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THERMOPHYSICAL BEHAVIOR OF NANO BORON TRIOXIDE UNDER HIGH INTENSE ELECTRON BEAM IRRADIATION

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Abstract. In the presented study, a nano boron trioxide sample with a purity of 99.5%, particle size 80 nm and density bulk 3.10 g/cm^3 was used. Nano boron trioxide samples were irradiated with the linear electron beam in the energy range of 2-3 MeV at doses of $4.16 \cdot 10^{16}$, $1.20 \cdot 10^{17}$ and $1.03 \cdot 10^{18}$ cm^{-2} at room temperature. Although there are characteristic first and second phase transitions in nano boron trioxide samples in the temperature range of -150˚C to 200˚C, the dynamics of the thermal function and the mechanism for the change of enthalpy in these samples depending on the dose of radiation occurs differently. It was found that in the non-irradiated sample, the heat function increased linearly at low temperatures, but in the irradiated sample at doses $4.16 \cdot 10^{16}$, $1.20 \cdot 10^{17}$ and $1.03 \cdot 10^{18}$ cm^{-2} increased in rapidly phase.

Keywords: *High intense electron beam, irradiation, specific heat capacity, DSC.*

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1. Introduction

Boron-based materials are widely used in nuclear technology, in technologies that convert solar energy into electricity, and in the manufacture of electronics and acoustic-optical devices (Khalifa *et al*., 1998; Yawale *et al*., 1995; Bahatti & Singh, 1994). The optical properties of various oxide compounds of boron have been widely investigated by several researchers (Jugan & Abraham, 1977; Yawale *et al*., 1992). It is known that the optical properties of complex compounds formed by boron oxide with some oxides are superior to other optical materials for information transfer (Singh *et al*., 2008). In additional carried out studies on the production of special glasses of boron oxide and their study of some optical properties. However, the focus of researchers and engineers has recently been the use of nano powder boron oxide compounds. In the manufacturing process of certain nanocomposites and glasses, boron oxide nano particles and boron silicate combinations depending on the percentage are used in the preparation of various optical fibers. Nano boron oxide, which is used in some optical devices and nanocomposites, has the best properties, depending on the concentration ratio (https://www.ssnano.com/nanopowders). A group of Borates containing boron oxide and borosilicate is widely used for the manufacture of optical devices and optical lenses with high refractive index and low scattering properties (El-Alaily & Mohamed, 2003). Also, it has been shown that boron oxide and boron compounds have high structural stability under irradiation (Mirzayev et al., 2018a, 2018b, 2018c, 2018d, 2019b, 2019d). In the literature, we have not been able to find any evidence information on the change of optical parameters in boron oxide compounds depending on temperature gradient, especially under high-electron beam irradiation. Therefore, in presented work investigated the thermodynamic properties of nano boron oxide compounds irradiated by high-energy electron beam, in particular, the dynamics of boron oxide heat flux.

2. Experimental

The experimentally investigated target material was nano boron trioxide samples. For this research nano boron trioxide powder with bulk density 3.10 g/cm^3, specific surface area 28 m^2/g, particle size 80 nm and a purity of 99.5 % (US Research Nanomaterial. Inc., TX, USA) was used. The measurements were made using a digital balance (M/s Sartorius, model BP221S, USA) and accuracy in the measurement of weight was ±0.1 mg. The samples were irradiated with high energy electron beams at the linear electronic accelerator “Electronics U-003” at room temperature at different electron fluence $4.16 \cdot 10^{16}$, $1.20 \cdot 10^{17}$ and $1.03 \cdot 10^{18}$ cm^{-2} at Institute of Nuclear Physics, Academy of Sciences of Uzbekistan. The energy of electron beams ~2-3 MeV and current density of electron beam 0.075 μA/cm$^2 \cdot$s. The DSC measurements were carried out using the DSC3 STAR^e Systems manufactured by METTLER TOLEDO. The standard adiabatic calorimetry was performed in the temperature range of -150˚C up to 30˚C at a heating rate of 5 K/min in an argon atmosphere at a flow rate (20 mL·min^{-1}) and which is previously calibrated with indium (Mirzayev, 2020a, 2020b; Mirzayev *et al.*, 2019a, 2019c, 2019d, Demir *et al.*, 2019a, 2019b; Alekperov *et al.*, 2019; Tashmetov *et al.*, 2019; Hashimov *et al.*, 2019; Agayev *et al.*, 2019; Aliyev, 2019; Klakabay *et al.*, 2019).

3. Results and Discussion

Figure 1 showed the measured DSC curves of heat flow rate curves non irradiated and irradiated at the different electron fluencenano boron trioxide samples at the -150≤T≤200˚C temperature range. The DSC kinetics for nano boron trioxide samples divided three regions. To the 443 K occurs doublet endo effects and after 456 K the thermal process is a very difficult, and constant temperature range. Taking into account that, boron trioxide samples are exposed to various solvothermal reactions with water molecules depending on the conditions of keeping in the open air at the synthesis conditions. Also taking into account all the above literature results, it becomes clear that the mechanism of hydration and dehydration reactions that occur in non-irradiated and irradiated by electron fluence boron trioxide samples is even more complex. The duplex effects in the samples are the decomposition of the reaction product $B_2O_3 \rightarrow HBO_2$ at 422 K and the reaction product of boron oxide $B_2O_3 \rightarrow B(OH)_3$ at 438 K temperature. The main decay products at this time are the complex decomposition reactions that result from the OH group and complex decomposition reactions of structural water. As can be seen from Figure 1, the fields of duplex effects that characterize the decomposition reaction in nano boron trioxide samples increase depending on electron fluence.

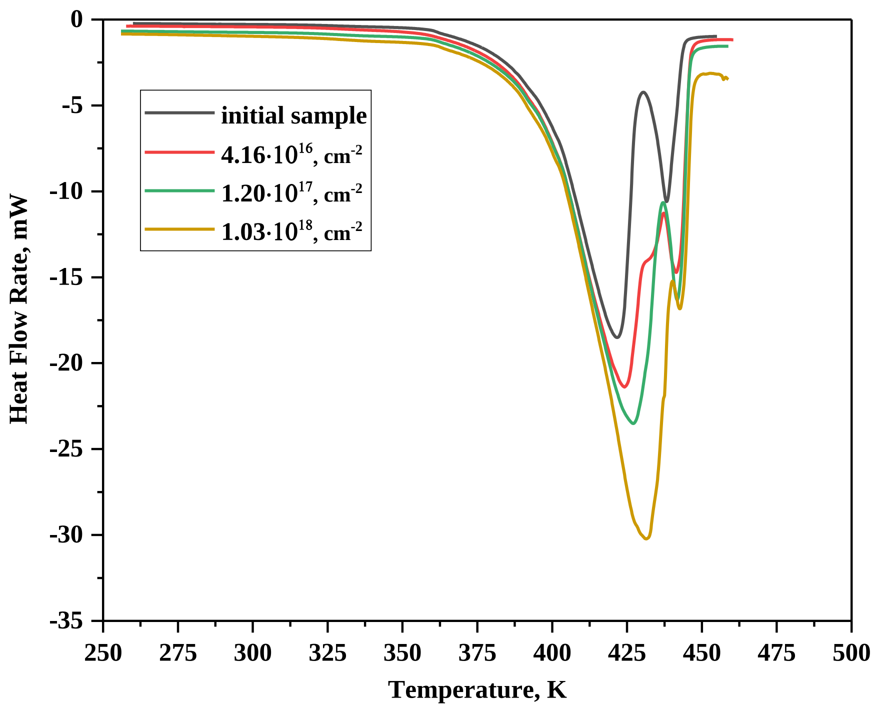

Fig. 1. Temperature depends on the heat flow rate of the nano boron trioxide sample at the different electron fluence $4.16\cdot10^{16}$, $1.20\cdot10^{17}$ and $1.03\cdot10^{18}$ cm^{-2}

Peak intensity formed in a non-irradiated sample is 1.614 times smaller than the irradiated samples at different absorption doses. An increase in both the effect area and the intensity indicates that a large amount of kinetic energy is required for the completion of the process. After each electron fluence, the OH group and water molecules increase freely, so the decompose of reaction products under the influence of temperature occurin more rapidly phase. The variation of the energy required for the decomposition reaction in duplex effects at temperatures $422 \leq T \leq 438$ K and $438 \leq T \leq 443$ K, depending on electron fluence, were shown in Figure 2. Depending on the density of electron flow conversion of the energy increasing linearly. It becomes clear that free water molecules and hydroxide groups increase under the influence of each electron fluence in the conversion reaction with a complex mechanism.

We assume that at high absorption doses the reaction of water vapor and OH groups is complete and the energy fluctuations are stable. For this purpose, experimental studies in a research reactor with high electron fluence are needed. Determination of heat capacity by DSC method and determination of the average value of heat flux have been reported in some literature (Kalkabay *et al.*, 2019). However, several factors of heat flux rate (behavior of the furnace)function must be taken into account for the more accurate recording experimental value of heat flux. The well-defined heat flow rate function affects the accuracy of the estimates of heat capacity and thermodynamic functions.

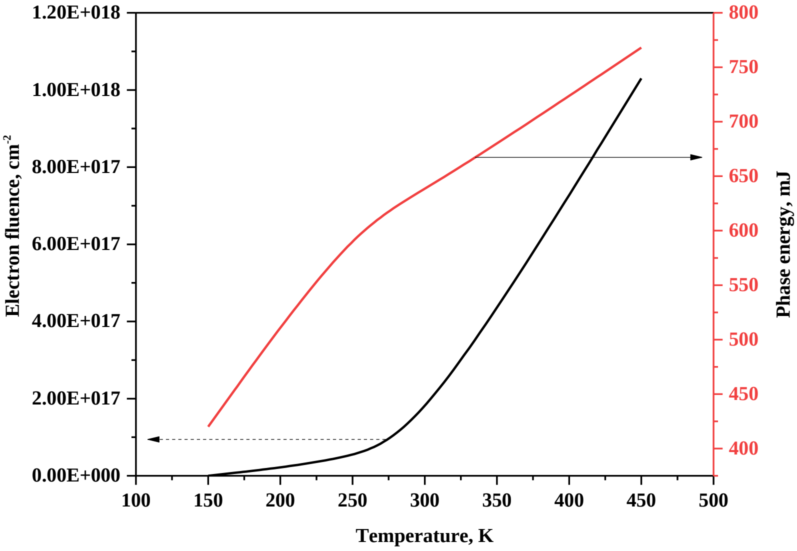

Fig. 2. Changes of phase energy and electron fluence of nano boron trioxide samples at the 100≤T≤450 K

Additionally, it is possible to switch to thermodynamic functions with determination heat flux, calibration factor, and heat capacity by the actual value of temperature-dependent functions. Figure 3 shows the temperature dependence of specific heat capacity for the decomposition reaction in the nano boron trioxide sample in the temperature range of 300≤T≤600 K. In the same way, the kinetics of the temperature fluctuations of the heat flux is also observed in the temperature dependence of the heat capacity. From the temperature dependence of the thermal capacity, it is clear that the heat capacity at the temperature 300 K for the non irradiated sample 0.310 J/K·g, at various electron flux densities $4.16\cdot10^{16}$, $1.20\cdot10^{17}$ and $1.03\cdot10^{18}$ cm^{-2}, increase 0.315 J/K·g, 0.317 J/K·g, and 0.322 J/K·g respectively. But at temperatures 600 K, the thermal capacity of the samples for the non-irradiated sample 0.458 J/K·g, and at various electron flux densities $4.16\cdot10^{16}$, $1.20\cdot10^{17}$ and $1.03\cdot10^{18}$ cm^{-2} increases 0.483 J/K·g, 0.488 J/K·g, and 0.497 J/K·g respectively. From giving function of the heat capacity dependency on the temperature is possible to calculate the numerical value of the enthalpy at various electron densities and at the temperature range of 300≤T≤600 K. However, the kinetics of the occurred effect in nano boron trioxide compound at a temperature range of 360≤T≤458 K shows that the enthalpy of the decomposition reaction happened by $A \rightarrow B \pm \Delta H$ mechanism at the same temperature range the varies in the range of 0.3325-0.7951 J/g. The mechanism of energy transferred by electrons with different flood density is decomposition by the transfer of hydrogen and water molecules decomposed in the combination HBO_2 at the 422 K and boronic acid $B(OH)_3$ at the 438 K temperature. The enthalpy of the endo-effects with a central peak at 422 K and 438 K depending on the radiation dose of the absorbance was calculated. It was found that the kinetics of the enthalpy change in the non irradiated nano boron trioxide combination in the temperature range of 360≤T≤458 K at the 118.095 J/g, $4.16\cdot10^{16}$, $1.20\cdot10^{17}$ and $1.03\cdot10^{18}$ $cm^{-2}$is change 165.952 J/g, 168.095 J/g, and 174.524 J/g respectively. It was found that Gibbs energy conversion kinetics in the nano boron trioxide combination at a temperature range of 360≤T≤458 K was 76,243 J / g for the non-irradiated sample, at different electron flood densities $4.16\cdot10^{16}$, $1.20\cdot10^{17}$ and $1.03\cdot10^{18}$ cm^{-2}, is change respectively123,166 J/g, 125,318 J/g, and 131,763 J/g. As a result, the values of all the thermal functions were obtained experimentally. Using obtained parameters and the known value of heat capacity, are expected to be used in future studies.

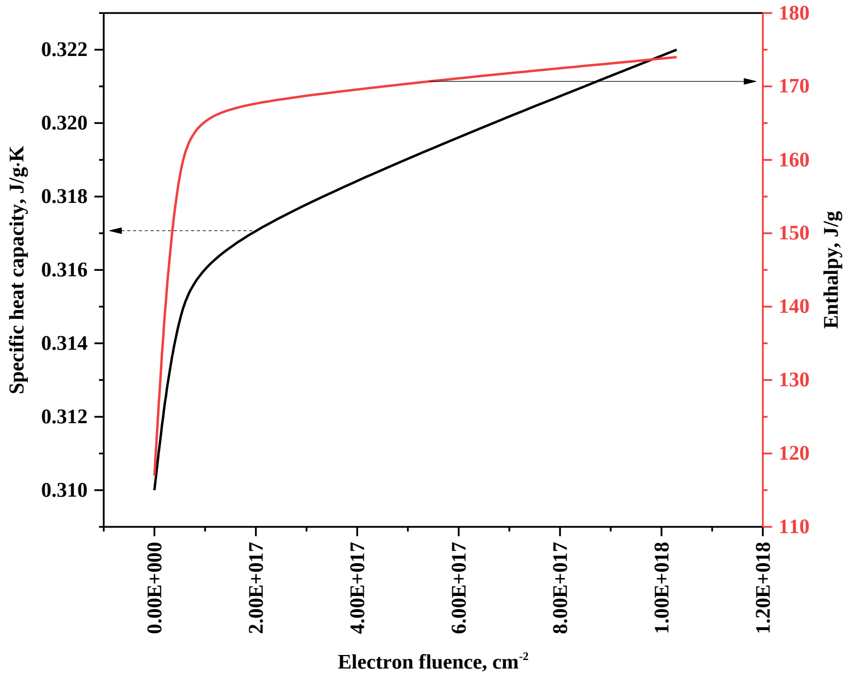

Fig. 3. Specific heat capacity and enthalpy of nano boron trioxide samples the different electron irradiation flux

4. Conclusion

In the present work, boron oxide nanopowder samples were irradiated ~2-3 MeV with high energy electron beams at different electron fluence of $4.16\cdot10^{16}$, $1.20\cdot10^{17}$ and $1.03\cdot10^{18}$ cm^{-2} cm^{-2} at the room temperature and density of electron beams was 0.075 μA/cm^2·s. Specific thermal capacity for the nano boron trioxide sample at a temperature range of 300≤T≤600 K for the non-irradiated sample 0.310 J/K·g, and for irradiated at different electron flood densities sample$4.16\cdot10^{16}$, $1.20\cdot10^{17}$ and $1.03\cdot10^{18}$ cm^{-2}, is 0.315 J/K·g, 0.317 J/K·g and 0.322 J/K·g, respectively.It was found that the kinetics of the enthalpy change for non-irradiated nano boron trioxide combination 118.095 J/g, $4.16\cdot10^{16}$, $1.20\cdot10^{17}$ and $1.03\cdot10^{18}$ cm^{-2} is 165.952 J/g, 168.095 J/g, and 174.524 J/g respectively.

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