UNIVERSITI PUTRA MALAYSIA

EFFECTS OF DIFFERENT SYNTHESIS METHODS ON PHYSICAL PROPERTIES OF La0.85K0.15MnO3

PAN KAI YAP

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MASTER OF SCIENCE
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By

PAN KAI YAP

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science.

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Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of requirements for the degree of Master of Science

EFFECTS OF DIFFERENT SYNTHESIS METHODS ON PHYSICAL PROPERTIES OF $La_{0.85}K_{0.15}MnO_3$

By

PAN KAI YAP

March 2013

Chair : Abdul Halim Shaari, PhD

Faculty : Science

The structure, microstructure, magnetic and electrical properties of $La_{0.85}K_{0.15}MnO_3$ polycrystalline manganites synthesized via three methods: solid state (SS), sol-gel (SG) and co-precipitation (CP) and then sintered with various sintering temperature and synthesized were investigated and reported. XRD patterns of all SS and SG sintered samples showed a pure perovskite phase of hexagonal structure while CP samples that sintered at 1000˚C and 1100˚C showed the appearance of secondary phases. SG samples showed pure phase at the calcination temperature of 700˚C while SS and CP methods showed same structure at 800˚C. SEM micrographs displayed an increase of average grain size with sintering temperature. Nevertheless, formation of melt-like structure grains was occurred at 1100˚C, for all methods. The room temperature magnetization curves of all SS and SG samples showed ferromagnetic ordering behavior. The magnetization was increased with the increasing of average grain sizes. Conversely, CP samples sintered at 1000˚C and 1100˚C showed paramagnetic behavior due to the presence of secondary phases and exhibited less content of potassium. By comparing the magnetization through

synthesized techniques, SS sample had the highest magnetization while CP synthesized sample obtained lowest magnetization. The Curie temperature (T_c) decreased with the increase of sintering temperature. This might associated with the elongation of Mn-O bond length and narrowed of Mn-O-Mn bond angle that had the responsibility in double exchange mechanism. The electrical transport properties at zero field of SS and SG samples showed that the metal-insulator transition temperature (T_p) increased with the increase of sintering temperature. The grain growth promotion and decrease of grain boundaries caused these phenomena because grain connectivity was improved when the sintering temperature was increased. Abnormal electrical curve was observed in CP samples with sintering temperature of 1000˚C and 1100˚C. This might affected by the vaporization of K and the occurrence secondary phases on the structure. By comparing T_c and T_p through synthesized techniques, SS method exhibits highest T_c and T_p while CP sample shows lowest T_c and T_p. This may due to the shortest Mn-O bond length, widest Mn-O-Mn bond angle and largest average grain size that possessed by SS samples. All samples exhibited MR effect at room temperature with the raised of field from 0 to 1T. The lack of DE mechanism in CP samples sintered at 1000˚C and 1100˚C due to the vaporization of potassium content causing low MR effect on that both samples. Pure LKMO system exhibited ferromagnetic-insulator (FI) phase at room temperature.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains.

KESAN TEKNIK-TEKNIK SINTESIS BERLAINAN KE ATAS SIFAT FIZIK $La_{0.85}K_{0.15}MnO_3$

Oleh

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Struktur, mikrostruktur, sifat magnet dan elektrik bagi polihabluran $La_{0.85}K_{0.15}MnO_3$ yang disintesis melalui tiga teknik, iaitu tindak balas keadaaan pepejal (SS), sol-gel (SG) dan ko-pemendakan (CP) dengan suhu pensinteran yang berlainan dikaji dan dilaporkan. Corak XRD bagi semua sampel yang disintesiskan oleh teknik SS dan SG membentuk fasa tulen dengan struktur heksagon manakala fasa campuran telah diperhatikan pada sampel CP dengan suhu pensinteran 1000˚C dan 1100˚C. Teknik SG memperoleh fasa tulen pada suhu pengkalsinan 700˚C manakala teknik SS dan CP memperoleh fasa yang sama pada suhu pengkalsinan 800˚C. Mikrograf SEM memaparkan peningkatkan purata saiz butiran berkadar langung dengan peningkatan suhu pensinteran. Namun, pembentukan butiran yang tanpa sempadan dengan stuktur serupa peleburan telah berlaku bagi semua sampel yang disinter pada suhu 1100˚C. Teknik SG menghasilkan polihablur LKMO yang mempunyai saiz butiran purata terkecil dan skala nano, iaitu sampel SG750 dan SG800. Ini adalah kerana teknik SG memperoleh suhu pengkalsinan dan pensinteran yang terendah jika berbanding dengan ketiga-tiga teknik tersebut. Semua sampel yang disintesiskan

oleh teknik SS dan SG memaparkan sifat ferromagnet. Nilai pemagnetan berkadar lansung dengan peningkatan saiz butiran purata. Sebaliknya, sampel CP yang disinter pada suhu 1000˚C dan 1100˚C mempunyai sifat paramagnet dengan kehadiran fasa campuran dan kekurangan kandungan K. Dengan membandingkan nilai pemagnetan melalui ketiga-tiga teknik tersebut, teknik SS memperoleh nilai pemagnetan yang tertinggi manakala teknik CP memperoleh nilai pemagnetan yang terendah. Penurunan suhu Curie (T_c) berkadar terus dengan peningkatan suhu pensinteran. Fenomena ini berkaitan dengan pemanjangan ikatan Mn-O dan penyempitan sudut Mn-O-Mn yang bertanggungjawab dalam mekanisme pertukaran ganda. Bagi SS dan SG sampel, sifat pengangkutan elektrik dalam medan sifar memaparkan peningkatan suhu peralihan logam-penebat (T_p) dengan peningktan suhu pensinteran. Ini adalah kerana pertumbuhan butiran digalakkan dan pengurangan sempadan butiran semasa suhu pensinteran dinaikkan. Oleh itu, sifat konduksi elektrik butiran ditingkatkan. Lengkungan elektrik yang luar biasa telah diperhatikan pada CP sampel yang disintesis dalam suhu 1000˚C dan 1100˚C. Hal ini mungkin disebabkan oleh pengewapan kandungan K dan kehadiran fasa campuran dalam struktur sampel tersebut. Dengan membandingkan T_c dan T_p melalui ketiga-tiga teknik tersebut, teknik SS memperoleh T_c dan T_p yang tertinggi manakala teknik CP memperoleh T_c dan T_p yang terendah. Ini disebabkan oleh sampel SS mempunyai ikatan Mn-O yang terpendek, sudut Mn-O-Mn dan saiz butiran purata yang terbesar. Semua sampel menunjukkan kesan MR pada suhu bilik dengan peningkatan medan dari 0 kepada 1T. Kekurangan mekanisme petukaran ganda pada sampel yang disintesiskan pada suhu 1000˚C dan 1100˚C (disebabkan kekurangan pengewapan kandungan K pada suhu tersebut) menyebabkan kesan MR yang rendah. Sistem LKMO yang tulen mempamerkan fasa ferromagnet-penebat pada suhu bilik.

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I certify that a Thesis Examination Committee has met on 18 March 2013 to conduct the final examination of Pan Kai Yap on his thesis entitled "Effects of Different Synthesis Methods on Physical Properties of $La_{0.85}K_{0.15}MnO_3$" in accordance with the Universities and Universiti College Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is nor concurrently, submitted for any other degree at Universiti Putra Malaysia or other institutions.

PAN KAI YAP

Date: 18 March 2013

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x	Concentration of dopant	-
K	Potassium	-
T_c	Curie temperature	K
T_p	Metal-insulator transition temperature	K
ºC	Degree Celsius	-
t	Tolerance factor	-
Å	Angstrom	-
a,b,c	Lattice Parameter	-
e_g	Sub-orbital of 3*d* orbital (higher energy level)	-
t_{2g}	Sub-orbital of 3*d* orbital (lower energy level)	-
eV	Energy in electron volt	
T	Temperature	K
R_H, r_H	Electrical resistance in applied field	Ω
R_0, r_0	Electrical resistance in zero field	Ω
B, H	Magnetic field	T
T	Tesla	-
N	Number of turns	-
L	Length	m
I	Current	A
Wb	Weber	-
M	Extent of magnetized of materials under applied magnetic field	Am^2m^{-3}
m	Magnetic moment	Am^2
V	Volume	m^3
χ_m, χ	Magnetic susceptibility	$m^3\ kg^{-1}$
μ_0	permeability in free space	$N\ A^{-2}$
M	Magnetization	$emu\ g^{-1}$
M_s	Magnetization saturation	$emu\ g^{-1}$
M_r	Remanence	$emu\ g^{-1}$
H_c	Coercivity	T
H_{ci}	Intrinsic Coercivity	T
~	Approximately	-

<	Less than	-
>	More than	-
≤	Less than or equal to	-
h	Hour	-
θ	Theta	-
λ	Wavelength	-
V	Potential difference	V
˚	Degree	-
G	Gauss	oe
LKMO	$La_{0.85}K_{0.15}MnO_3$ system	-
DE	Double exchange	-
JT	Jahn-Teller	-
MR	Magnetoresistance	-
CMR	Colossal magnetoresistance	-
LFMR	Low-field magnetoresistance	-
SS	Solid state	-
SG	Sol-gel	-
CP	Co-precipitation	-
SSC800	LKMO synthesized by solid state with calcination temperature of 800˚C	-
SS900	LKMO synthesized by solid state with sintering temperature of 900˚C	-
SS1000	LKMO synthesized by solid state with sintering temperature of 1000˚C	-
SS1100	LKMO synthesized by solid state with sintering temperature of 1100˚C	-
SGC500	LKMO synthesized by sol-gel with calcination temperature of 500˚C	-
SGC600	LKMO synthesized by sol-gel with calcination temperature of 600˚C	-
SGC700	LKMO synthesized by sol-gel with calcination temperature of 700˚C	-
SG750	LKMO synthesized by sol-gel with sintering	-

	temperature of 750˚C	
SG800	LKMO synthesized by sol-gel with sintering temperature of 800˚C	-
SG900	LKMO synthesized by sol-gel with sintering temperature of 900˚C	-
SG1000	LKMO synthesized by sol-gel with sintering temperature of 1000˚C	-
SG1100	LKMO synthesized by sol-gel with sintering temperature of 1000˚C	-
CPC700	LKMO synthesized by co-precipitation with calcination temperature of 700˚C	-
CPC750	LKMO synthesized by co-precipitation with calcination temperature of 750˚C	-
CPC800	LKMO synthesized by co-precipitation with calcination temperature of 800˚C	-
CP900	LKMO synthesized by co-precipitation with sintering temperature of 900˚C	-
CP1000	LKMO synthesized by co-precipitation with sintering temperature of 1000˚C	-
CP1100	LKMO synthesized by co-precipitation with sintering temperature of 1100˚C	-
MRAM	Magnetoresistive random access memory	-
SOFC	Solid oxide fuel cells	-
R, *RE*	Rare earths ions	-
A	Doped cations	-
IMR	Intrinsic magnetoresistance	-
EMR	Extrinsic magnetoresistance	-
XRD	X-ray diffraction	-
FWHM	Full-width half maxima	-
SEM	Scanning Electron Microscope	-
EDAX	Energy Dispersive X-ray Spectroscopy	-
VSM	Vibration Sample Magnetometer	-
DC	Direct current	-

AC	Alternate current	-
ACS	AC susceptometer	-
FM	Ferromagnetic metal	-
FI	Ferromagnetic insulator	-
PI	Paramagnetic insulator	-
CO	Charge ordering	-
CAF	Canted antiferromagnetic	-
FESEM	Field Emission Scanning Electron Microscope	-

CHAPTER 1

INTRODUCTION

1.1 Brief History of Mixed Valence Manganites

Mixed valence manganites are compounds with chemical composition of $RE_{1-x}A_xMnO_3$ where *RE* = rare earth elements such as La, Pr and Nd while *A* = alkali metals or alkali earth metals such as Ca, Sr, and K. The manganese ions exhibited in mixed valence states of Mn^{3+} and Mn^{4+} upon the doping process of *A* into *RE*. These materials were first reported by Jonker and Santen (1950) who found out that the manganites exhibit metallic properties and a transition temperature of ferromagnetic to paramagnetic (T_c) as the finite doping of $LaMnO_3$ by Ca, Ba and Sr. Then in 1951, Clarence Zener, an American scientist, explained this correlation of electrical and magnetic properties by a brand new concept, called "double exchange mechanism". His work was then further studies in theorectical part by Anderson and Hasegawa in 1955. Besides, Volger (1954) found out that $La_{0.8}Sr_{0.2}MnO_3$ has a resistivity drop in ferromagnetic state when external field is applied.

In 1955, Wollan and Koehler study the magnetic structure of $La_{1-x}Ca_xMnO_3$ (x = 0 to 1) by using neutron diffraction techniques. They found out that $LaMnO_3$ exhibited ferromagnetic phase at *ab*-plane and antiferromagnetic at *c*-axis which they defined as A-type antiferromagnetism; while $CaMnO_3$ exhibited a G-type antiferromagnetism. The intermediate doping shows variety type of antiferromagnetism and at x=0.33, the manganites are fully ferromagnetism.

Manganites received a wide attention since 1990's due to the discovery of a very large magnetoresistance in bulk $Nd_{0.5}Pb_{0.5}MnO_3$ (Kusters et al., 1989), $La_{2/3}Ba_{1/3}MnO_3$ thin films (Helmolt et al., 1993) and $La_{3/4}Ca_{1/4}MnO_3$ thin films (Chahara et al., 1993). The latter two have observed large MR at room temperature (-60% and -53%, respectively). In 1994, Jin et al. observed a negative ~1500% MR value at 200K and ~100,000% at 77K for $La_{2/3}Ca_{1/3}MnO_3$. Since that time, this large negative MR is named as colossal magnetoresistance (CMR). However, this CMR values required a high field to appear (6T) so it is not suitable for technology application. Hwang et al. (1996) studied the MR in ferromagnetic phase, and found out the different of MR behavior for single crystal and polycrystalline of $La_{2/3}Sr_{1/3}MnO_3$. He observed high negative MR values occur at low temperature even in low magnetic field (0.1 T) for polycrystalline manganites, due to the effect of spin-polarized electron tunneling between the grains. This property is latter named as extrinsic CMR.

In 21st century, researchers are interested in nano-scale materials including manganites. Manganites in nanoparticles or nanocrystallines exhibit different properties in magnetism, magnetoresistance, Curie temperature and metal-insulator transition temperature with their bulk counterparts. Sol-gel method is a very famous process to prepare nanoscale manganites by lowering the calcination and sintering temperature (Venkataiah et al., 2012).

1.2 Monovalent Doped Manganites

Monovalent cations (Li^+, Na^+, K^+, Cs^+ and Ag^+) are also good candidates for doping with manganites ($LaMnO_3$), and possessed similar trend of electrical and magnetic properties with the manganites that doped with divalent cations. However, the

monovalent elements are only possessing one valence electron. Hence, every x amount of monovalent doping to the trivalent (La) site will create an amount of 2x Mn^{4+} and double up the double exchange mechanism. As a result, a small amount of monovalent doping results in a large number of charge carriers and enhanced the conductivity (Shaikh and Varshney, 2012). Furthermore, the solid solubility of monovalent cations in manganites are very narrow. Coey et al. (1999) stated that the solubility range is up to x =0.2. Besides, Teraoka et al. (2001) found that the solubility limit of potassium ion, K^+ in La-K-Mn-O is lies between x = 0.2 and 0.25 and K_2MnO_4 appeared to be the byproduct beyond the solubility limit. Furthermore, in the investigation of Shen et al. (2009), the XRD results of the $La_{0.8}Sr_{0.2}MnO_3$ gives a single phase while $La_{0.8}K_{0.2}MnO_3$ and $La_{0.8}Na_{0.2}MnO_3$ shows the additional secondary phase which is defined as K_4MnO_4 and Na_4MnO_4 through analysis, respectively. This results indicating that the solid solubility of divalent cations are higher than the monovalent cations and the solubility limit of monovalent cations is lower than x = 0.20.

1.3 Application of Mixed Valence Manganites

The discovery of CMR effect in manganites since 1994 has made this materials become potential to apply in MR type devices such as magnetic recording, data storage technique on computer hard discs and magnetoresistive random access memory (MRAM). This large MR effect produced can increase the data storage densities of hard drive. However, manganites only show CMR effect at low temperature and high applied field, which is contradict with the practical application that need MR near room temperature and low applied field (Jin, 1997). Furthermore, the discovery of extrinsic CMR in polycrystalline manganites may fulfill the

requirement of low field and widen the temperature range of MR effect but the high MR values only produced at low temperature (Hwang et. al., 1996). Currently, many researchers are trying to find the CMR materials that can operate in low field and having high MR values at room temperature.

Manganites are potential candidates for making sensors. In 2002, polycrystalline of $La_{2/3}Sr_{1/3}MnO_3$ thick film has been investigated and the results has shown the feasible use of this material in making low-cost contactless potentiometer (Balcells et. al., 2002) manganites can also be used in making microwaves sensors and bolometric uncooled infrared sensors (Venkatesan et al., 1998).

Lanthanum strontium manganites are suitable to use as the cathode of solid oxide fuel cells (SOFC) due to its high electrical conductivity at higher temperature (Stambouli and Traversa, 2000). The advantages of SOFC include high effiency, long-term stability, environmental friendly and low emissions of NO_x, dust and noise (Joo and Choi, 2008). Manganites can also be employed in the magnetic refrigeration technology due to the exhibition of magnetocaloric effect (Dhahri et al., 2008). Spintronics is the new technology emerged nowadays which utilizes the electronic's spin of electron to carry the information. Manganites doped at x = 1/3, is half-metal ferromagnets. The high spin polarization of conduction electron is potential for spintronics devices (Felser et al., 2007).

1.4 Problem Statement and Objectives

There are several techniques to fabricate perovskite manganites, including solid state reaction, sol-gel and co-precipitation. Solid state is the most common and a traditional way to produce the homogenous ceramic by multiple grindings and extended heat treatment (Rao et al., 1993). Thus, the grain size of powders or polycrystalline samples obtained usually is large (subnano- or micro- range).

Sol-gel and co-precipitation methods have been developed to achieve better mixing of the initial product. The homogenous mixing of cations is attained on the atomic scale in the solution and enhanced the reaction during the heat treatment process (lowering the heat treatment temperature) and results a more homogenous powder (Rao et al, 1993; Hamadneh et al., 2006; Hamadneh et al, 2010). Grain size in nanometer range can achieve.

Therefore, in this project, polycrystalline $La_{0.85}K_{0.15}MnO_3$ was prepared by 3 synthesis method, i.e. solid state reaction, sol-gel and co-precipitation. The duration and rate of change of heat treatment (calcination and sintering) is fixed. The lowest calcination temperature of each synthesis techniques was investigated. The technique with the lowest calcination temperature indicates the lowest sintering temperature it can produce, and exhibits smallest grain size of polycrystalline sample.

In this work, the main objectives are list down as follow:

- To synthesize polycrystalline lanthanum potassium manganites, $La_{0.85}K_{0.15}MnO_3$ via three different methods: solid state reaction, sol-gel and co-precipitation.

- To investigate the effect of different synthesis methods with the difference of initial particles to the structure, microstructure, electrical and magnetic properties of polycrystalline $La_{0.85}K_{0.15}MnO_{3.}$
- To investigate the effect of sintering temperature to the structure, microstructure, electrical and magnetic properties of polycrystalline $La_{0.85}K_{0.15}MnO_{3.}$
- To study the relationship between the electrical and magnetic properties of polycrystalline $La_{0.85}K_{0.15}MnO_{3.}$

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Appendix A
Ratio of Samples

Atomic Mass of Starting Materials

Element	Atomic Mass (g/mol)
La	138.906
K	39.098
Mn	54.938
O	15.999
H	1.008
N	14.007
C	12.001

(i) Solid State (SS)

Standard Equation

$0.425\ La_2O_3 + MnO_2 + 0.075\ K_2CO_3 \rightarrow La_{0.85}K_{0.15}MnO_3$

Materials	Atomic Mass (g/mol)
0.425 La_2O_3	138.469
0.075 K_2CO_3	10.364
MnO_2	86.936
Total	235.769

To form a 15g sample powder, 8.810g of La_2O_3, 0.659g of K_2CO_3 and 5.531g of MnO_2 were needed.

(ii) Sol-gel

Standard Equation

$0.425\ La_2O_3 + MnCO_3 + 0.15\ KNO_3 \rightarrow La_{0.85}K_{0.15}MnO_3$

Materials	Atomic Mass (g/mol)
0.425 La_2O_3	138.469
0.15 KNO3	15.165
$MnCO_3$	114.936
Total	268.570

To form a 15g sample powder, 7.734g of La_2O_3, 0.847g of KNO_3 and 6.419g of $MnCO_3$ were needed.

Calculation of Weight of Citric Acid and Ethylene Gylcol Used

The weight ratio of metal ions (MI), citric acid (CA) and ethylene glycol (EG) used:

MI : CA : EG = 1 : 4 : 2

Molecular weight of MI, CA and EG were 268.57 g/mol, 192.12 g/mol and 62.07 g/mol, respectively. Hence, the mass of CA used was 42.94g and EG used was 6.933 ml.

(iii) Co-precipitation

Standard Equation

$0.85\ La(CH_3COO)_3.1.5H_2O + 0.15\ KNO_3 + Mn(CH_3COO)_2.4H_2O \rightarrow$

$La_{0.85}K_{0.15}MnO_3$

Materials	Atomic Mass (g/mol)
0.85 $La(CH_3COO)_3.1.5H_2O$	291.601 268.632 (without H_2O)
0.15 KNO3	15.165
$Mn(CH_3COO)_2.4H_2O$	245.086 173.026 (without H_2O)
Total	603.312 456.823 (without H_2O)

In the calculation steps of co-precipitation, we need to consider the presence of H_2O in the starting materials. Thus, to prepare 20g of $La_{0.85}K_{0.15}MnO_3$, 12.766g of $La(CH_3COO)_3.1.5H_2O$, 0.664g of KNO_3 and 10.730g of $Mn(CH_3COO)_2.4H_2O$ were needed.

Appendix B

X-ray Diffraction Pattern (XRD) for the standard peak LKMO

Name and formula

Reference code:	98-005-3701
Chemical name:	Lanthanum Potassium Manganese Oxide (0.85/0.15/1/3)
Common name:	Lanthanum Potassium Manganese Oxide (0.85/0.15/1/3)
ICSD name:	Lanthanum Potassium Manganese Oxide (0.85/0.15/1/3)
Chemical formula:	$K_{0.15}La_{0.85}Mn_1O_3$
Second chemical formula:	$(La_{0.85}K_{0.15})\ MnO_3$

Crystallographic parameters

Crystal system:	Hexagonal
Space group:	R -3 c
Space group number:	167
a (?):	5.5040
b (?):	5.5040
c (?):	13.3950
Alpha (°):	90.0000
Beta (°):	90.0000
Gamma (°):	120.0000
Calculated density (g/cm^3):	6.43
Volume of cell (10^6 pm^3):	351.42
Z:	6.00
RIR:	5.65

Subfiles and Quality

Subfiles:	Inorganic ICSD Pattern
Quality:	Calculated (C)

Comments

Structure: NdAlO3
ICSD collection code: 88441
Original ICSD space group: R3-CH
X-ray diffraction (powder)
Structure type : NdAlO3
Rietveld profile refinement applied
The structure has been assigned a PDF number (calculated powder diffraction data): 01-089-8127
Structure type: NdAlO3
Recording date: 7/16/2001
ANX formula: ABX3
Z: 6

Calculated density: 6.43
R value: 0.014
Pearson code: hR10
Wyckoff code: e b a
Publ. title: Low temperature synthesis, structure and magnetic properties of La0.85 (Na1-x Kx)0.15 Mn O3 perovskites: the role of A cation size disparity in the electronic properties of mixed-valence manganates

References

Primary reference: Lloret, F. Beltran, D. Beltran, A. Martinez, E. Sapina, F. Coret, E. El-Fadli, Z., *Journal of Materials Chemistry*, **9**, 1793, (1999)

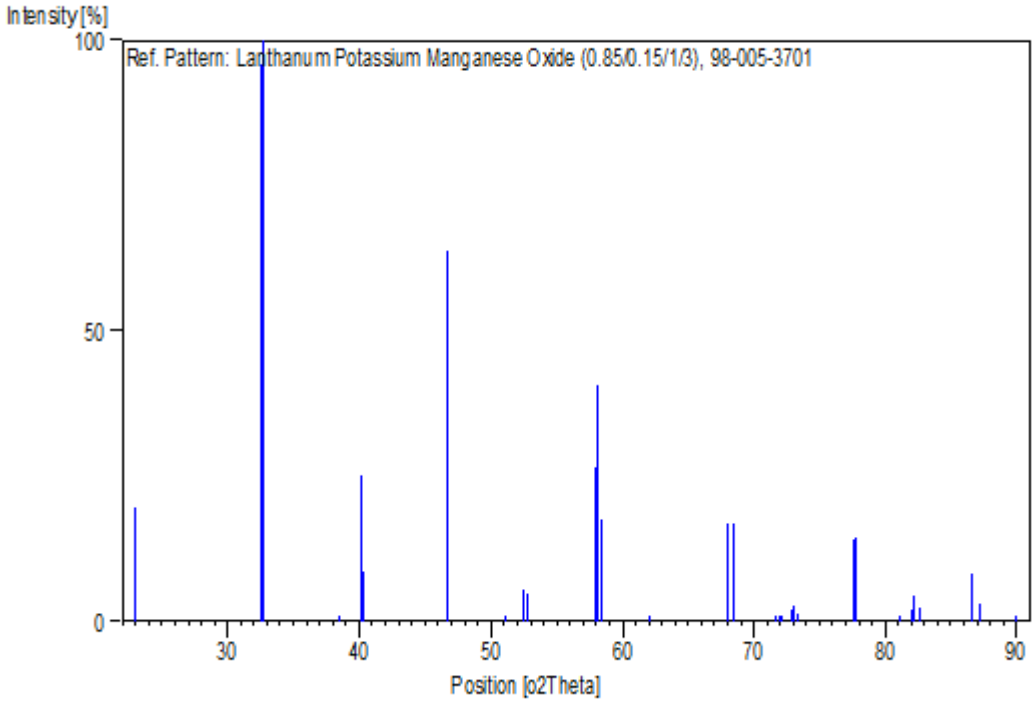
Peak list

No.	h	k	l	d [A]	2Theta[deg]	I [%]
1	0	1	2	3.88349	22.881	19.5
2	1	1	0	2.75200	32.509	95.9
3	1	0	4	2.74012	32.654	100.0
4	1	1	3	2.34275	38.392	1.1
5	2	0	2	2.24537	40.127	25.2
6	0	0	6	2.23250	40.368	8.7
7	0	2	4	1.94175	46.745	64.0
8	2	1	1	1.78553	51.114	0.3
9	1	2	2	1.73976	52.560	5.5
10	1	1	6	1.73375	52.757	4.9
11	0	3	0	1.58887	58.000	26.4
12	2	1	4	1.58657	58.092	40.7
13	0	1	8	1.57975	58.367	17.5
14	1	2	5	1.49500	62.029	0.1
15	2	2	0	1.37600	68.085	17.0
16	2	0	8	1.37006	68.421	17.0
17	1	3	1	1.31563	71.677	0.3
18	2	2	3	1.31497	71.718	0.2
19	2	1	7	1.31173	71.923	0.1
20	1	1	9	1.30914	72.087	0.1
21	3	1	2	1.29699	72.870	2.1
22	0	3	6	1.29450	73.033	2.8
23	1	0	10	1.28955	73.359	1.2
24	1	3	4	1.22966	77.575	14.0
25	1	2	8	1.22648	77.814	14.5
26	3	1	5	1.18553	81.046	0.2
27	0	4	2	1.17323	82.077	2.1
28	2	2	6	1.17138	82.234	4.5
29	0	2	10	1.16771	82.549	2.4
30	4	0	4	1.12269	86.648	8.3
31	0	0	12	1.11625	87.273	2.9
32	3	2	1	1.08991	89.943	0.0

Structure

No.	Name	Elem.	X	Y	Z	Biso	sof	Wyck.
1	O1	O	0.46250	0.00000	0.25000	0.7000	1.0000	18e
2	MN1	Mn	0.00000	0.00000	0.00000	0.3000	1.0000	6b
3	K1	K	0.00000	0.00000	0.25000	0.3000	0.1500	6a
4	LA1	La	0.00000	0.00000	0.25000	0.3000	0.8500	6a

Stick Pattern



Appendix C

EDAX Patterns of all Sintered LKMO