

ON CRYSTAL STRUCTURE OF FERRIMAGNETIC RARE EARTH GARNETS IN COLINEAR MAGNETIC PHASE

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Abstract

The aim of this investigation was the determination of the crystal structure of ferrimagnetic rare earth garnets, in temperature region in which the corresponding magnetic structure is colinear, so that the magnetic moments are directed along the [111] direction. Crystal structure of garnets is usually described by the space group $O_h^{10} - Ia3d$, as low as the liquid nitrogen temperature, and lower. But, while in the paramagnetic phase there is no principal obstacle for the structure to be truly cubic, in the ferrimagnetic phase the magnetic order has the role of perturbation which causes the changes in the crystal structure. On the other hand, numerous experimental results have verified no structure deviation relative to the cubic structure. Taking into account the compatibility conditions of crystal and colinear magnetic structure of ferrimagnetic rare earth garnets, the corresponding point group -3 was found. According to the selected rules for the two possible extensions of this point group, one space group was eliminated, so that there was found the space group to the ferrimagnetic rare earth garnets in their colinear magnetic phase — P3.

INTRODUCTION

Numerous investigations take the $O_h^{10} - Ia3d$ space group as the most probable space group of the rare earth garnets [1]. All reflections in the diffraction experiment at room and higher temperatures can be indexed in this space group. However, the spontaneous magnetostriction, below the Curie-temperature, leads to the deformation of crystal lattice. Due to ordering of magnetic moments, the symmetry class of ferromagnetics is lower than the symmetry class of the corresponding paramagnetic. Ferromagnetics must have such a transformation group symmetry which leaves invariant the magnetic moment as pseudovector. Ferromagnetism and ferrimagnetism are possible only in crystals in

which the magnetic symmetry class is one of subgroups within the magnetic moment symmetry group [2]. Known are the magnetic symmetry classes which allow the resulting magnetic moment and the corresponding space groups [3], among which there are not the cubic symmetry groups. Crystals having some class of magnetic symmetry which are not in the Tavger's table, are undoubtedly antiferromagnetics [2].

It has been shown experimentally that the heavy rare earth garnets at temperatures below 100 K (below T_{comp}) have the rhombohedral structure [4, 5]. Other authors think that the structure in Er_3G , above T_{comp} is rhombohedral, and below T_{comp} some other structure [6].

Magnetic structure of ferrimagnetic rare earth garnets above T_{comp} is colinear, magnetic moments are oriented in the [111] direction, with the vectors of \bar{a} and d positions antiparallel to one another, and the c -position vector antiparallel to the resulting vector of the iron sublattices [7, 8].

THE POINT GROUP DETERMINATION

In the paramagnetic phase ($T > 570$ K) there is no principal obstacle for the space group of rare earth ferrimagnetic garnets to be $O_h^{10} - Ia3d$, as experimentally obtained, at all temperatures down to temperatures near the liquid nitrogen temperatures.

In colinear ferrimagnetic phase, magnetic moments are oriented along the [111] direction. Of all elements of O_h group, only the elements generated by the third order axis of [111] direction are included in the magnetic moment pseudovector group: $C_3, C_3^2, C_3^3 = E$, inversion and its multiplicands with the mentioned elements. In that way, the symmetry group Λ includes the group $C_{3i} - 3$, with six elements. From Neuman's principle and axial vector representation, it can be seen that no more rotation, except the mentioned ones, belongs to the Λ group. May be the elements of ia group (where i is inversion, a rotation and a $\bar{E} C_3$) including also the reflections, could belong to this group. In that case, because of the group multiplication being hermetic, follows: $i \cdot i a \in \Lambda \Rightarrow a \in \Lambda$, which cannot stand, since no rotation out of the C_3 group belongs to Λ . Therefore, in accordance with the Neuman's principle, the point group of garnets symmetry in colinear ferrimagnetic phase, on the basis of the magnetic moment group, is group 3.

DETERMINATION OF THE SPACE GROUP

Point group 3 yields two space groups as its extensions — groups R3 and P3. The question is which of these groups is the space group of ferrimagnetic garnets in their colinear magnetic phase? Diffractograms of polycrystal Gd_3G , obtained by $\text{CuK}\alpha_1$ rays, are indexed in the space group $O_h^{10} - Ia3d$. Next, we transform the Miller indices from the cubic into the trigonal system with hexagonal axis. We give some results of this transformation: reflections (420) and (422) of the cubic system transform into reflections (426) and (228) of the trigonal system, respectively. Reflection (426) is allowed both in group P3 and group R3, while reflection (228) is allowed only in space group P3. In space group R3, it is forbidden by selection rule — $h + k + l = 3n$. This eliminates space group R3 as a possibility, which leaves space group P3 as the only possible space group for ferrimagnetic garnets of rare earths in their colinear magnetic phase.

DISCUSSION

The obtained results apply to ferrimagnetic garnets of rare earths below the Curie point. Since group P3 represents a subgroup of group $O_h^{10} - Ia3d$, the phase transition ferrimagnetic-paramagnetic is, as was expected, a second-order phase transition. The colinear magnetic phase in light garnets of rare earths is conserved up to at least 300 K [1]. Therefore, the determined space group is their space group in the interval $300\text{ K} - T_c$. In heavy rare earth garnets, canted magnetic structure appears below the compensation point, while magnetic structure above T_{comp} is colinear [9]. That is why P3 represents the space group of these garnets in the interval $T_{\text{comp}} - T_c$. The magnetization of GdIG between 0 K and T_c can be described by the colinear model [10], except in the vicinity of the compensation point. P3 is, therefore, the GdIG space group in the interval $0\text{ K} - T_c$, with the exception of the region in the vicinity of the compensation point. The magnetization of YIG in the region $0\text{ K} - T_c$ is described by the colinear model [10], and therefore its space group is P3 in this region.

The equation connecting lattice constants and interplanar distances for rhombohedral structures transforms into an equation for cubic structures if the angle of rhombohedral distortion is sufficiently small. Since the magnetostriction of REIG is weak in the temperature region above 100 K, the angle of rhombohedral distortion corresponding to the colinear magnetic phase is small. It is believed that the cubic structures which appear in diffraction experiments instead at rhombohedral structures are a result at insufficient resolution [11]. The second reason for the appearance of cubic structures is the existence of domains. Different orientations of magnetization in domains lead to the averaging of experimental results if the distortions are small. In order to observe single-domain structures (to which this paper is devoted), it is necessary to apply an external magnetic field.

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