Optical Materials: X 25 (2025) 100396

Contents lists available at ScienceDirect

Optical Materials: X

journal homepage: www.journals.elsevier.com/optical-materials-x

Study of defect formation mechanisms in Li_2ZrO_3/$MgLi_2ZrO_4$ ceramics using EPR spectroscopy

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ARTICLE INFO

Keywords:
Radiation damage
Electron spin resonance method
Stabilizing dopant
Lithium-containing ceramics

ABSTRACT

The article presents the results of experimental studies of the effect of the stabilizing MgO dopant using the electron spin resonance (ESP) method on enhancement of the stability of Li_2ZrO_3 ceramics to defect formation processes and accumulation of radiolysis products in the near-surface layer in the case of high-dose irradiation with protons simulating the hydrogenation effects characteristic of processes associated with tritium production. During the conducted studies, it was established that the addition of the stabilizing MgO dopant results in formation of inclusions in the form of the tetragonal $MgLi_2ZrO_4$ phase, which leads to an increase in the resistance of the near-surface layers to destructive damage due to the accumulation of structural damage (oxygen vacancies and point defects), as well as products of the physicochemical processes of radiolysis, characteristic of high irradiation fluence values. It was found that in the case of unmodified Li_2ZrO_3 ceramics, the formation of HC_2 – centers is observed at a fluence of 10^{16} proton/cm^2, while for two-phase ceramics, the formation of HC_2 – centers is observed at higher fluences, while the intensity of the bands is significantly less than in the case of single-phase unmodified ceramics. The difference in the nature of changes in the intensities of singlet bands responsible for the presence of vacancy defects in the damaged layer, as well as HC_2 – centers for single-phase and two-phase ceramics is a direct confirmation of the inhibition of structural degradation mechanisms in two-phase ceramics.

1. Introduction

To solve the problem of exhaustion of energy resources in the modern world for the next 50–100 years, the development of alternative energy methods, including nuclear (enhancement of the efficiency of energy generation by increasing the nuclear fuel burnup degree, as well as the transition to the use of high-temperature nuclear reactors) and thermonuclear energy, which is based on the construction of thermonuclear reactors in which tritium is used as fuel [1–3]. Moreover, in the case of thermonuclear energy, one of the restraining factors, in addition to the development of plasma retention methods, is the problem of tritium production, the amount of which produced by classical methods is insufficient to fully support thermonuclear fusion in reactors [4–6]. The solution to the problem of tritium production for supporting thermonuclear reactions and energy generation is the technological solution of using blanket materials containing lithium, in which tritium is produced during nuclear reactions of neutrons with lithium, as a result of which tritium is released, as well as a number of products, such as helium, hydrogen and other products of radiolysis [7–9]. At the same time, the concomitant accumulation of nuclear reaction products in blanket materials requires a detailed study in view of the possible initialization of gas swelling processes due to agglomeration of products and the formation of gas-vacancy complexes in pores of ceramics, as well as deterioration of strength and thermophysical parameters, which play an important role in determination of the stability of ceramics during their operation [10–12].

Interest in lithium-containing ceramics, especially lithium metacirconate, is due to the possibility of expanding the technological processes of tritium production in blanket materials, which is one of the types of fuel for thermonuclear fusion [13–15]. In this case, interest in this type of ceramics is primarily due to chemical and thermal stability, as well as higher strength and resistance to external influences compared

This paper was presented at the 21st International Conference on Defects in Insulating Materials (ICDIM 2024), Astana, Kazakhstan, August 19-23, 2024.

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https://doi.org/10.1016/j.omx.2024.100396
Received 19 September 2024; Received in revised form 4 December 2024; Accepted 17 December 2024
Available online 18 December 2024

to other types of lithium-containing ceramics [16–18]. Recently, much attention has been paid not only to a detailed and comprehensive study of the mechanisms of structural damage, but also to methods of increasing the resistance of ceramics to such changes associated with the accumulation of nuclear reaction products in the structure. One way to improve stability is to use two-phase ceramics, which consist both in mixing two different types of lithium-containing ceramics together and then pressing them into tablets, or by adding different stabilizing additives, the use of which leads to the formation of impurities in the form of new phases equally distributed in the volume of ceramics [19–22].

The aim of the study is to determine the effectiveness of modification of lithium-containing ceramics with a stabilizing MgO dopant on resistance to the formation of structural defects, as well as radiolysis products during hydrogenation. To determine defect structures in the damaged layer depending on the radiation dose, the electron spin resonance method was used, the use of which allows for a high-precision determination of the type of defects arising as a result of structural changes, as well as the kinetics of their accumulation associated with evolutionary mechanisms of damage, as well as the formation of radiolysis products. For example, in work [23], using the EPR method, structural defects in lithium metazirconate exposed to gamma irradiation were studied, according to which it was established that the main type of defects formed during irradiation are oxygen vacancies (F-centers) with $g = 2.0012$. Possible types of structural distortions associated with both the processes of lithium metazirconate synthesis and its operation are examined in detail in Ref. [24], in which the authors systematize the main types of defects possible in Li_2ZrO_3 ceramics and also provide their activation energy. Also in the work [25], using the EPR method, alongside the density functional theory, the mechanisms of defect formation in lithium-containing ceramics were studied depending on the conditions of external influences, according to which it was established that the main type of defects are oxygen vacancies, capable of forming more complex clusters when combined with H, which in turn leads to an alteration in the charge states and their stability. Thus, it should be noted that the use of the EPR spectroscopy method for identifying structural damage in lithium-containing ceramics is one of the most promising methods for assessing defects, as well as establishing their type, in contrast to classical methods of X-ray diffraction and Raman spectroscopy, with which it is possible to obtain a quantitative assessment of structural damage without detailing the type of structural defects, as well as variations in concentration in the case of the formation of vacancy defects and more complex complexes.

The objects of the study were lithium-containing ceramics Li_2ZrO_3 with different concentrations of the dopant MgO, the choice of which was due to such factors as the possibility of creating inclusions in the form of the tetragonal $MgLi_2ZrO_4$ ($MgO \times Li_2ZrO_3$) phase, the formation of which occurs as a result of partial substitution of zirconium ions by magnesium ions, which in turn initiates the processes of phase transformations of the monoclinic - Li_2ZrO_3 → tetragonal - $MgLi_2ZrO_4$ type, which are similar to polymorphic transformations of the monoclinic - ZrO_2 → tetragonal – $Zr(Mg)O_2$ type, arising as a result of thermal annealing of ZrO_2 ceramics stabilized by MgO. The choice of MgO as a stabilizing additive is due to the possibility of increasing the resistance of ceramic materials to softening processes due to the possibility of forming impurity phases that act as buffer particles located in the intergranular space, thereby inhibiting the mechanisms of defect migration in the structure of the damaged layer.

2. Materials and research methods

To study the effect of variation in the concentration of the stabilizing dopant MgO and the associated processes of phase transformations caused by the processes of formation of the tetragonal $MgLi_2ZrO_4$ phase, lithium-containing ceramics based on lithium metazirconate were synthesized using the solid-phase synthesis method. Powders of MgO, ZrO_2 and $LiClO_4 \times 3H_2O$ were chosen as the initial components. The synthesis of ceramics was carried out using the method of mechanical activation by grinding the initial powders in a given stoichiometric ratio followed by thermal annealing, which makes it possible to obtain ceramics with a controlled phase ratio. To obtain two-phase ceramics with a substitution phase, the concentration of the stabilizing dopant MgO was varied in the range of 0.1–0.25 M, as a result of which two-phase $(x\text{-}1)Li_2ZrO_3$ – $xMgLi_2ZrO_4$ ceramics with different phase ratios in the ceramics were obtained. A detailed description of the synthesis stages, as well as the dependence of the dopant concentration variation on the change in the phase composition of the ceramics was presented in Ref. [26], on the basis of which samples were selected with an impurity phase content of $MgLi_2ZrO_4$ equal to 5 wt %, 25 wt % and 50 wt %, obtained at MgO dopant concentrations equal to 0.1 M, 0.2 M and 0.25 M, respectively. Moreover, as was shown in the work [26], the use of the mechanochemical solid-phase synthesis method results in formation of ceramics with an equally probable distribution of the impurity phase in the composition of the ceramics throughout the entire volume of the tablets used for irradiation experiments and subsequent study of structural features using the electron spin resonance (EPR) method.

Simulation of hydrogenation processes, alongside accumulation of radiolysis products in the case of high-dose irradiation, was carried out by irradiation of ceramics with protons with an energy of 1.5 MeV and irradiation fluences in the fluence range from 10^{15} to 5×10^{17} proton/cm^2. Irradiation was carried out at room temperature in a vacuum. The choice of irradiation fluences is determined by the possibilities of modeling the processes of deep overlapping of defective areas arising as a result of the interaction of ionizing radiation with the surface layer associated with both ionization processes and atomic displacements, which play a very important role in determining the kinetics of structural degradation, characteristic of the possibilities of modeling the processes of operation of these materials as blankets. According to simulation using the SRIM Pro 2013 software code, it was found that for a given range of irradiation fluences, the accumulation of the damage dose in the case of maximum fluence is about 30–50 dpa, which corresponds to a sufficiently large degree of structural damage accumulation in the near-surface layer, which can initiate effects in the damaged layer that can result in destruction and embrittlement, due to the accumulation of point and vacancy defects, as well as complex defects associated with the formation of radiolysis products. According to the calculated data of the assessment of the values of ionization losses of protons in the near-surface damaged layer, the dominant role at a depth of about 20–25 μm is played by ionization losses of protons during interaction with electron shells, which results in ionization processes, and as a consequence, in the case of large changes in electron density during high-dose irradiation, to the formation of an anisotropic distribution of electron density, and the formation of a large number of vacancy defects and radiolysis products.

The determination of structural changes associated with the formation of point and vacancy defects, alongside radiolysis products, was carried out using the EPR spectroscopy method implemented on a Bruker BioSpin X-band spectrometer. The measurements were carried out in the range of 295 mT–350 mT, at a modulation frequency of 100 kHz. The measurements were carried out in an inert atmosphere at room temperature. Formula (1) was used to determine the concentration of defects [27]:

$$C_{defects} = \frac{S_x \times N_{ref}}{S_{ref} \times m}, \tag{1}$$

S_x is the area under the EPR signal absorption curve, S_{ref} is the area under the absorption curve of the reference sample, N_{ref} is the concentration of unpaired electrons in the reference sample, m is the mass of the sample. Based on the data obtained using this formula, the dependences of the change in the concentration of defects in the composition of the samples, as well as the rate of their accumulation and the effect of inhibiting their formation due to the presence of impurity inclusions in the form of the $MgLi_2ZrO_4$ phase were determined.

3. Results and discussion

Fig. 1 demonstrates the results of a comparative analysis of alterations in the ESR spectra of the studied ceramics contingent upon the proton irradiation fluence, reflecting the change in structural features associated with the accumulation of defects in the damaged layer with a change in irradiation fluence. In the initial state, the EPR spectra of the studied ceramics, regardless of their phase composition, are characterized by the absence of any peaks associated with the formation of singlet lines (characteristic of E-centers associated with oxygen vacancies), alongside peaks characteristic of more complex defect inclusions. The general appearance of the observed alterations in the case of irradiated samples can be divided into two characteristic types of changes, associated primarily with the formation of a singlet line at g = 2.001–2.003, characteristic of E-centers, the formation of which is inextricably linked with the formation of oxygen vacancies, and secondly, the formation of local maxima in the region with g = 2.04, g = 2.01, the presence of which can be due to structural defects such as O^-, HC_2-centers, alongside more complex gas-vacancy complexes, the presence of which is due to the effects of accumulation of radiolysis products during high-dose irradiation. Also, at fluences above 10^{17} proton/cm^2 for Li_2ZrO_3 and 0.95 Li_2ZrO_3 – 0.05 $MgLi_2ZrO_4$ ceramics samples, the formation of bands with a maximum of g = 1.92–1.94, characterized by the presence of structural defects such as Zr^{3+} defects, is observed.

In the case of Li_2ZrO_3, when irradiated with protons with fluences of 10^{15}–5×10^{16} proton/cm^2, the formation of a singlet line, characteristic of E-centers associated with oxygen vacancies, is observed, and the change in the line intensity with an increase in the irradiation fluence and its width indicates the accumulation of this type of structural defects in the damaged ceramic layer. In this case, for fluences of 5×10^{16} proton/cm^2 and higher, the formation of local maxima, associated with the formation of complex defects in the structure, associated with gas-vacancy defects, as well as HC_2-centers, formed as a result of the occurrence of physicochemical radiolysis processes in the damaged layer with the subsequent accumulation of radiolysis products, which are most pronounced at irradiation fluences of 3×10^{17} - 5×10^{17} proton/cm^2 in the form of the formation of lines characteristic of Zr^{3+} defects, is observed.

For ceramic samples stabilized by MgO, the addition of which leads to the formation of the tetragonal $MgLi_2ZrO_4$ phase with an alteration in the weight contribution of this phase in the composition of the ceramics, the changes in the EPR spectra associated with structural defects are less pronounced than in the case of single-phase Li_2ZrO_3 ceramics. Such a difference in the EPR spectra (in Fig. 1, all spectra are shown on the same scale in order to clearly demonstrate the effect of the impurity phase on the change in line intensities) indicates a positive effect of impurity inclusions on the degree of resistance to degradation, especially in the case of high-dose irradiation. It should be noted that, as in the case of Li_2ZrO_3

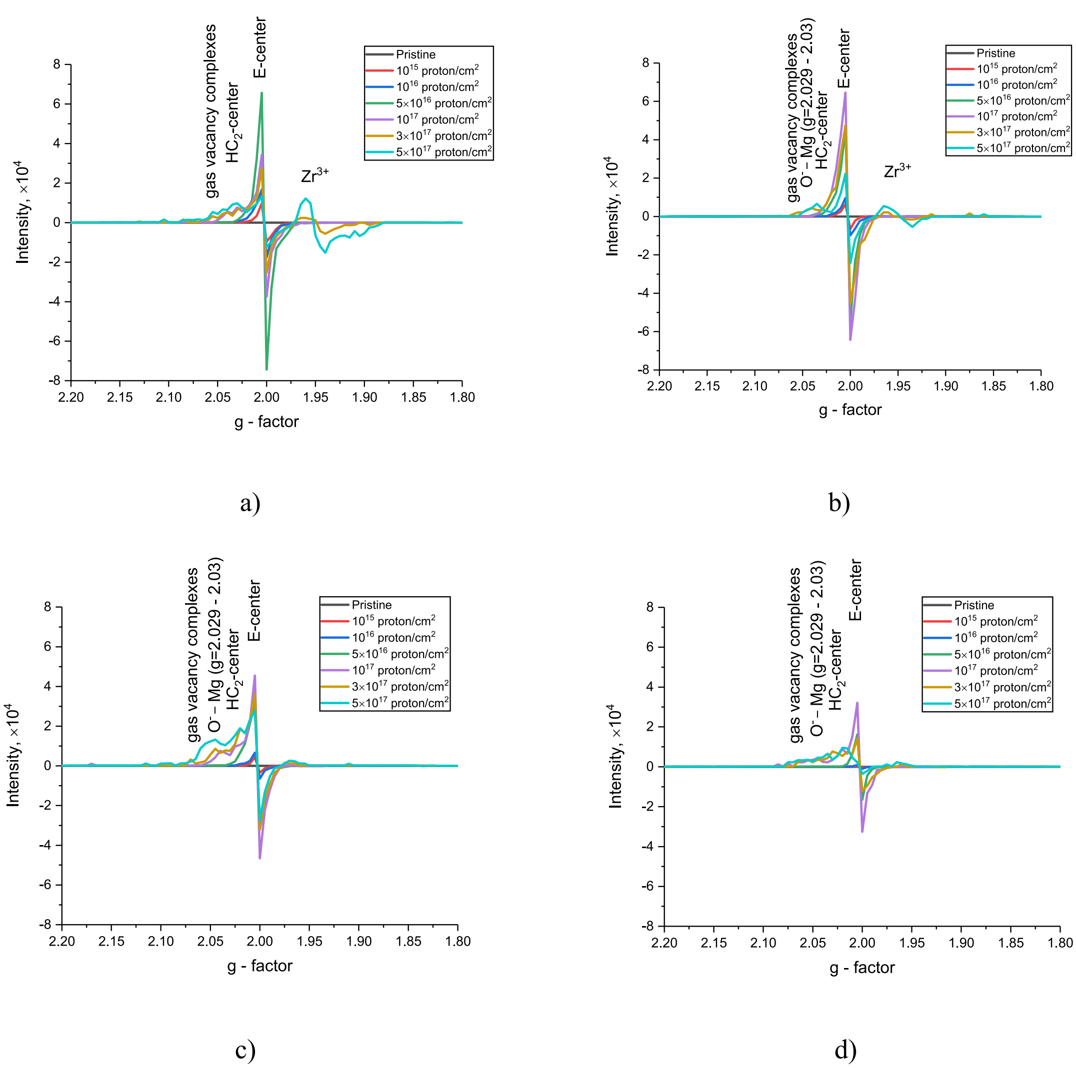


Fig. 1. Results of ESR spectroscopy of ceramic samples before and after proton irradiation with different irradiation fluences: a) Li_2ZrO_3 ceramics; b) 0.95 Li_2ZrO_3 – 0.05 $MgLi_2ZrO_4$ ceramics; c) d) 0.5 Li_2ZrO_3 – 0.5 $MgLi_2ZrO_4$ ceramics.

ceramics, for two-phase ceramics, regardless of the concentration of impurity inclusions at irradiation fluences of 10^{15} - 5×10^{16} proton/cm^2, the main changes are associated with the formation of oxygen vacancies in the structure, and at fluences above 10^{17} proton/cm^2, the main alterations are due to the accumulation of radiolysis products in the form of complex defects, and gas-vacancy complexes. At the same time, the intensity of the lines for two-phase ceramics, depending on the impurity phase concentration, is significantly lower than in the case of single-phase ceramics, which indicates a positive influence of the interphase boundary effect on elevation of the resistance to destruction of the near-surface damaged layer, as well as a growth in resistance to softening processes that occur during high-dose irradiation. The observed results of the effectiveness of structural degradation resistance enhancement due to interphase boundaries are in good agreement with a number of studies [28–30], which revealed that two-phase ceramics have higher indicators of degradation resistance due to structural features.

In the case of 0.95 Li_2ZrO_3 – 0.05 $MgLi_2ZrO_4$ ceramics, at irradiation fluences above 5×10^{16} proton/cm^2, a local maximum with g = 2.029–2.030, which is characteristic of O^- - Mg type defects, the presence of which is due to the effect of magnesium doping and the formation of impurity phases, is formed [31]. At the same time, the intensity of the peak characteristic of Zr^{3+} - defects in the case of these ceramics is significantly lower compared to undoped samples, which indicates less pronounced destruction under high-dose irradiation.

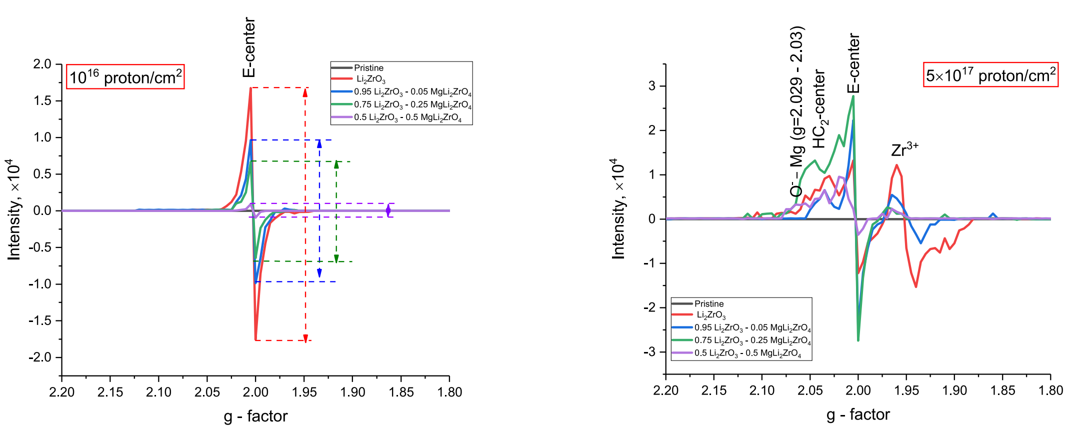
A magnification in the weight contribution of $MgLi_2ZrO_4$ in the composition of ceramics to 0.25 results in clearly expressed alterations in the intensities of the singlet line characteristic of E-centers, as well as the absence of peaks characteristic of Zr^{3+} defects at irradiation fluences of 3×10^{17} - 5×10^{17} proton/cm^2.

In the case of elevation in the impurity $MgLi_2ZrO_4$ phase concentration to 50 wt % in the composition, according to the results of ESR spectra at fluences of 10^{15}–10^{16} proton/cm^2, the intensity of the singlet characteristic of E-centers associated with oxygen vacancies is significantly less than the intensity of the singlet observed under similar irradiation conditions of single-phase ceramics. In this case, the observed difference in intensities, especially at low irradiation fluences (10^{15}–10^{16} proton/cm^2), indicates the high resistance of ceramics to disordering due to the large number of interphase boundaries, which in this case make it possible to create the effect of so-called interphase dispersion hardening, associated with the presence of a large number of grain boundaries and dislocations near these boundaries, which restrain the migration of defects, and also create additional obstacles in the redistribution of energy from kinetic to thermal as a result of collisions.

Fig. 2 reveals comparative analysis results of the EPR spectra of ceramics, given for two irradiation fluences (10^{16} proton/cm^2 and 5×10^{17} proton/cm^2) in order to demonstrate alterations in the peak intensities characteristic of different types of defects formed as a result of ceramic irradiation. The data are given as a function of the MgO dopant concentration, a change in which leads to an alteration in the phase composition ratio of the ceramics.

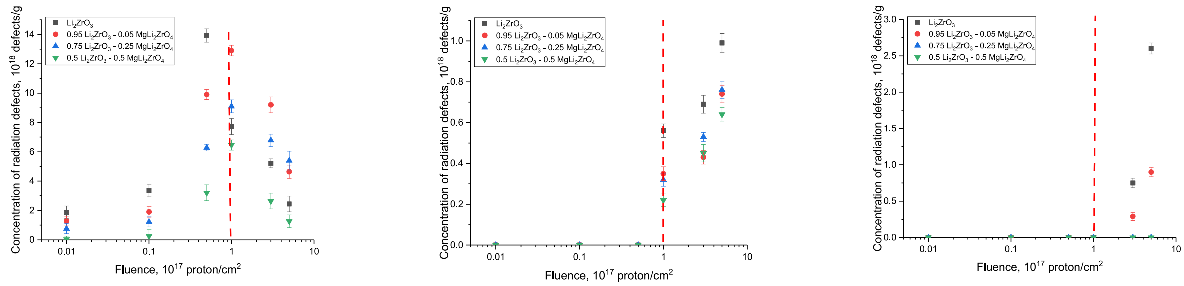
A comparative analysis of the presented EPR spectra clearly demonstrates the effect of variation in the phase composition of ceramics due to the formation of a $MgLi_2ZrO_4$ phase in the structure, which is expressed in a reduction in the intensity of the singlet line characteristic of E-centers associated with oxygen vacancies (see data in Fig. 2a), as well as a change in the concentration and type of structural defects at a maximum irradiation fluence of 5×10^{17} proton/cm^2, indicating the inhibition of the damaged layer disordering mechanisms in ceramics due to the presence of inclusions in the form of an impurity $MgLi_2ZrO_4$ phase, a change in the weight contribution of which results in inhibition of the radiation-induced degradation rate of ceramics.

Fig. 3 illustrates the assessment results of the change in the concentration of various defects in ceramic samples depending on the proton irradiation fluence, which were obtained based on assessment of the change in the intensities of spectral lines characteristic of each type of defect using formula (1) given above. The general view of the presented data on changes in the concentration of defects in ceramics can be divided into two characteristic trends caused by variations in the phase composition of ceramics (with a change in the concentration of the stabilizing dopant) and the irradiation fluence. In the case of variation in the phase composition of ceramics, the following can be concluded: the addition of a stabilizing MgO dopant to the composition of ceramics, leading to the formation of the $MgLi_2ZrO_4$ phase and a subsequent growth in its content in the composition of ceramics, leads to a decline in the trend of accumulation of defects in the structure, which indicates the inhibition of the defect formation mechanisms in the damaged layer due to the presence of interphase boundaries. Moreover, evaluating the observed changes in the concentrations of defect types depending on the irradiation fluence, it can be concluded that at fluences of 10^{15}–10^{17} proton/cm^2, the dominant role in the defect formation processes in the damaged layer is played by the processes of formation of vacancy defects, while at fluences above 10^{17} proton/cm^2, an elevation in the contribution of complex defects of the HC_2-center type and gas-vacancy defects, the formation of which is due to radiolysis processes, is observed. In this case, for single-component ceramics, as well as in the case of a low content of the impurity 0.05 $MgLi_2ZrO_4$ phase in the structure of ceramics in the damaged layer at fluences above 10^{17}



a) b)

Fig. 2. Comparative analysis of EPR spectra of ceramics depending on their type at different irradiation fluences characteristic of different defect formation mechanisms (the dotted lines indicate the difference in amplitude caused by irradiation and, as a result, the accumulation of structural damage): a) at irradiation with a fluence of 10^{16} proton/cm^2; b) at irradiation with a fluence of 5×10^{17} proton/cm.^{2}.



a) b) c)

Fig. 3. Results of changes in the concentration of defects in the structure of the damaged layer, estimated on the basis of changes in the amplitude of the intensity of the EPR spectra (the dotted lines in the figure highlight the transition region in which a change in the type of structural damage is observed with the dominance of radiolysis products in the damaged layer, which arise in the case of high-dose irradiation): a) concentration of E – center; b) concentration of HC_2 – center; c) concentration of Zr^{3+} - defects.

proton/cm^2, the presence of the Zr^{3+} type defects is recorded, while a rise in the $MgLi_2ZrO_4$ phase content in the composition of ceramics results in inhibition of the processes of formation of this type of defects, which indicates inhibition of the destruction processes due to the presence of interphase boundaries.

Determination of the structural degradation degree of the near-surface layer depending on the irradiation fluence, as well as in the case of variation in the phase ratio in the composition of two-phase ceramics on the disordering degree was carried out by the assessment of the change in the structural parameters of the crystal lattice and its volume as a result of irradiation, and as a consequence, the accumulation of defects. The results of the calculations are presented in Fig. 4. The assessment was carried out by calculating the crystal lattice parameters during the analysis of X-ray diffraction patterns of the samples after irradiation, followed by their comparison with the initial data obtained for non-irradiated samples. The general form of the observed changes in the structural parameters is due to the accumulation of strain distortions of the tensile type (since with a growth in the irradiation fluence, an elevation in the crystal lattice parameters is observed), and the growth of the degradation degree has an exponential trend, with a clearly expressed increase at high irradiation fluences. Moreover, alterations in the phase ratio in the composition of ceramics, according to the calculations, result in slowdown in the structural disorder degree, which implies a decrease in the rate of radiation-induced degradation of the near-surface layer. It is important to highlight that the main differences in changes in the structural disorder degree are observed at irradiation fluences above 5×10^{16} proton/cm^2, which consist in a growth in the gap between the assessment results of the structural disorder degree for different ceramics at the same irradiation fluence in comparison with the previous values. Such differences in this case indicate a slowdown in the processes of structural degradation caused by the accumulation of radiolysis products, which are restrained by the presence of interphase boundaries.

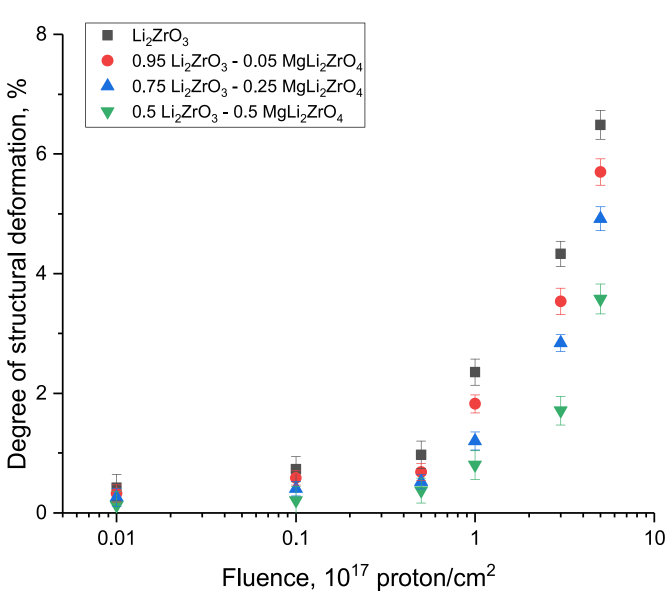


Fig. 4. Assessment results of the change in the degree of structural degradation caused by deformation distortion of the damaged layer crystalline structure.

Fig. 5 reveals the results of a comparative analysis of changes in the structural disorder degree and the concentration of various defects in the structure of the near-surface layer of the damaged layer, calculated on the basis of data on alterations in the EPR spectra.

As can be seen from the presented comparative analysis data, the accumulation of structural defects associated with radiolysis products is observed in the case where the structural disorder degree exceeds 5 %. In this case, the main mechanisms of disorder are effects associated with the crystal lattice destruction, caused by the formation of structural defects in the structure in the form of complexes, alongside their agglomeration, which can lead to the formation of gas-filled inclusions, which in turn results in acceleration of the damaged layer degradation.

Based on the obtained results, it can be summarized that the addition of MgO to the ceramics, leading to the formation of two-phase ceramics, leads to an increase in resistance to radiation-induced disordering processes, a damaged layer, as well as to the inhibition of the mechanisms of accumulation of structural defects and their subsequent evolution associated with the accumulation of radiolysis products. At the same time, the observed strengthening effect for binary or two-phase ceramics agrees well enough with a number of research papers [30–35], which showed that the transition from single-phase ceramics to two-phase ones, as well as in the case of the formation of impurity inclusions in the structure, leads to an increase in resistance to external influences, as well as destructive embrittlement processes under high-dose irradiation. In this case, the effect of increasing resistance to radiation damage is due to the formation of additional interphase boundaries that restrain the migration of point and vacancy defects in the damaged layer, as well as the emergence of buffer layers in the form of finely dispersed particles of impurity phases, the presence of which leads to increased stability against weakening and destabilization.

4. Conclusion

Using the EPR spectroscopy method, experiments to detail the structural changes in the near-surface damaged layer of lithium-containing ceramics based on lithium metazirconate, were conducted,

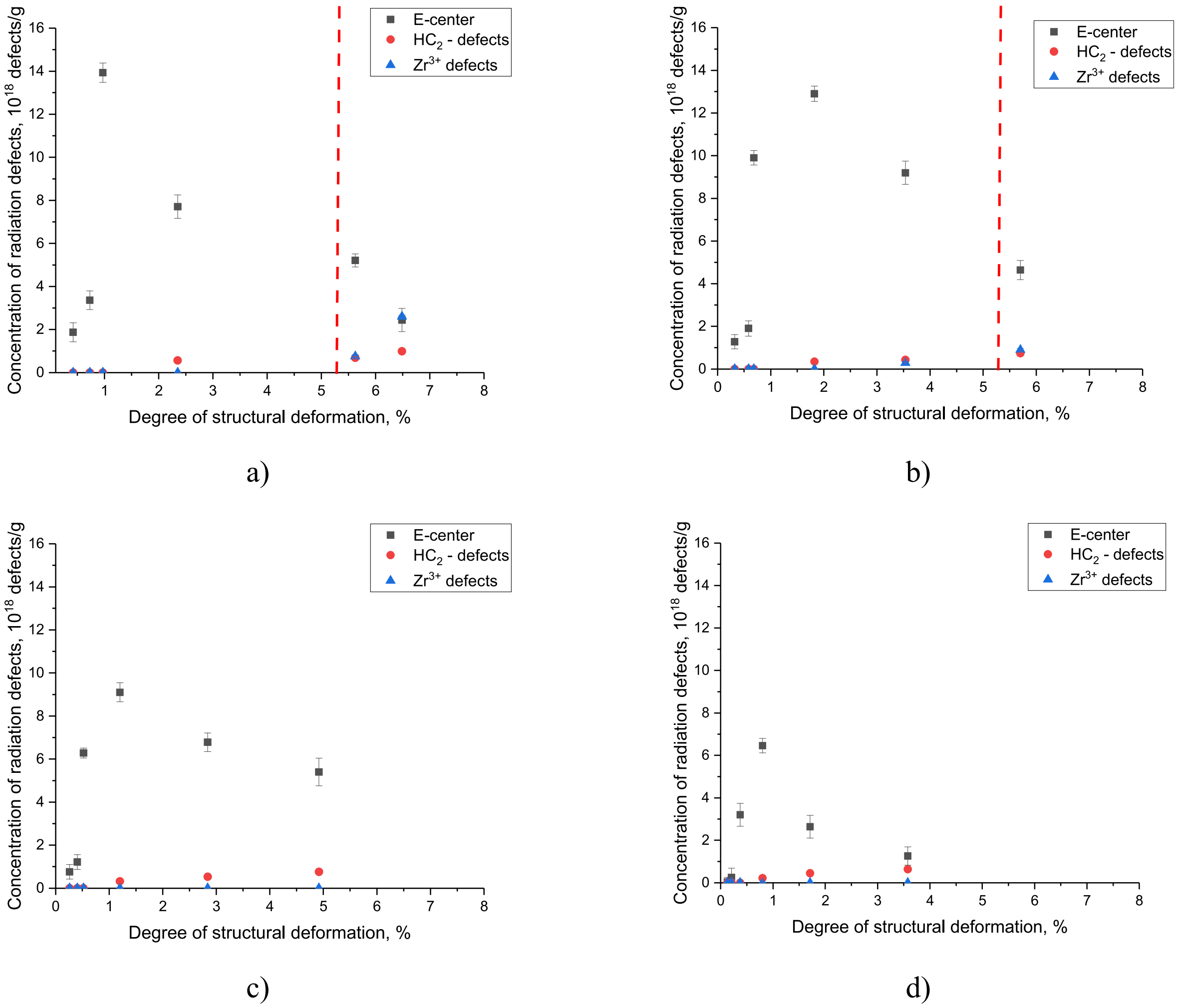


Fig. 5. Comparative analysis results of changes in the concentration of various types of structural defects in ceramics from the structural disorder degree determined on the basis of changes in the structural parameters of the crystal lattice: a) Li_2ZrO_3 ceramics; b) 0.95 Li_2ZrO_3 – 0.05 $MgLi_2ZrO_4$ ceramics; c) d) 0.5 Li_2ZrO_3 – 0.5 $MgLi_2ZrO_4$ ceramics.

and the effects of the influence of impurity inclusions in the form of the tetragonal $MgLi_2ZrO_4$ phase on enhancement of the resistance to structural degradation under high-dose proton irradiation were established. During the conducted studies it was established that the formation of inclusions in the form of the tetragonal $MgLi_2ZrO_4$ phase in the composition of ceramics leads to the inhibition of the mechanisms of accumulation of radiolysis products, characteristic of high doses of irradiation, alongside a decline in the rate of formation of oxygen vacancies, characterized by a singlet band with g = 2.001–2.003. Analysis of the dependencies of alterations in the concentration of defects in the structure of the damaged layer revealed that at irradiation fluences of up to 10^{17} proton/cm^2, the dominant role in structural distortions is played by the accumulation of oxygen vacancies, the formation of which is due to the processes of ionization and structural deformation caused by irradiation. At fluences above 10^{17} proton/cm^2, the key role in the structural disordering of the damaged near-surface layer is played by the forming gas-vacancy complexes, and the products of radiolysis caused by high concentrations of deformation distortions in the damaged layer. At the same time, the change in the phase composition of ceramics due to the formation of the tetragonal $MgLi_2ZrO_4$ phase results in significant slowdown in the processes of accumulation of radiolysis products in the damaged layer, due to the presence of interphase boundaries, which are a restraining factor in the migration of defects and vacancies in the structure.

CRediT authorship contribution statement

Dmitriy I. Shlimas: Resources, Investigation, Formal analysis, Data curation, Conceptualization. **Ainagul A. Khametova:** Project administration, Investigation, Formal analysis, Data curation, Conceptualization. **Artem L. Kozlovskiy:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Maxim V. Zdorovets:** Writing – original draft, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Funding

This research was funded by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (No. AP14870105).

Declaration of competing interest

+ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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