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Radiation swelling decrease by means of explosive wave

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Abstract

The report covers the results of an investigation into the possibility of decreasing the irradiation-induced swelling of non-metallic materials. Initial materials were subjected to explosive wave treatment within the pressure range of 12–70 MPa. This treatment increases the number of dislocations in the crystal in a few orders of magnitude and it can be applied to reduce the radiation damage in some materials for ITER, especially in the ceramics. The results of X-ray investigation of powders exposed to explosive waves and irradiated in distorted and initial states are described. The change of crystal lattice periods and degree of structural distortion on the modification of X-ray lines profiles were investigated. It was shown that the explosive wave treatment reduces "X-ray swelling" of (for example, beryllium oxide) 10 times after irradiation with neutron fluence of $\sim 6 \times 10^{25}$ n/m^2 and temperature of ~150°C.

1. Introduction

The radiation effect in ceramics are qualitatively different than the radiation effect in metals. Ceramics have a large volume change connected with an integrated change of atomic (molecular) volume. The volumes change of graphite, diamond, beryllium oxide are well known [1,2], and can achieve up to 10% increase in volume. These changes are typically measured from average value of lattice parameters referred to us "X-ray swelling". Significant X-ray swelling is observed also for AlN, B_4C, SiC, Al_2O_3, $GdAlO_3$, $Gd_2Ti_2O_7$, BN, etc. (for irradiation was carried out at moderate temperatures). These changes are explained by phase transformations or changes bonding strengths between atoms in the local spaces. However the real picture of atomic interactions in the area of the point defects or in the defects accumulation is often hypothesis.

Nevertheless it is suggested to discuss the problem on decrease of the ceramic materials swelling. According to common notions of radiation damage of solids it is necessary to increase the density of dislocations or the subgrain boundaries in lattice for decreasing radiation swelling. Large dislocation densities metals can be created by plastic deformation. In the case of ceramics it can be made by effect of an explosive wave. It is known that the explosive wave can increase the density of dislocations in ceramics up to 10^9–10^{12} cm^{-1} [3] and decrease the dimension of mosaic blocs up to 10 nm [4].

In our early work [5] it was shown that the effect of an explosive wave on AlN, ZnO, $GdAlO_3$, $Gd_2Ti_2O_7$ has decreased X-ray swelling by 25–70% in comparison with the swelling of initial materials. Materials with initial and subjected to explosion, were irradiated together up to fluence 1.1×10^{-25} m^{-2}.

In this paper we present the results of X-ray swelling research on beryllium oxide irradiation in the initial condition and after effect of an explosive wave at a pressure ~50 MPa.

2. Experiment

2.1. Working of material before irradiation and its investigation

Beryllium oxide was milled in the agate mortar and filled in a steel ampoule with inner diameter 6 mm and thickness of a wall 10 mm. An explosive wave was generated in outcome of a detonation of an axially

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symmetry explosion. Conditions of the explosive wave effect were selected in view of deriving the greatest possible number of structure imperfections. The calculated peak pressure was ~50 MPa.

The explosive wave effect has caused the visible increase of diffraction lines width. At the same time the change of lattice parameters was insignificant. Increase of lines width depended on diffraction angle and did not depend on indices of lines. It means that the diffuse scattering was absent on lines, i.e. the imperfection of 1st type (due to Krivoglaz [6]) – the dislocation loops of small diameter – were absent. So the explosive wave effect has caused an increase in concentration of dislocations and fragmentation. The calculation of dependence of lines width from an angle of diffraction for two pairs of lines (1 0 0 0), ($1\ 1\ \bar{2}\ 0$) and (0 0 0 2) ($1\ 0\ \bar{1}\ 3$) has shown one magnitude of microdistortions: 0.35 ± 0.05%.

2.2. Conditions of irradiation and post irradiation investigation

Powder, an initial and acted by explosive wave, were loaded in stainless steel ampoules with ∅6.9 × 80 mm. The powder filled no more than half of an ampoule. The ampoules were sealed hermetically and were irradiated in primary coolant water of the SM-reactor. The temperature of coolant was 50–60°C. Neutron fluence was 7×10^{25} m^{-2} ($E > 0.1$ MeV), and 34×10^{25} m^{-2} ($E < 0.68$ eV). The ampoules containing initial and treated powders were placed in pairs at equal distances from the center of the reactor core.

Irradiated powders were investigated with X-ray diffractometer DARD, the radiation was copper. Diamond powder was used as the measurements standard.

2.3. Results

Radiation distortion of beryllium oxide at low temperatures is accompanied by anisotropic increase of lattice parameters and appearance of the diffuse scattering on lines ($h\ k$ 1) with $1 \neq 0$ [7]. At the fluence 1×10^{25} m^{-2} the Bragg's component is already indistinguished on the (0 0 0 2) line. In this case the measurement of the period C is possible only on lines with small indices 1: ($1\ 0\ \bar{1}\ 1$), ($2\ 0\ \bar{2}\ 1$), ($1\ 2\ \bar{3}\ 1$). Criterion of correct measurements of C is the coincidence of its values with the measurements on different lines.

The width of ($h\ k$ 0) lines of the material after explosive wave effect has not varied. These lines remained wider than similar lines of the material irradiation in an initial condition (Fig. 1). But the lines with large indices one of the initial material are much wider: their profile is formed by diffuse scattering. And the influence of diffuse scattering on the width of similar lines of materials after explosive wave effect is insignificant. Since there exist connection between intensity of diffusion scattering and value of the parameter C, it is possible to expect very small increase of C.

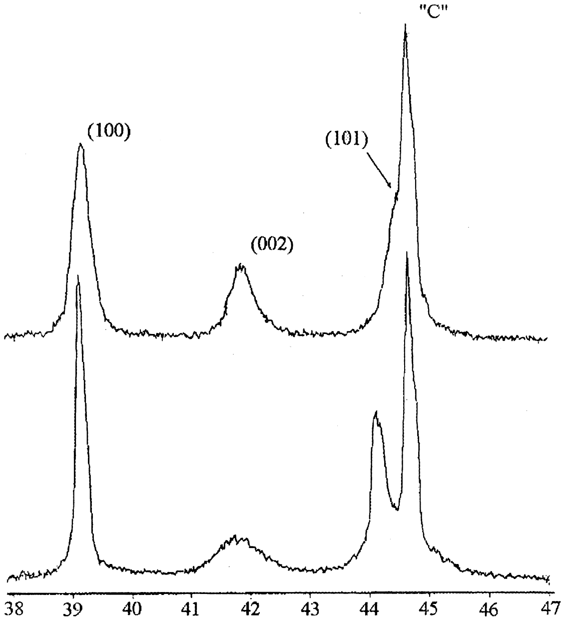

Fig. 1. X-ray powder patterns of irradiated BeO: initial (below) and after explosion (above). C-the diamond's line.

The results of measurements of lattice period for two pairs of specimens are shown in Table 1.

This simultaneous irradiation of the powders, initial and subjected to explosive wave treatment, under the same irradiation conditions have shown that, on average, the X-ray swelling explosive wave effect was 11 times less than the X-ray swelling of the initial material.

3. Discussion

The effectiveness of explosive wave treatment was shown already by the authors on BeO, AIN, ZnO, $GdAlO_3$, $Gd_2Ti_2O_7$ [5]. The main problem of treatment is the realization of optimal regime of an explosion. It is necessary to prevent the relaxation of distortions appearing during the pass of the explosive wave. Probably in the case of beryllium oxide the treatment was the most successful.

In the case of beryllin, effects of helium gas should assessed. But X-ray density and macrodensity of beryllin is equal under our conditions of irradiation [8].

These results allow us to speak about the perspective of the fabrication of ceramic materials with little change of volume after irradiation. Especially, if the new method will allow the products of a definite form to be produced.

Table 1
The results of measurements of beryllium oxide lattice period after explosive wave effect and irradiation

Material condition	Before irradiation		After irradiation		$\Delta V/V$,(%)
	a, A	*c*, A	*a*, A	*c*, A	
Initial	2.6993 ± 0.0004	4.382 ± 0.001	2.703 ± 0.001	4.583 ± 0.002	4.85
After explosion	2.6991 ± 0.0002	4.3739 ± 0.0008	2.7043 ± 0.0004	4.388 ± 0.003	0.58
Initial	–	–	2.703 ± 0.0001	4.563 ± 0.0002	4.45
After explosion	–	–	2.701 ± 0.0001	4.386 ± 0.0003	0.31

All this can have a great meaning for materials used in fission and fusion reactors: insulators, in diagnostic systems, etc. In some noncubic structure materials the anisotropical change of lattice parameters (even moderate) can cause significant change of properties.

The essential effect of X-ray swelling decreasing observed on BeO, AIN, ZnO means effectivity of dislocations and bonds of grains as sinks for defects. Firstly these materials possess hard coordinated interatomic bonds, secondly, the specific point defects are formed in them (the model of point defects in these wyrtzite crystal supposes change of the type of valency configuration from sp^3 to sp^2 [9]). It is especially important for such materials if to assume small (or zero) probability of recombination of Frenkel pairs in an aspect of their singularities within the framework of the offered model.

It is possible to state supposition that the fast saturation on fluence of the shown effect will not happen. It follows from the fact that lines width (*h k* 0) of materials, treated by explosion, did not vary, after irradiation and is wider than similar lines of materials irradiated in an initial condition.

4. Conclusions

The comparative measurements of volume of beryllium oxide lattice irradiated in initial condition and after explosive wave effect were carried out. The samples were irradiated up to fluence 7×10^{25} m^{-2} at the temperature $<150°C$, the peak of pressure of explosive wave effect was ~50 MPa. The explosive wave handling has reduced magnification of volume increasing by a factor of 11 (on the average from 4.6% up to 0.44%).

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