Magnetic domain and magnetic resistance phase transition in strongly correlated electronic material of perovskites junction

Ren R†, Weiren Wang, Xuan Li, Zhongxia Zhao

Department of optics, Xian Jiao Tong University, Xi’an, 710054, China

The junction magnetoresistivity and domain phase transition were studied between ZnO and La$_{0.4}$Gd$_{0.1}$Sr$_{0.5}$CoO$_3$ thin films grown on LaAlO$_3$ (100) substrates epitaxially by pulse laser deposit. The ferromagnetic transformation into phase-separated (two phase) state was displayed below $T_c \sim 127$ and has observed that the lattice change discontinuously in the doped cobalt perovskites La$_{0.4}$Gd$_{0.1}$Sr$_{0.5}$CoO$_3$. The Ginzburg-Landau phase field is introduced to deduce antiferroelectric domain structure in LGSCO thin film. On the basis of the domain structures, the phase boundary of thin film is strongly dependent on the combination of electric-mechanical coupling. The phase transformation into phase separated state occurs below $T_c \sim 127$-128K, and have displayed that the lattice constants change discontinuously at the transformation. The positive MR of ZnO/LGSCO heterojunction exhibited the MIT behavior at 0.2 T is 4.86%, at 0.5 T is 6.05% for approximately 140K.

Keywords: magnetic domain, magnetoresistivity, carrier injection, spin-orbit, MIT transition

PACS: 42.87.-d, 75.70.Kw, 75.10.Hk, 73.22.2f, 73.61.Wp, 73.63.Rt, 52.38.-r

DOI: 10.1063/1.1850192

Author to whom correspondence should be addressed mail: renrnnano@126.com
1. INTRODUCTION

Recently, it is found that LaCoO$_3$ was charge transfer insulator, while La$_{0.7}$Sr$_{0.3}$CoO$_3$ was oxides have attracted much attention of material science intermediate between charge transfer and Mott since coupled ferromagnetic ordering and insulate-metal Hubbard-type compounds. The spin ordering, charge transition, as well as the colossal magnetoresistance and orbit ordering transition observed at around the CMR phenomenon which make R$_{1-x}$A$_x$CoO$_3$ half-filling is strongly coupled with lattice distortion. ZnO/La$_{0.4}$Gd$_{0.1}$Sr$_{0.5}$CoO$_3$ heterojunction an interesting candidate for ferromagnetic and ferroelectric applications. Especially, CMR effect is strengthened spin-dependent scattering and the interface resistance near the phase separated between the charge ordered. In the DE mechanism, the ferromagnetic phase insulator and the ferromagnetic metal. R$_{1-x}$A$_x$CoO$_3$ has a transition was suggested to be introduced by hopping of rhombohedral perovskite structure, lead to altered spin eg electrons between Co$^{3+}$ and Co$^{4+}$ through the oxygen ordering and phase boundary, which is due to Co$^{3+}$ and ions that also result from conductivity in carriers Co$^{4+}$ having spin Co$^{3+}$, $t^6_e$ and $t^4_e$, and $t^4_e$ under transport. The heterojunction quantum energy band was various doped concentration and temperature. ZnO modified by spin, orbital ordering, and lattice field is generally regarded as n-type due to oxygen impurity, exhibit photoinduced resistance and colossal and their carrier concentration is dominated by oxygen magnetoresistance (CMR) effect. However, the deficiency. So far, many theoretical and experimental phase transition and domain separation mechanism of studies have been carried out on the phase boundary ZnO/LGSCO heterojunction are little explored from the problem. Among them, LSCO, which is ferromagnetic direction of junction CMR effect in the heterostructure but is transferred in to antiferromagnetic charge in the past few years. Furthermore, the insulator (CI) phase below T$_{CI}$ have exhibited La$_{0.4}$Gd$_{0.1}$Sr$_{0.5}$CoO$_3$ topological evolutions by 2D grain coexistence of FM and CI microdomains. Phase growth using a continued diffuse interface field are little separation in rare-earth metals of studied. The ferromagnetic and charge properties are hydrogen-concentration have been investigated at attributed to the further understanding of charge ambient temperature and high pressure by x-ray ordering, magnetic order, electric-mechanical coupling, diffraction changed in structural, electronic, and spin-orbital coupling, optical field and lattice structure. Goodenough reported the The domain wall orientations structure and magnetic properties of the metallic spin-orbital coupling strongly influence the ferroelectric double-perovskite system, and suggested that and antiferromagnetic properties of ferromagnetic long-range ordered domains are coupled ZnO/La$_{0.4}$Gd$_{0.1}$Sr$_{0.5}$CoO$_3$. The LGSCO material was antiferromagnetically across antiphase boundaries, accompanied from ferromagnetic to antiferromagnetic random disorder within domains may be transition, which is called double exchanged P doping. Yacaman et al. investigate the self-assembly La$_{0.4}$Gd$_{0.1}$Sr$_{0.5}$CoO$_3$ from ferromagnetic to of this material through controlling the material antiferromagnetic ordering was accompanied by a Co$^{3+}$/structure and chemical order and found that bimetallic Co$^{4+}$ charge orbit ordering. The mechanics and electric core/shell has the structure of faced centered cubic coupling of ZnO/La$_{0.4}$Gd$_{0.1}$Sr$_{0.5}$CoO$_3$ thin films strongly octahedron. The FM metallic state and the influence domain structure and domain wall. Domain charge/orbital ordered insulator Cr-doped walls can produce pinning sites that reduce remnant Nd$_{0.5}$Ca$_{0.5}$MnO$_3$ have ferromagnetic (FM) polarization, as well as domain structure plays a role in microdomains in the phase-separated state and FM ferroelectric and ferromagnetic order. In this work, we present the structural analysis spin glass phase separation behavior. elucidated the phase separated state in the
heterojunction of cobalt perovskites $\text{La}_{0.4}\text{Gd}_{0.1}\text{Sr}_{0.5}\text{CoO}_3$ and ZnO films fabricated by pulse laser deposition surface morphology ZnO/ $\text{La}_{0.4}\text{Gd}_{0.1}\text{Sr}_{0.5}\text{CoO}_3$/LAO. consist of ZnO and $\text{La}_{0.4}\text{Gd}_{0.1}\text{Sr}_{0.5}\text{CoO}_3$ grown on LaAlO substrate. The IMT effect is enhanced near the soft phase. The FIG. show the surface roughness for phase boundary between the ferromagnetic metallic(FM)ZnO/ $\text{La}_{0.4}\text{Gd}_{0.1}\text{Sr}_{0.5}\text{CoO}_3$/Si was 2nm and the surface and the charge-ordered insulating phase, where the quality is very well. AFM results were presented for phase separation effect is also enhanced. The ZnO/$\text{La}_{0.4}\text{Gd}_{0.1}\text{Sr}_{0.5}\text{CoO}_3$/LaAlO and ZnO/ $\text{La}_{0.4}\text{Gd}_{0.1}\text{Sr}_{0.5}\text{CoO}_3$/ZnO junction exhibited excellent $\text{La}_{0.4}\text{Gd}_{0.1}\text{Sr}_{0.5}\text{CoO}_3$/LaAlO and ZnO/ $\text{La}_{0.4}\text{Gd}_{0.1}\text{Sr}_{0.5}\text{CoO}_3$/ZnO structure respectively. rectifying behavior and MR properties over the $\text{ZnO}/\text{La}_{0.4}\text{Gd}_{0.1}\text{Sr}_{0.5}\text{CoO}_3$/Si, respectively. dependence of mechanics and electric coupling properties determined the phase properties of LaGdCoO and ZnO thin films. The phase-field of domain structure in epitaxial ZnO/$\text{La}_{0.4}\text{Gd}_{0.1}\text{Sr}_{0.5}\text{CoO}_3$/Si and gain size effect of our sample have been investigated.

2. EXPERIMENTS

In order to obtained an appropriate chemical composition for present study, the target $\text{La}_{0.4}\text{Gd}_{0.1}\text{Sr}_{0.5}\text{CoO}_3$ was prepared from the analytically pure oxides used proportion of La$_2$O$_3$, Gd$_2$O$_3$, Co$_3$O$_4$ and SrCO$_3$ by solid state reaction, after repeated grinding and sintering at 1250 °C for 24h for $\text{La}_{0.4}\text{Gd}_{0.1}\text{Sr}_{0.5}\text{CoO}_3$. The ZnO was sintering at 500°C for 48h by solid state reaction. The LGSCO and ZnO layers were successively deposited on the single-crystal LAO (100) substrate by pulse laser deposition. The multilayer thin films were annealed at 800°C with an oxygen pressure 6 Pa for 5h in order to get better epitaxial character and oxygen doped deposit. The structure of the target and the orientation of the deposited film were studied by XRD (Bruker D8 Advance XRD, 40KV, 40mA, smallest angular step 0.0001°). The sample of heterojunction thin film was placed in a JanisCCS-300 closed-circuit refrigerator cryostat (JanisCCS-300) over the range from 50 to 300 K. The magnetic field of 0.2 and 0.5 T was supplied by the electromagnet perpendicularly applied to heterostructure.

The MR and $\rho$-T in film was studied in a JanisCCS-300 over the range from 50 to 300 K at 0.2 and 0.5T, respectively. The topography of ZnO/$\text{La}_{0.4}\text{Gd}_{0.1}\text{Sr}_{0.5}\text{CoO}_3$/LAO was measured though the AFM image. The AFM surface morphology and phase field image for ZnO/$\text{La}_{0.4}\text{Gd}_{0.1}\text{Sr}_{0.5}\text{CoO}_3$/LAO and ZnO/ $\text{La}_{0.4}\text{Gd}_{0.1}\text{Sr}_{0.5}\text{CoO}_3$/Si were characterized by atomic force microscopy (AFM), respectively.

3. RESULTS AND DISCUSSION

FIG.1 a, b show the AFM phase field image of the surface morphology ZnO/ $\text{La}_{0.4}\text{Gd}_{0.1}\text{Sr}_{0.5}\text{CoO}_3$/LAO. The bright region was hard phase, and the dark region $\text{La}_{0.4}\text{Gd}_{0.1}\text{Sr}_{0.5}\text{CoO}_3$ was structure. The Ginzburg-Landau phase field is used to evolution antiferroelectric domain interface roughness of ZnO/$\text{La}_{0.4}\text{Gd}_{0.1}\text{Sr}_{0.5}\text{CoO}_3$/Si. The LGSCO/ZnO structure was characterized by x-ray diffraction pattern at 220K shown in Fig. 2. Two crystalline phases were identified from the XRD patterns. One was ZnO film crystalline phase of a hexagonal wurtzite. Other was LGSCO crystal phase of
hexagonal perovskite structures (space group: R3c) with no more than 1% Co$_3$O$_4$ as the second phase by grain refinements.

It is known that the charge and orbital ordering transition at Gd half filling ($x$=0.5) is strongly coupled with lattice distortion. The CoO$_6$ is distortion of oxygen octahedral. The LGSCO lattice parameters, Co-O bond length and Co-O-Co bond angle, were adjusted by Gd$^{3+}$ ions size, and dependence on average radio of A (La, Gd) site ion $<$A$>$. The Fig.3(a) image indicated that the La$_{0.4}$Gd$_{0.1}$Sr$_{0.5}$CoO$_3$ (100) and (200) diffraction peaks occurred at $2\theta$=32.8$^0$ and $2\theta$ =47.2$^0$, while the Fig.3(b)ZnO (100) (002) (101) (102) (110) (103) (200) diffraction peak occurred at $2\theta$=31.59$^0$, $2\theta$=34.37$^0$, $2\theta$=36.09$^0$, $2\theta$ =47.3$^0$, $2\theta$ =56.4$^0$, $2\theta$ =62.78$^0$, and $2\theta$ =66.15$^0$. The spectrum peak showed crystal indices of LGSCO. The diffraction peaks of LAO (100), (200) substrate appear at $2\theta$=23$^0$ and $2\theta$=47$^0$. This chart identified LGSCO film in the crystal plane (100) identically matching with the LAO substrate with multi-crystal structure. The XRD of La$_{0.4}$Gd$_{0.1}$Sr$_{0.5}$CoO$_3$ has GdO characteristic diffraction peak at $2\theta$ =28$^0$. The doped Gd goes in to the LGSCO lattice. Because the Gd$^{3+}$ electronic structure is 4f$^7$, Gd$^{3+}$ ion radius is
smaller than La\(^{3+}\) and Sr\(^{2+}\). The Gd\(^{3+}\) has an effect on both structure factor and electronic state balance.

Table 1, structure and properties of La\(_{0.5}\)Sr\(_{0.5}\)CoO\(_3\) and ZnO (\(\mathcal{A}\))

| Ln   | A    | ZnO  | Space group | \(<r_\lambda>\) | \(\sigma(A)\) | Lattice parameter (\(\mathcal{A}\)) |
|------|------|------|-------------|-----------------|--------------|----------------------------------|
| La   | Sr   | R3c  | 1.400       | 0.0016          | 5.4152       |                                  |
| Gd   | Sr   | Pnma | 1.329       | 0.0123          | 5.3746, 7.5601, 5.3723 |          |
| La\(_{0.25}\)Gd\(_{0.25}\)Sr\(_{0.5}\)CoO\(_3\) | R3c   | 1.363  | 0.0081     | 5.3948        |                                  |
| La\(_{0.4}\)Gd\(_{0.1}\)Sr\(_{0.5}\)CoO\(_3\) | Pm3m  | 1.329  | 0.00468    | 3.8402        |                                  |
| ZnO  |      | P63mc | 1.99       | 0.0471         | 3.2511, 5.1993 |                                  |

We listed the weighted average radius given in peak, XRD wavelength, diffraction angle and Table 1.\(^{30}\) The La\(_{0.5}\)Sr\(_{0.5}\)CoO\(_3\) have representative 12 proportional constant \(K\), we calculated the average coordination number of A sited cations, as well as grain size of LaGdSrCoO\(_3\) film using the Scherrer Gd\(_{0.5}\)Sr\(_{0.5}\)CoO\(_3\) representative 9. The structure exhibit equation. The LaGdSrCoO\(_3\) average grain size of the that when A=Sr, the LnACoO\(_3\) structure is rhombohedral (space group: \(R\tilde{3}c\)) until Ln =La. The Sr-site coordination number is 12 when the crystal structure is rhombohedral, and 9 when it is orthorhombic. In the situation of A=Sr, Ln=La, Gd, we could get an satisfactory good fit for the Pnma, Pm3m and \(R\tilde{3}c\) space groups, and we have, furthermore, preferred the space group with higher symmetry as per the normal practice. The rhombohedral and orthorhombic structure illustrate how the CoO\(_6\) octahedra is distorted in the orthorhombic structure, especially in \(R\tilde{3}c\) and Pm3m space group of the La\(_{0.4}\)Gd\(_{0.1}\)Sr\(_{0.5}\)CoO\(_3\). The Co-O bond increase with the variation from La\(_{0.5}\)Sr\(_{0.5}\)CoO\(_3\) to La\(_{0.4}\)Gd\(_{0.1}\)Sr\(_{0.5}\)CoO\(_3\), at the same time the Co-O bond decrease.

The antiferromagnetic spin-ordering accompanied is for the long c phase. To determine critical a charge-order transition with CO phase structure temperature, i.e., Curie temperature \(T_c\) and the exhibited a strong correlated coupling between the charge-ordering temperature \(T_{co}\), we have tested spin and orbital degrees of freedom. The diffraction temperature dependence of resistivity and peak of ZnO/La\(_{0.4}\)Gd\(_{0.1}\)Sr\(_{0.5}\)CoO\(_3\) was matched with magnetization. The resistance decrease with an increase of temperature, \(1.45 \times 10^6\Omega\) for 100K and \(5.81 \times 10^5\Omega\) for 280K, exhibits a LGSCO phase separated behavior(two phase). \(T_c\) is determined \(2\theta = 34^\circ\) for the (002) orientation with the structure of from the R-1/T curve, which measured an IM a hexagonal wurtzite. According to the width of half transition at 128 K. The \(T_c\) goes up to a \(<r_\lambda>\) value of

\(1\). Electronic feature of phase separated state

Figure 4, we showed the temperature dependence of the ZnO/LGSCO junction resistance, and Figure 5 MR of compositions of LGSCO at variation 0.2T, 0.5T. The magnetoresistance mechanism in perovskite cobalt oxides attracted special interested due to its Tc sensitivity and cation-size mismatch applications. The most important message of Fig.2 is that domain boundary and lattice mismatch. The lattice constant shows a discontinuous change at Tco. In another word, the system is transformed into phase separation. Such a paramagnetic state at Tco 200 K is described to the random nucleation of a low temperature phase and subsequent stress-induced growth of the secondary phase. The phase separation is considered stress-induced phase separation which is origin from lattice constant. At Tco 200 K, a b and the short c is for paramagnetic insulator while those ferromagnetic
LGSCO and decease therefore. The resistance of cobaltates also increases with the effects of cation size and mismatch disorder. This result also show the effect of carriers captured at interface. Both La0.4Gd0.1Sr0.5CoO3 and ZnO show the expected metallic behavior, but orthorhombic Gd0.5Sr0.5CoO3 show a slight departure from metallic behavior. While La0.4Gd0.1Sr0.5CoO3 at low temperature is metallic, La0.4Gd0.1Sr0.5CoO3 at high temperature is an insulator.

(2) Magnetic feature of phase separated state

The experiment shows important role of cation size and disorder on both the electric and the magnetic resistance properties. A large lattice mismatch led to resistance of the heterostructure under applied different more defects at interface, and captured more carriers. The lower the temperature, the more carriers will be captured, and the junction resistance is increased. On the other hand, the electrons transport and M-I transition based on double exchange and polarons hopping were due to spin-orbit coupling between localized electrons Co-3d t2g and itinerant electrons O-2p eg in the films. With an increase of temperature above Tco, the sample properties represent the intensity characteristics to the single glass phase and COI insulator, because the charge-orbital ordering transition. With a decrease of temperature below Tc shown as Fig5 (a) behaviour of Log ρ versus T for the LGSCO/ZnO (b) behaviour of ρ/T versus 1/T for the LGSCO/ZnO, the components represent the intensity properties to two phases, ferromagnetic and antiferromagnetic ordering, because long c lattice constant is for spin transition. Such state is described to the strong coupling system between the orbital and lattice degree of freedom via the Jahn-Teller effect. The magnetoresistance is defined as MR=ΔR/R=(RH−RO)/RO where R_H is the resistance of heterojunction with the applied magnetic field, R_O is the resistance without the magnetic field shown in Fig.5c. The temperature was dependence of junction ΔR/R and MR of the heterostructure. We could measure the charge-orbit variation and spin-orbital coupling from junction ΔR/R and MR. Here, we have exhibited lattice constant C for the magnetic feature: short c is for ferromagnetic and antiferromagnetic type, further short c for COI. As well as, we described the long c for ferromagnetic and
We adopted the two rectangular systems, one is local system which the pseudocubic crystal cell, other is globe system with orthogonal axes $x_i$, $x_j$ and $x_k$ in the film plane.

We begin the simulation with small random polarization. The $P_3$ polarization component was built by the magnetic field and voltage resulting from the film/substrate interface. The evolution of phase field of polarization is controlled by the time-dependent Ginzburg-Landau and Cahn-Hilliard free energy equation.

$$\frac{\partial P_i(r,t)}{\partial t} = -L \frac{\partial F}{\partial P_i(r,t)} \quad (i=1,2,3),$$

where $L$ is the kinetic coefficient, and the $L$ is related with domain wall mobility. $F$ is the total free energy.

Moreover, domain structure takes effect on the boundary resistivity of LGSCO film, finally varied the boundary resistivity of LGSCO film, finally varied the magnetic domain structures in LGSCO vary significantly with the doping level. The polarizations within these two doping level variants are related to $71^0$ and $109^0$ domain walls. The domain wall orientations and domain structure strongly influence the paramagnetic insulator properties of LGSCO.

Further, the phase transition of junction from ferromagnetic metal to paramagnetic insulator occurred at Curie temperature $T_c = 127$ K. The maximum value of the positive MR at 0.2 T is 4.86%, at 0.5 T is 6.05% for approximately 140K. There were main factors which influenced the spin orientation of $Co^{3+}$ and $Co^{4+}$. We speculated that the junction resistance was mostly derived from the interface diffusion of ZnO/LGSCO due to the lattice mismatch of the spontaneous polarization process (The number of iterations step $t=3000-5000$) was shown in Fig 6.
domain boundary scattering and capture effect, which were controlled by optical and magnetic perturbations.  

Fig. 6. The domain structure of polycrystalline LGSCO thin film of the spontaneous polarization process (The number of iterations step $t=3000-5000$)

4. CONCLUSIONS

In summary, the presence of FM phase and carrier injection effect mechanism is clearly demonstrated in the ZnO/La$_{0.4}$Gd$_{0.1}$Sr$_{0.5}$CoO$_3$. The ferromagnetic transformation into the phase-separated (two phase) state were observed below $T_c \approx 127$ and have observed the lattice change discontinuously in the doped cobalt perovskites La$_{0.4}$Gd$_{0.1}$Sr$_{0.5}$CoO$_3$. We use Ginzburg-Landau-Devonshire phase-field model to observe the evolution of ferromagnetic and ferroelectric domain structure LGSCO thin film. It was found that the domain structures of thin film were strongly dependent on the combination of force electric coupling. The positive MR effect were observed 4.86% for 0.2 T, 6.05% for 0.5 T in the ZnO/La$_{0.4}$Gd$_{0.1}$Sr$_{0.5}$CoO$_3$/LaAlO heterostructure at approximately 140K. The ZnO/ LGSCO junction exhibited the carrier transfer of MIT transition at different temperatures. The electric-mechanical coupling was introduced by domain anisotropy due to temperature, optical and magnetic perturbations. This inhomogeneous should play a crucial role in the further understanding of charge order, spin-orbital coupling, magnetic order, optical field and lattice structure from the view of energy band in ZnO/ La$_{0.4}$Gd$_{0.1}$Sr$_{0.5}$CoO$_3$/LaAlO and positive CMR effect found in doped cobalt perovskites.

ACKNOWLEDGEMENTS

This work is supported by MOE Key Laboratory for Nonequilibrium of China 2009 (Grant No. 2009, 1001).

REFERENCES

[1] J.B Goodenough, Phy.Rev.100, 564(1955)  
[2] R.Lengsdort, M. Ait-Tahar,S.S.Saxena et al, Phys. Rev. B. 69, 140403, (2004)  
[3] R.Vonhelmolt, J. Wecker, B.Holzapfel, L.Schultz, K. Samwer, Phys.Rev.Lett. 71,2331(1993)  
[4] N. A. Spaldin and M. Fiebig, Science 309, 391 (2005).  
[5] C. Zener, Phys.Rev. 82,403(1951)  
[6] M.M. Savosta, P.Novak,Phys.Rev.Lett.87,137204  
[7] A Machida, T.Watanuki,D.Kawana, Physical Rev. B, 83(5), 054103,(2011).  
[8] S. Jin, T. H. Tiefel, M. McCormack, R. A. Fastnacht, R. Ramesh, and L.H. Chen, Science 264, 413 (1994)  
[9] S Mori, R Shoji, N Yamamoto, T Asaka, Y Matsui, Y Moritomo, Physical Rev. B, 67(1), 012403,(2003).  
[10] Clément Barraud, Pierre Seneor, Richard Mattana, Stéphane Fusil, Karim Bouzehouane, Cyrille Deranlot, Patrizio Graziosi, Luis Hueso, Ilaria Bergenti, Valentin Dediu, Frédéric Petroff1 & Albert Fert1, Nature Physics 6, 615-620(2010)  
[11] T. Botond,C. Ioan-Augustin,N. Zoltan,Central European Journal of Physics,11(4), 487-496
[12] S. H. Baek, H. W. Jang, C. M. Folkman, Y. L. Li, B. Winchester, J. X Zhang, Q. He, Y. H. Chu, C. T. Nelson, M. S. Rzchowski, X. Q. Pan, R Ramesh, L. Q. Chen, and C. B. Eom, Nature Mater. 9, 309 (2010).

[13] W. Luo, F. Shi, F. Wang, J. Magnetism and Magnetic Material, 305, 509 (2006)

[14] J. Wang, J. B. Neaton, H. Zheng, V. Nagarajan, S. B. Ogale, B. Liu, D. Viehland, V. Vaitheyanathan, D. G. Schlom, U. V. Waghmare, N. A. Spaldin, K. M. Rabe, M. Wuttig, and R. Ramesh, Science 299, 1719 (2003)

[15] J. X. Zhang, Y. L. Li, S. Choudhury, L. Q. Chen, Y. H. Chu, F. Zavaliche, M. P. Cruz, R. Ramesh, and Q. X. Jia, J. Appl. Phys. 103, 094111 (2008).

[16] F. Fan, CL Chen, BC Luo, J. Appl. Phys. 109, 073716, (2011)

[17] J. Wu, X. Lou, Y. Wang, and J. Wang, Electrochem. Solid-State Lett. 13, 2 (2010)

[18] JB Goodenough, F Rivadulla, E Winkler, Central Europhysics Letters, 61(4), 527 (2003)

[19] G. Gutierrez and M. J. Yacaman, J. Phys. Chem. B 109, 3813 (2005).

[20] JB Goodenough, RI Dass, International Journal of Inorganic Materials, 2, 3-9 (2000)

[21] C. Mitra, P. Raychaudhuri, K. Dörr, K. H. Muller, L. Schultz, P. M. Oppeneer, and S. Wirth, Phys. Rev. Lett. 90, 017202 (2003)

[22] Mariscal, M. M.; Velazquez-Salazar, J. Jesus; Yacaman, M. J., Crystengcomm, 14, 544-549 (2012)

[23] GC Xiong, B Zhang, SC Wu, ZK Lu, JF Kang, GLian, DS Dai, Solid State Comm. 97, 17 (1996)

[24] W. Yang, Y. Chang, C Huang, Y. Chen, J. Electronic Materials 38(3), 460 (2009)

[25] G. Yuri I, K. Volodymyr V., Central European Journal of Physics, 11(3), 375, (2013)

[26] J. Wu, C. Leighton, Phys. Rev. B 67, 174408 (2003)

[27] M.G. Aleksandra, L. Tomasz, G.K. Katarzyna, Central European Journal of Physics, 11(2), 213, (2013)