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Considerably Strong Magnetodielectric Coupling in Zircon-type $DyVO_4$

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Abstract. We investigate the magnetic and dielectric properties of zircon-type $DyVO_4$. The evidence of dielectric anomaly at the Jahn-Teller (JT) transition temperature (T_D) in $DyVO_4$ points a direct consequence of the onset of an electric polarization. We also report that the JT domain control gives rise to a remarkable magnetodielctric (MD) coupling, which is probably maximum in the RVO_4 series. MD coupling scales linearly with the squared magnetization as described by the Ginzburg-Landau theory.

INTRODUCTION

Recently, the RVO_4 (R = rare-earth) compounds have received renewed attention for their unusual magnetic properties [1, 2]. These materials usually crystallize in the zircon-type structure with space group $I4_1/amd$ for smaller ionic radius of R ion [3]. The crystal structure of this phase consists of VO_4 tetrahedra and RO_8 bisdisphenoid polyhedra. RO_8 units connect with one another along the a and b axes as depicted in Fig. 1. Along the c-axis, RO_8 alternately align with VO_4 units, as a result, the VO_4 units are spatially isolated by RO_8 polyhedra. The magnetic properties of RVO_4 are mainly determined by the 4f spin of R ion. Recent studies showed that some of the materials of RVO_4 family have a very high magnetocaloric effect in low temperature, which is technologically promising for cryogenic magnetic refrigeration [4, 5].

$DyVO_4$ is also a promising material with significant magnetic [5] and optical properties [6]. The zircon-type $DyVO_4$ is a typical example of showing the Jahn-Teller (JT) effect induced by the quadrupolar interaction. It undergoes the JT transition from the $I4_1/amd$ tetragonal to an orthorhombic structure at T_D (~15 K), which is associated with the ordering of 4f quadrupole moments of the Dy^{3+} ions [7]. $DyVO_4$ also shows high magnetocaloric effect near the antiferromagnetic (AFM) ordering of Dy^{3+} moments and the structural transition associated with 4f ferroquadrupolar ordering of Dy^{3+} ion [5]. The structure analysis showed that quadropolar distortion in $DyVO_4$ also induces an antiferroelectric lattice distortion, and makes it promising for investigation of the multiferroic properties in details [7].

In this paper, we report magnetic and dielectric properties in zircon-type $DyVO_4$. We observe a strong magnetodielectric (MD) effect around the JT transition temperature of $DyVO_4$. MD coupling scales linearly to the squared magnetization indicating the presence of spontaneous electric polarization around T_D in $DyVO_4$.

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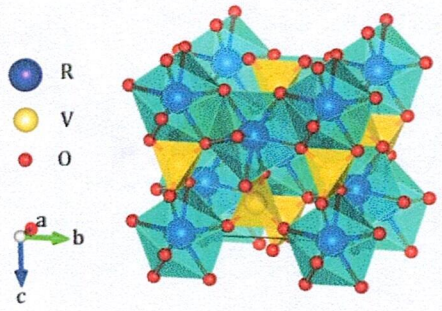

FIGURE 1. Zircon-type crystal structure of RVO_4 at room temperature.

EXPERIMENTAL DETALS

The polycrystalline $DyVO_4$ is prepared using a solid-state reaction [4]. The single-phase chemical composition is confirmed by the x-ray diffraction studies at room temperature recorded in a Bruker D8 Advance powder diffractometer using the Cu K_α radiation. The powder sample pressed into a pellet is used for the dielectric measurements using a E4980A LCR meter (Agilent Technologies, USA) equipped with a commercial PPMS evercool-II system of Quantum Design. The electrical contacts are fabricated using an air-drying silver paint. Magnetization is measured in a commercial magnetometer of Quantum Design (MPMS, evercool).

EXPERIMENTAL RESULTS AND DISCUSSIONS

The Rietveld refinement of the x-ray diffraction data of $DyVO_4$ at room temperature are shown in Fig. 2. The refinement is done using tetragonal structure with $I4_1/amd$ space group with atomic positions Dy (0,0,0), Cr (0,0,0.5), and O [0,0. 0.1781(2), 0.3375(6)]. The reliability parameters $R_w(\%)\sim3.92$, $R_{expt}(\%)\sim3.71$, and $\chi^2\sim 1.38$ are reasonably small. The refined lattice parameter of the unit cell are a = 7.1461(2) and c = 6.3071(8) Å, which are close to the previously reported values [8]. The difference plot shown at the bottom confirms the single phase without trace amount of impurity.

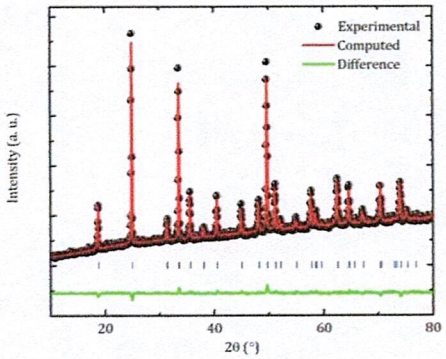

FIGURE 2. Rietveld refinement of x-ray powder diffraction patterns of $DyVO_4$ at room temperature.

The thermal variations of the zero-field cooled (ZFC) and field-cooled (FC) magnetization curves recorded at 100 Oe are depicted in Fig. 3(a). Both curves show a paramagnetic (PM) to AFM transition below $T_N\sim3.5$ K due to the long-range ordering of the Dy^{3+} moments. No significant difference has been observed between ZFC and FC cycles. Analogous the previous reports, no signature of JT transition around 15 K is observed in the M(T) curve [5]. Figure 3(b) shows the magnetization curve [M(H)] at selected temperatures above and below T_N. The M(H) at 2 K increases rapidly above a critical field $B_C\sim2.5$ kOe due to the metamagnetic transition from AFM to ferromagnetic (FM) state. The M(H) curve shows a saturating trend above 40 kOe indicating the FM nature above B_C. The nonlinear nature of

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M(H) is observed at 12 K, which indicates the existence of short-range ordering due to the reported JT transition associated with 4f ferroquadrupolar ordering of Dy^{3+} ion. With further increasing the temperature the M(H) curve becomes linear in the PM state.

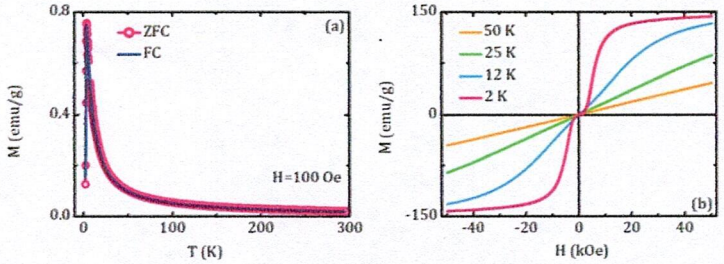

FIGURE 3. (a) T variation of ZFC-FC magnetization curves at 100 Oe. (b) Magnetization curves at selected temperatures.

The dielectric permittivity (ε) is recorded at different frequencies (f) by varying T for $DyVO_4$. Figure 4(a) depicts thermal variation of the real component (ε') of ε at different f. Inset of Fig. 4(a) clearly shows a Curie-type temperature dependence above T_D (~15 K) and a sudden drop below T_D, which is consistent with the results reported previously [9, 10]. The peak around T_D does not show any frequency dispersion. The dielectric anomaly observed at the JT transition temperature in $DyVO_4$ was understood as a direct consequence of the onset of an antiferroelectric ordering which is driven by the softening B_{1g} strain mode, i.e., as an optical-mode condensation without it's softening [9]. No signature around T_N is observed in ε'(T).

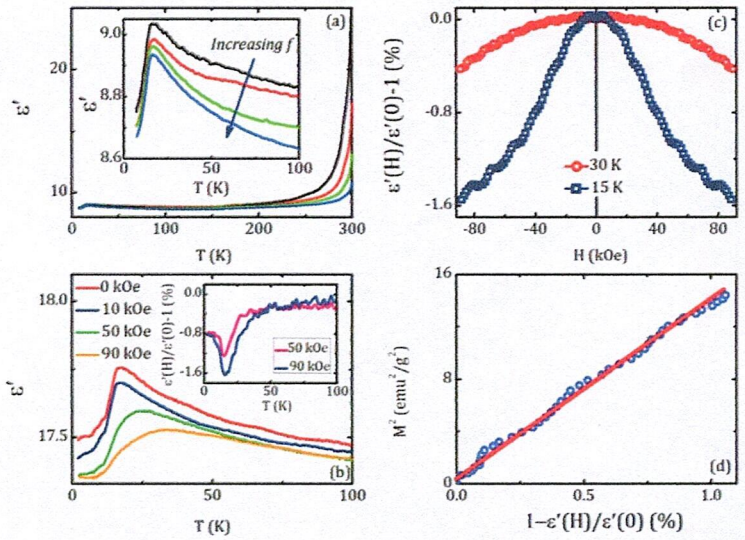

FIGURE 4. (a) T variation of ε' at different f. (b) T variation of ε' at different magnetic fields at f=2 kHz. (c) The H variation of [ε'(H)/ε'(0)-1] at selected T. (d) The M^2 vs −[[ε'(H)/ε'(0)-1](%)] plots at 15 K up to 50 kOe magnetic field. Inset of (a) shows the ε'(T) in low temperature region and (b) shows the variation of ε'(H)/ε'(0)-1 with T at H= 50 and 90 kOe.

The magnetization curve below T_D indicates the existence of short-range magnetic ordering above T_N. Figure 4(b) depicts the thermal variation of ε' at different applied magnetic fields. With increasing filed the peak at T_D depressed rapidly. The magnetodielectric (MD) response, defined as ε'(H)/ε'(0)-1, is measured with T, as depicted in the inset of Fig. 4(b) at H= 50 and 90 kOe. The MD% value shows maximum around T_D for both the magnetic fields and we get 1.6% MD at T_D for 90 kOe applied field. This high value of MD is probably maximum in the RVO_4 series of compounds. The MD effect is further investigated with H above and below T_D. The MD effects as a function of magnetic field are shown in Fig. 4(c) at T=15 and 30 K. The value of MD increases with H up to ~1.6% at 90 kOe at 15 K. The MD effect relates the ME coupling, which can be phenomenologically expressed using the Ginzburg-

Landau theory through the ME coupling term γP^2M^2 in the thermodynamic potential (Φ) defined as,

$$\Phi = \Phi_0 + \alpha P^2 + \frac{\beta}{2}P^4 - PE + \alpha' M^2 + \frac{\beta'}{2}M^4 - MH + \gamma P^2 M^2 \quad (1)$$

Where α, β, α', β', and γ are the constants and functions of temperature. In the magnetically ordered state, the role of magnetic order on MD in a field is followed by the linear curve of M^2 versus $[\varepsilon'(H)/\varepsilon'(0)-1](\%)$ in the low-field region. Here, the M^2 versus $-[\varepsilon'(H)/\varepsilon'(0)-1](\%)$ plot at 15 K is depicted in Fig. 4(d). The result indicates that the ME coupling term γP^2M^2 of the Ginzburg-Landau theory [Eq. (1)] is significant up to 50 kOe magnetic field, which is similar as reported earlier for various magnetodielctric compounds [11, 12].

CONCLUSION

The above results demonstrate that the applied magnetic field rearranges the quadropolar moments of Dy^{3+} ions associated with the JT transition. As a result, the proposed antiferroelectric ordering near T_D is strongly affected by the applied magnetic field and gives a very promising MD effect. These results indicate that $DyVO_4$ may exhibit a good multiferroic nature around the JT transition temperature. Further studies in experimental and theoretical calculations are suggested for establishing a possible multiferroic order in $DyVO_4$.

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REFERENCES

1. P. Radhakrishna, J. Hammann and P. Pari, J. Magn. Magn. Mater. **23**, 254 (1981).
2. M. Moussa, M. Djermouni, S. Kacimi, M. Azzouz, A. Dahani and A. Zaoui, Comput. Mater. Sci. **68**, 361–366 (2013).
3. M. J. Martıinez-Lope, J. A. Alonso, M. Retuerto and M. T. Fernandez-Dıaz, Inorg. Chem. **47**, 2634 (2008).
4. K. Dey, A. Indra, S. Majumdar and S. Giri, J. Mater. Chem. C **5 (7)**, 1646-1650 (2017).
5. A. Midya, N. Khan, D. Bhoi and P. Mandal, Physica B **448**, 4345 (2014).
6. J. C. Wright and H. W. Moos, J. Appl. Phys. **41**, 1244-1245 (1970).
7. C. Detlefs, F. Duc, Z. A. Kaze, J. Vanacken, P. Frings, W. Bras, J. E. Lorenzo, P. C. Canfield, and G. L. J. A. Rikken, Phys. Rev. Lett. **100**, 056405 (2008).
8. G. Will and W. Schafer, J. Phys. C: Solid St. Phys. **4**, 811-819 (1971).
9. H. Unoki and T. Sakudo, Phys. Rev. Lett. **38**, 137 (1977).
10. J. H. Page, D. R. Taylor and S. R. P. Smith, J. Phys. C: Solid State Phys. **17**, 51-71 (1984).
11. A. Indra, K. Dey, J. K. Dey, S. Majumdar, U. Rütt, O. Gutowski, M. v. Zimmermann, and S. Giri, Phys. Rev. B **98**, 014408 (2018).
12. K. Dey, A. Karmakar, A. Indra, S. Majumdar, U. Rutt, O. Gutowski, M. v. Zimmermann, and S. Giri, Phys. Rev. B **92**, 024401 (2015).

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