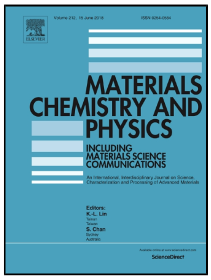
Accepted Manuscript



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PII:	S0254-0584(18)30410-3
DOI:	10.1016/j.matchemphys.2018.05.014
Reference:	MAC 20629
To appear in:	*Materials Chemistry and Physics*
Received Date:	20 October 2017
Accepted Date:	11 May 2018

Please cite this article as: S.Yu. Sokovnin, M.E. Balezin, V.G. Ilves, Effect of electron beam irradiation on the magnetic, thermal and luminescence properties of various oxide metal nanopowders, *Materials Chemistry and Physics* (2018), doi: 10.1016/j.matchemphys.2018.05.014

Effect of electron beam irradiation on the magnetic, thermal and luminescence properties of various oxide metal nanopowders

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Abstract

Magnetic nanopowders of oxides Al_2O_3, SiO_2, CeO_2 and YSZ (ZrO_2-8% Y_2O_3) with a high specific surface area irradiated in air by electrons with energy of 700 keV, pulse duration 100 ns, using the repetitively pulsed accelerator URT-1 within 15 and 30 min. The magnetic, thermal, and cathode luminescence characteristics of NPs were measured before and after irradiation. It was established that the electron irradiation non-monotonically changes the magnetization of the pristine samples. On the contrary, a clear correlation between the intensity of cathode luminescence and the irradiation dose is found in the most of the oxides. Thermal stability and phase transformations of unirradiated and irradiated CeO_2 and YSZ oxides were analyzed with the aid of synchronous analysis, using the methods of thermogravimetry and differential scanning calorimetry. The luminescent and thermal properties reflect the transformation of structural defects in NPs more strongly after exposure to a pulsed electron beam in comparison with corresponding changes of the NP's magnetic response.

Highlights

Nanopowders (NPs) of various oxides were irradiated in air by 700 keV electrons

The magnetic, thermal and luminescence properties of the NPs were measured

The luminescent and thermal properties reflect the transformation of defects in NPs most strongly

Keywords:

Oxide nanopowders; PEBE; Electron beam irradiation of nanopowders; Pulsed cathode luminescence; Specific magnetization

1. Introduction

The magnetic properties of nanoparticles (NPles) depend on many factors – the chemical composition, type of the crystal lattice, degree of its deficiency, shape and size, morphology, interaction of particles with the matrix and neighboring particles, phase structure and type of structural defects, etc. [1-3]. By changing the size, shape, composition and structure of NPles, it is possible, within limits, to control the magnetic characteristics of nanomaterials.

Over the last fifteen years, many articles have reported that some semiconductors become magnetically ordered at room temperature (RT) when doped with magnetic ions, [4-9]. At present, a consensus has been reached on magnetic ordering in dilute magnetic semiconductors (DMS). The room temperature ferromagnetism (RTFM) is associated with lattice defects and/or added ions, but the added ions can be non-magnetic. This phenomenon is called defect-induced magnetism [10].

The identification of RTFM in non-magnetic dopant-doped oxide also attracts a lot of attention in connection with possible use of the oxides in semiconductor spintronics. Therefore, the search for a suitable non-magnetic additive which makes non-magnetic oxides magnetic is very important [11-12].

The study of the relationship between magnetic and luminescent characteristics (luminescence being a good tool for studying structural defects in solids) makes it possible to reveal the nature of magnetism in DMS more deeply, in particular, in DMS based on nonmagnetic oxides. Presently, engineering of nanostructures using electronic irradiation is widely used [13-15]. Electron irradiation is an effective method of changing the size of NPles, and consequently their magnetic properties. For example, by applying an electron beam with electron energy of 6 MeV with fluencies from 1 x 10^{15} e/cm^2 to 2.5 x 10^{15} e/cm^2 to ZnO NPles obtained by microwave synthesis, the size of NPles was modified from 46 to 15 nanometers [16].

Analysis of the recent literature has shown that electron irradiation has a different effect on the magnetization of magnetic, paramagnetic, and diamagnetic NPles.

The effect of an electron beam on magnetic NPles, for example, Fe_3O_4 [17], $NiFe_2O_4$ [18] NP and others, greatly changes their magnetic properties. At irradiation doses of 0, 100 and 200 kGy, the change in the magnetization saturation (M_s) in $NiFe_2O_4$ NPs at RT was 31.33, 35.12 and 39.36 emu/g, respectively, while the crystal size of the NPs, according to X-ray diffraction (XRD), decreased from 13.16 nm to 7.52 nm, with an increase in the irradiation dose [18]. The crossover from paramagnetism to superparamagnetism as function of the crystal size of zinc ferrite NPles was recently shown in work [19]. Note that the effect of gamma radiation on magnetic NPles of oxides and ferrites can lead to an increase in magnetization [20] as well as to a decrease in magnetization [21].

The effect of electron beam irradiation on the structural, electrical, thermo-electric power and magnetic properties of $LaCoO_3$ cobaltites has been investigated in [22]. The magnetization results give clear evidence of an increase in the effective magnetic moment due to an increase in dosage of electron beam irradiation.

A well-known multiferroic (magnetism and ferroelectricity coexist in materials called multiferroics [23] in the bulk state), $Bi_2Fe_4O_9$, shows paramagnetic nature at room temperature and transforms to an antiferromagnetic state below Neel temperature, T_N=240-267 K[24]. The magnetic and ferroelectric properties of $Bi_2Fe_4O_9$ strongly depend on the grain size. At a grain size of 60 nanometers $Bi_2Fe_4O_9$ shows weak FM with a corresponding coercivity of H_c=240 Oe and magnetization saturation of M_s=0.58 emu/g, [25]. With increase in the grain size from 60 nm to 1-2 μm, the saturation magnetization decreased and the FM behavior was transformed into paramagnetism. A similar effect of grain size on magnetism was also reported in nanosized $BiFeO_3$ [26, 27].