Magnetic Properties of Frustrated Ytterbium and Holmium Rare Earth Titanates Doped With Yttrium and Bismuth

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OUTLINE

Holmium and ytterbium titanates doped with yttrium and bismuth have been synthesized. The magnetic properties of doped and undoped titanates have been studied. The magnetization curves and temperature dependences of the susceptibility have been measured in the fields of up to 30 kOe at the temperatures from 2 to 300 K. The comparative analysis of the magnetic properties of the doped and undoped titanates, as well as the titanates with various degree of doping, has been carried out. The magnetic dipole and exchange interactions of titanates have been analyzed based on the study of the temperature dependences of the susceptibility. For the undoped holmium titanate, the magnetic dipole interaction has been found to predominate. Doping with yttrium and bismuth leads to the significant decreasing the dependence slope, which is caused by the sharp weakening of the magnetic interactions between the rare-earth ions. For the undoped yttrium titanates the exchange interaction predominates. The concentration of R3+-O-R3+ ion pairs in this frustrated rare earth titanate, between which there is the superexchange, decreases because of the presence of a large number of the randomly distributed yttrium or bismuth ions, which occupy the positions of the ytterbium ions in the crystal lattice. In the doped compounds, the magnetic dipole interaction, which is capable to act at large distances than the exchange one, begins to dominate.

SAMPLES

5 holmium titanates $Y_{1.5}Ho_{0.5}Ti_2O_7$
30 % pores, 4-5 % impurity

4 ytterbium titanates $Y_{1.5}Yb_{0.5}Ti_2O_7$
30 % pores, 3 % impurity

(a) (b)

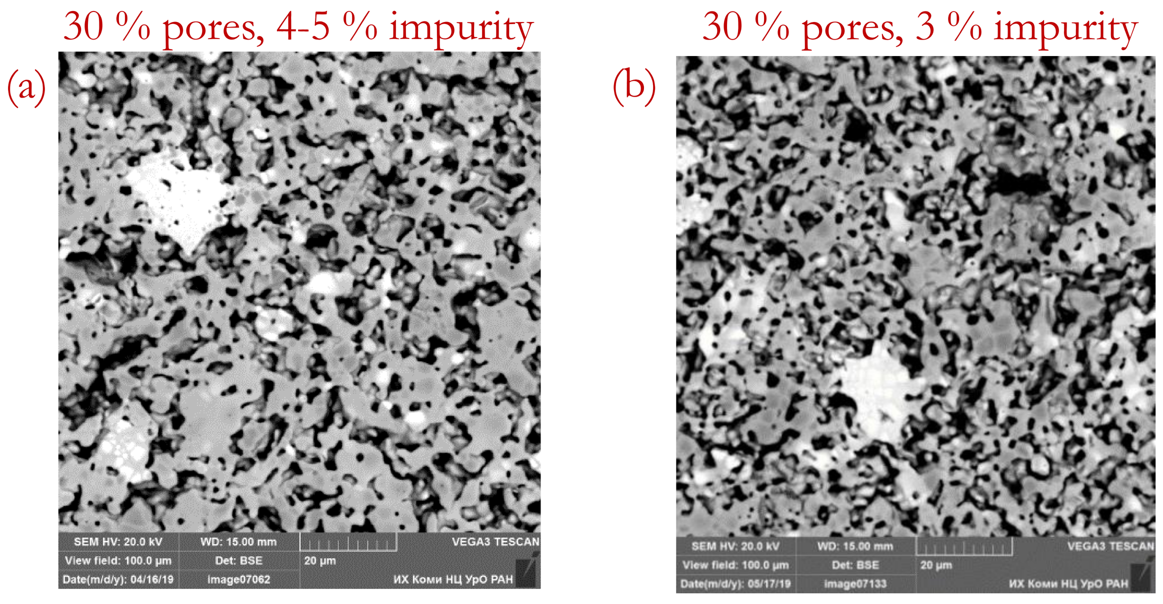

Fig. 1. Structure of the samples of the holmium (a) and ytterbium (b) titanates doped with yttrium, obtained by an Vega3 Tescan electron microscope

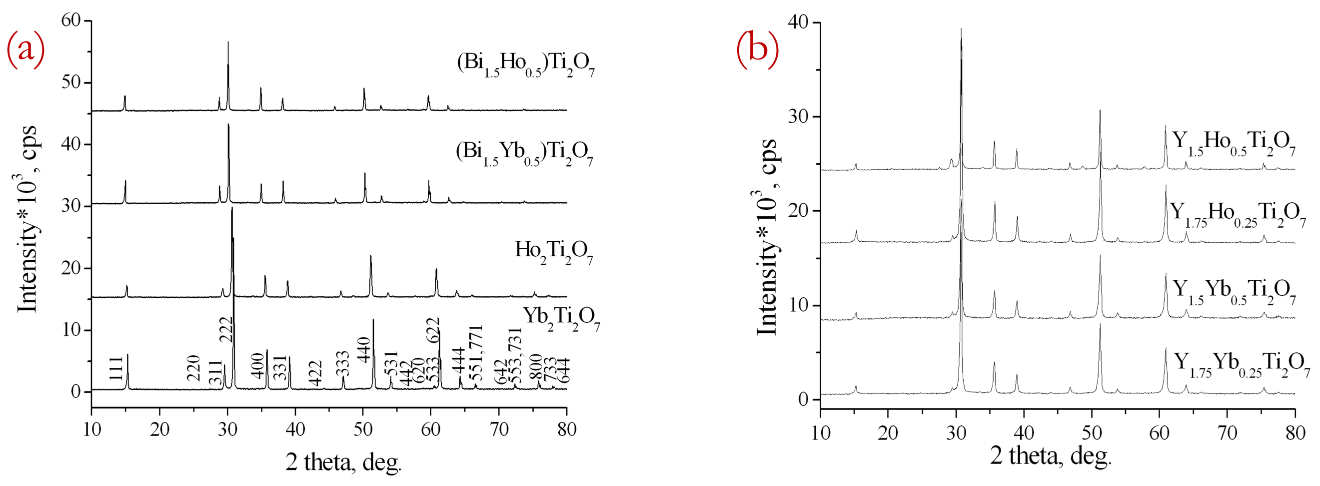

Fig. 2. X-ray diffraction patterns for the samples of the holmium - (a) and ytterbium - (b) titanates doped with yttrium and bismuth

Magnetization curves

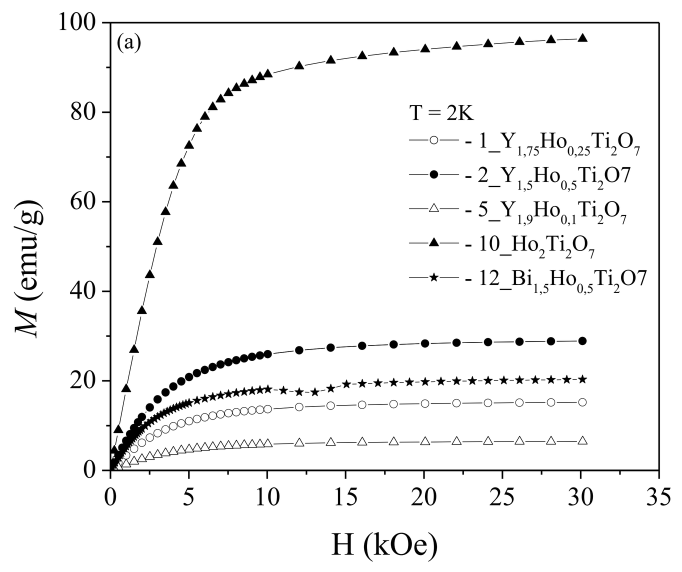

Fig. 3. The magnetization curves for the samples of the holmium titanates

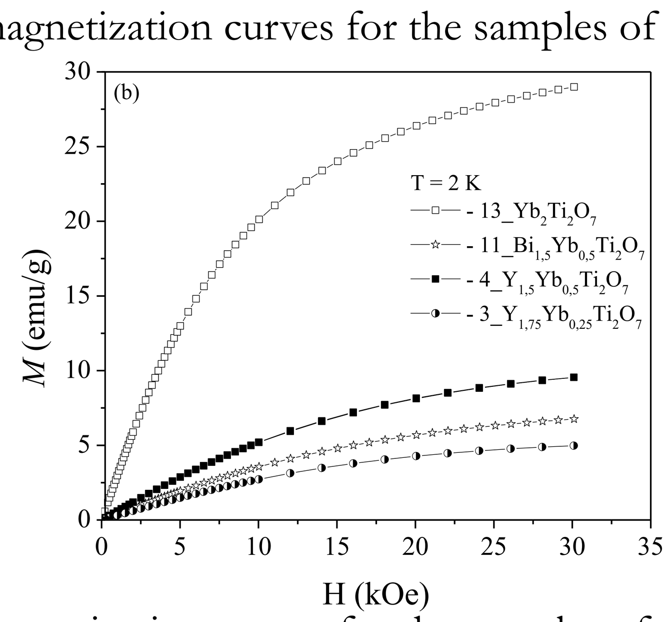

Fig. 4. The magnetization curves for the samples of the ytterbium titanates

Table 1. Unit cell parameters and density of the titanates-pyrochlores at 25 ° C

Compound	*a*, Å	Distance R (Bi) - R for positions with coordination number of 6, Å	Distance R (Bi) - R for positions with coordination number 12, Å	*ρ*, g/cm³
$Yb_2Ti_2O_7$	10.025	3.5446	6.1394	7.30
$Ho_2Ti_2O_7$	10.092	3.5701	6.1813	6.95
$Bi_{1.5}Yb_{0.5}Ti_2O_7$	10.264	3.6302	6.2877	7.46
$Bi_{1.5}Ho_{0.5}Ti_2O_7$	10.279	3.6325	6.2916	7.38
$Y_{1.75}Ho_{0.25}Ti_2O_7$	10.0887(2)	3.56688(7)	6.17802(12)	5.234
$Y_{1.5}Ho_{0.5}Ti_2O_7$	10.0914(1)	3.56784(5)	6.17968(9)	5.475
$Y_{1.75}Yb_{0.25}Ti_2O_7$	10.0861(2)	3.56597(8)	6.17645(13)	5.264
$Y_{1.5}Yb_{0.5}Ti_2O_7$	10.0752(3)	3.56212(11)	6.16977(19)	5.554
$Y_{1.9}Ho_{0.1}Ti_2O_7$	10.0909(1)	3.56769(5)	6.17941(8)	5.083

Calculation of the temperature dependence of the susceptibility

Ising model

$$\chi(T)=\frac{N(g\mu_B)^2}{k_BT}\frac{S^2}{3}\left[1-\frac{3S^2}{2k_BT}\left(2.18J_D+2.67J_S\right)\right] \quad (1)$$

g=8/7 is the Lande factor of the $^2F_{7/2}$ multiplet,
N is the number of magnetic ions per cm³,
k_B is the Boltzmann constant,
μ_B is the Bohr magneton,
S is the spin of an ion in the ground state.

J_D constant takes into account the dipole interaction of the nearest neighbors,
J_S constant - the superexchange interaction.

Dependences of the product of the susceptibility χ and temperature T on the reciprocal temperature 1/T

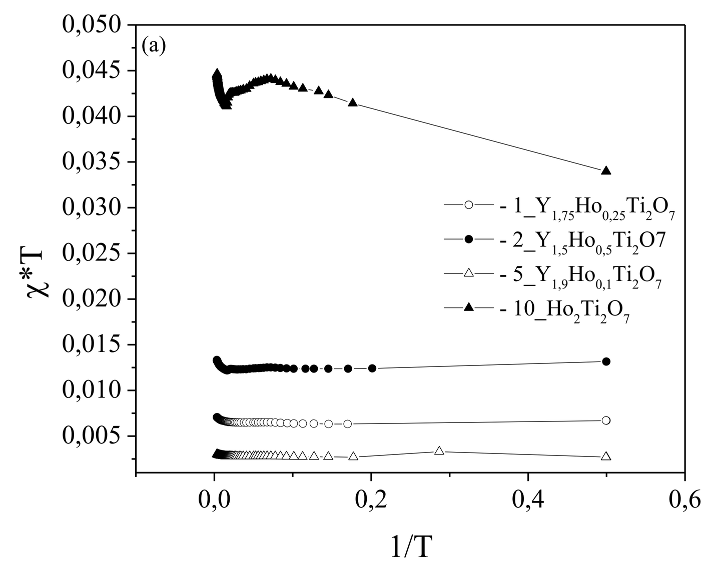

Fig. 5. Dependences of the product χ*T on the reciprocal temperature 1/T

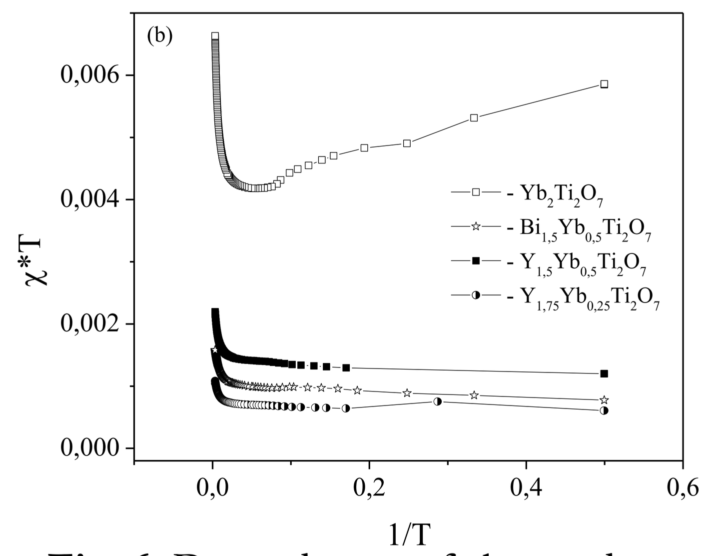

Fig. 6. Dependences of the product χ*T on the reciprocal temperature 1/T

Conclusions

- For the holmium and ytterbium titanates, when increasing the doping degree, the saturation magnetization decreases. This is related to the fact that the Bi3+ and Y3+ ions do not have a magnetic moment.
- Doping with the yttrium and bismuth does not lead to any significant variation in the cell parameters. The change of the interaction nature doesn't related with a change of a distance between the rare-earth ions.
- For the undoped holmium titanate the magnetic dipole interaction predominats. Doping with the yttrium and bismuth leads to the significant decreasing the dependence slope, which is caused by the sharp weakening of the magnetic interactions between the rare-earth ions.
- For the undoped yttrium titanates the exchange interaction predominates. The concentration of R3+-O-R3+ ion pairs in this frustrated rare earth titanate, between which there is the superexchange, decreases because of the presence of a large number of the randomly distributed yttrium or bismuth ions, which occupy the positions of the ytterbium ions in the crystal lattice. In the doped compounds, the magnetic dipole interaction, which is capable to act at large distances than the exchange one, begins to dominate.

[1] Gingras M.J.P., McClarty P.A. Quantum spin ice: A search for gapless quantum spin liquids in pyrochlore magnets // Rep. Prog. Phys.- 2014.- V. 77. - 056501.

[2] Siddharthan R., Shastry B.S., Ramirez A.P., Hayashi A., Cava R.J., Rosenkranz S. Ising pyrochlore magnets: low-temperature properties, «ice rules»," and beyond //Phys. Rev. Lett.- 1999. -V. 83. - 1854.