing radiation defects in samples of zirconia nanoceramics is detected after irradiated by electrons with energy 41-47.2 or 86-88.9 MeV. The color centers for samples of zirconia nanoceramics after irradiated by electrons with energy 41-47.2 MeV practically completely was annealed at 500°C (fig. 3). For samples of zirconia nanoceramics after irradiated by electrons with energy 86-88.9 MeV and after annealing at 500°C significant absorption for lengths of waves of 430 and 470 nm is observed (fig. 4). It is supposed that these distinctions at annealing the colour centres of zirconia are caused by formation in nuclear reactions by high-energy electrons on isotopes of a matrix of krypton atoms. The krypton atoms are the centers segregation point defects. As a result the steady defective complexes were formed [5-8].

3. CONCLUSION

1. Formation of radioactive isotopes is investigated at an irradiation relativistic electrons with energy up to 100 MeV. The present data are necessary at planning a choice of a material of a dielectric wave guide of wake-field accelerators. The greatest danger at operation of accelerators represents ^{88}Y.

2. Formation of radiation defects in nanoceramics is investigated. The various types of radiation defects are found out at an irradiation relativistic electrons with energy 47 and 86 MeV. It is revealed, that krypton atoms are centers of segregation of point defects.

3. Formation of the F and F'-centres of monocline phases is detected at an irradiation by relativistic electrons.

This work was supported by Global Initiatives for Proliferation Prevention (GIPP) program ANL-T2-247-UA (STCU Agreement P522).

AKNOWLEDGEMENTS

Authors are grateful to Elena Medvedeva for a critical reading of the manuscript and his valuable comments.

REFERENCES

1. I.N. Onishchenko, *PAST*. **No.3**, 145 (2012).
2. G.V. Sotnikov, T.C. Marshall, J.L. Hirshfield, *PAST*. **No3**, 164 (2012).
3. *Handbook on photonuclear data for applications. Cross-section and spectra* (Vienna: IAEA-TECDOC-1178: 2000).
4. M.M. Mikhailov, M.I. Dvoretsky, N.Y. Kuznetsov, *Izv.AS USSR: Inorg. Mater*. **20,** 449 (1984).
5. J.M. Costantini, F. Beuneu et al., *J. Phys.: Condens. Matter*. **16**, 3957 (2004).
6. M.M. Mikhailov, V.V. Neshchimenko et al., *Persp. Mater*. **No.3**, 14 (2010).
7. W.J. Weber, R.C. Ewing, C.R.A. Catlow et al., *J. Mater. Res*. **13**, 1434 (1998).
8. R.A. Andrievski, *Rev. Adv. Mater. Sci*. **29**, 54 (2011).