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Ferromagnetism and strong magnetic anisotropy of the $PbMnBO_4$ orthoborate single crystals

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ABSTRACT

The $PbMnBO_4$ orthoborate single crystals were first grown and their magnetic properties and ferromagnetic resonance were studied. It was found that the ferromagnetic state below the Curie temperature $T_C=31$ K is characterized by the strong magnetic anisotropy. The significant effective anisotropy fields of $PbMnBO_4$ determine the energy gap in the FMR spectrum, which is extraordinary large for ferromagnets (112 GHz at $T=4.2$ K). It was shown that the static Jahn–Teller effect characteristic of the Mn^{3+} ion leads to both the ferromagnetic ordering and the strong magnetic anisotropy in the crystal. In the strong external magnetic field the induced ferromagnetic ordering is retained in the crystal above the Curie temperature up to the temperatures multiply higher than T_C. A weak anomaly of the dielectric permittivity was observed in $PbMnBO_4$ at the Curie temperature at which the long-range ferromagnetic order is established.

1. Introduction

The search for new materials and study of their physical properties is one of the priorities of modern solid state physics. It is aimed at finding advanced materials for engineering applications and providing experimental data for studying new physical effects that arise at the intersection of magnetic, electrical, elastic, and other properties.

The $PbMnBO_4$ crystal belongs to a relatively new family of $PbMBO_4$ orthoborates whose structure for M=Ga, Al was first studied in [1]. Afterwards, the authors of this study investigated the magnetic properties of the isostructural series of polycrystalline samples with M=Fe, Cr, and Mn and established antiferromagnetic properties of the compositions with Fe^{3+} and Cr^{3+} ions and ferromagnetic properties of the composition with Mn^{3+} ions [2]. The strong dependence of the type of magnetic order on the kind of magnetic ion M stimulated us to investigate in detail the magnetic properties of these compounds. Note that the ferromagnetic order is extremely rarely met in oxide dielectrics and $PbMnBO_4$ is the only ferromagnet in this family.

Another stimulus for these investigations was a stereochemical feature of the Pb^{2+} ion. The electronic structure of this ion is characterized by the unusual electron density distribution caused by outer $6s^2$ electrons, which are not involved in the formation of a chemical bond and create isolated (lone) pairs [3]. These pairs strongly affect the ionic coordination and can lead to the occurrence of ferroelectric, nonlinear optical, and other interesting properties of the investigated crystals. Many compounds containing the stereochemical Pb^{2+} and Bi^{3+} ions with lone pairs, including $PbVO_3$ [4], $BiMnO_3$ [5], $BiFeO_3$ [6], and $Pb_3Mn_7O_{15}$ [7], exhibit the multiferroic properties.

Investigations of single-crystal samples yield more information on characteristics of materials, e.g., on their magnetic anisotropy. As a rule, it is convenient to study the physical properties of new compounds on their single crystals, since the latter have high quality. High-purity single crystals can be obtained when their chemical composition includes potential solvents, such as PbO, B_2O_3 and Bi_2O_3 oxides or their combinations. Using spontaneous crystallization by a flux technique, we synthesized $PbFeBO_4$ single crystals and established that their magnetic behavior [8] strongly differs from that of polycrystalline samples [2]. We showed that the features of magnetic behavior of polycrystalline samples are caused by the contribution of a concomitant *hematite* phase.

In addition, we investigated the dielectric properties of $PbFeBO_4$ [8] and found anomalies for both polycrystalline and single-crystal samples at the temperature of short- and long-range antiferromagnetic ordering, which indicates the correlation

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