

# Synthesis and Electrochemical Properties of Lithiated Multi-component Oxides

Tatiana Kulova<sup>1</sup>, Alexander Skundin<sup>1</sup>, Oxana Grigrieva<sup>1</sup>, Victor Mukhin<sup>2</sup>, and Sergei Rezvov<sup>2</sup>

<sup>1</sup>Laboratory of Power Sources, Frumkin Institute of Physical Chemistry and Electrochemistry, Russian Academy of Sciences Moscow, 119071, Russia

<sup>2</sup>JSC "NCCP", Novosibirsk, 630110, Russia

## Abstract

A number of lithium cobalt oxide samples doped with Mg and/or Ti with general formula  $\text{LiCo}_{1-x-y}\text{Mg}_x\text{Ti}_y\text{O}_2$  have been synthesized. Their crystal structure was studied by XRD, their chemical composition was determined by atomic absorption spectroscopy and complexometric titration. The average initial discharge capacity amounted to 145 to 150 mAh g<sup>-1</sup>. Degradation rate of non-doped samples was 0.74 mAh g<sup>-1</sup> per cycle. Doping results in decrease of degradation rate, doping effect manifests itself at net dopant content more than 0.02. The degradation rate happens to be the least at  $x+y = 0.03-0.05$ . In this case degradation rate is less than 0.1 mAh g<sup>-1</sup> per cycle, which is 7.5 times less than that for non-doped lithium cobaltite.

**Keywords:** lithium-ion batteries, lithium cobaltite, doping, magnesium, titanium

## 1. Introduction

Lithium-ion batteries (LIB) are the most attractive rechargeable power sources due to their high energy density and specific power [1]. Positive electrodes of commercialized LIB are based on such oxide materials as  $\text{LiCoO}_2$ ,  $\text{LiNiO}_2$ , and  $\text{LiMn}_2\text{O}_4$ .  $\text{LiCoO}_2$  is the most popular material owing to high discharge capacity and good cyclability. In this respect  $\text{LiCoO}_2$  excels both  $\text{LiNiO}_2$  and  $\text{LiMn}_2\text{O}_4$  [1]. At the same time the prolonged cycling of LIB with  $\text{LiCoO}_2$ -based positive electrodes results in gradual diminishing discharge capacity. Meanwhile, the doping  $\text{LiCoO}_2$  with other metals, e.g. Zr, Al, Mg, and Ti is known to lead to improvement of cyclability [2–10]. According to authors [9] small concentrations of dopant ions in the lithium plane can act as pillars that provide extra structural stability to the system, resulting in enhanced cyclability. At the same time authors [5] point to increase of bond lengths of Li–O and Co–O; decrease in the thickness of  $\text{CoO}_2$  slab; and increase in the distance of inter-slab with increasing Mg content in  $\text{LiCo}_{1-x}\text{Mg}_x\text{O}_2$ . Larger inter-slab distance can favour to facilitate the intercalation and deintercalation of lithium ions in the lattice. As a rule, dopant content, i.e.

index  $x$  in the formula  $\text{LiCo}_{1-x}\text{M}_x\text{O}_2$ , where M is doping metal, must be no more than 0.1. For instance, according to [6]  $\text{LiCoO}_2$  doping by aluminum and magnesium results in decrease of discharge capacity up to 125 mAh g<sup>-1</sup> at  $x = 0.2$  and to 100 mAh g<sup>-1</sup> at  $x = 0.4$ . According to [11]  $\text{LiCoO}_2$  doping by rather high amounts of aluminum, specifically  $x = 0.25$  leads to fast degradation upon cycling.

Also the authors [12–14] have reported about positive influence of Mg-doping of a lithium cobalt oxide onto its electrochemical behavior.

The present work is devoted to studying material with general formula  $\text{LiCo}_{1-x-y}\text{Mg}_x\text{Ti}_y\text{O}_2$ , where  $x = 0, 0.007, 0.01, 0.014, 0.02, 0.034, 0.036$  and  $y = 0, 0.009, 0.01, 0.011, 0.017, 0.018, 0.02, 0.026$ .

## 2. Experimental

### 2.1 Synthesis

All samples were synthesized by solid-state method from  $\text{Li}_2(\text{CO}_3)$ , MgO,  $\text{Co}_3\text{O}_4$  and  $\text{TiO}_2$ . Stoichiometric amounts of starting materials were treated in planetary mill for 30 s. Then the mixture was dried and calcined for 3 to 16 hours at the temperature 650–950 °C in air. The samples thus obtained were characterized by X-ray diffraction (XRD) analysis. X-ray diffraction (XRD) patterns of the calcined powders were obtained with an X-ray powder diffractometer DRON-3 (Cu K $\alpha$  radiation). The data were collected with the rate of 0.25 degree/min over the range  $18 < 2\theta < 72^\circ$ . True composition was determined with atomic absorption spectroscopy and complexometric titration.

### 2.2 Electrode preparation

Active mass for electrodes under investigation was prepared via mixing of 85 w/o  $\text{LiCo}_{1-x-y}\text{Mg}_x\text{Ti}_y\text{O}_2$ , 10 w/o acetylene black (Timcal, Belgium) as a conducting additive and 5 w/o polyvinylidene fluoride (PVdF) as a binder. PVdF was used as a solution in N-methyl

pyrrolidone (Aldrich). Such slurry was homogenized at ultrasonic mixer VCX-130 and then it was cast onto both sides of current-collector by the doctor-blade technique. The current-collectors were made from stainless steel mesh with thickness 0.1 mm. The electrodes were dried firstly for 5 h at the temperature 90 °C in air for NMP removal. After that the electrodes were pressed by 500 kg/cm<sup>2</sup> for 30 s and dried at 120 °C under vacuum for 8 h for water traces removal. The active substance load amounted to 40–50 mg at the electrodes sized 15 x 15 mm.

Counter and reference electrodes were made of lithium metal rolled up on the nickel mesh with a welded-on current lead made from nickel foil. All potential values thereafter are referred to this very reference electrode. The electrochemical measurements (registration of galvanostatic charge-discharge curves) were performed in Teflon cells with tightly assembled electrodes. The design of the cells simulated the commercial lithium-ion batteries. Every cell contained one work, two counter and one reference electrodes separated by porous polypropylene film. This film 25 μm-thick (analog of "Celgard", production of the UFIM Co., Russia) was impregnated with electrolyte. The 1 M LiPF<sub>6</sub> in a mixture of ethylene carbonate-diethyl carbonate-dimethyl carbonate (1:1:1) (all components of the electrolyte were qualified as 'extra dry' and were purchased from Aldrich) was used as an electrolyte. The water content in the electrolyte was less than 10 ppm as determined by the Fischer coulometric titration using a 684 KF-Coulometer (Metrohm, Switzerland). The assembling of the cells and their filling with electrolyte was carried out in a glove box with argon atmosphere ("Spectro-systems", Russia). The galvanostatic charge-discharge curves were recorded using a homemade multichannel computerized setup for the potential cycling. The potential range of the cycling was 3.0 to 4.3 V, current density was equal to 20 mA per 1 g of active substance. This value corresponds to 0.18–0.22 mA cm<sup>-2</sup>. Cycling of the electrochemical cells was performed with computerized cycler of Buster Co. (St. Petersburg, Russia).

### 3. Results and discussion

#### 3.1 Structure analysis of LiCo<sub>1-x-y</sub>Mg<sub>x</sub>Ti<sub>y</sub>O<sub>2</sub> (0 ≤ x ≤ 0.36; 0 ≤ y ≤ 0.26).

X-ray diffraction patterns of LiCoO<sub>2</sub> and LiCo<sub>0.968</sub>Mg<sub>0.014</sub>Ti<sub>0.018</sub>O<sub>2</sub> are shown in Fig. 1. All doped samples were shown to contain no impurities, whereas plain LiCoO<sub>2</sub> contained some amounts of Co<sub>3</sub>O<sub>4</sub>. Composition (formula, sum and ratio of stoichiometric coefficients *x* and *y*) and structure parameters (constants of hexagonal lattice, *a*<sub>hex</sub> and *c*<sub>hex</sub>, and ratio of reflex (003)

and reflex (104) intensities) along with electrochemical characteristics (discharge capacity at the first cycle and average capacity fading) of all samples are summarized in the Table 1 and Table 2.

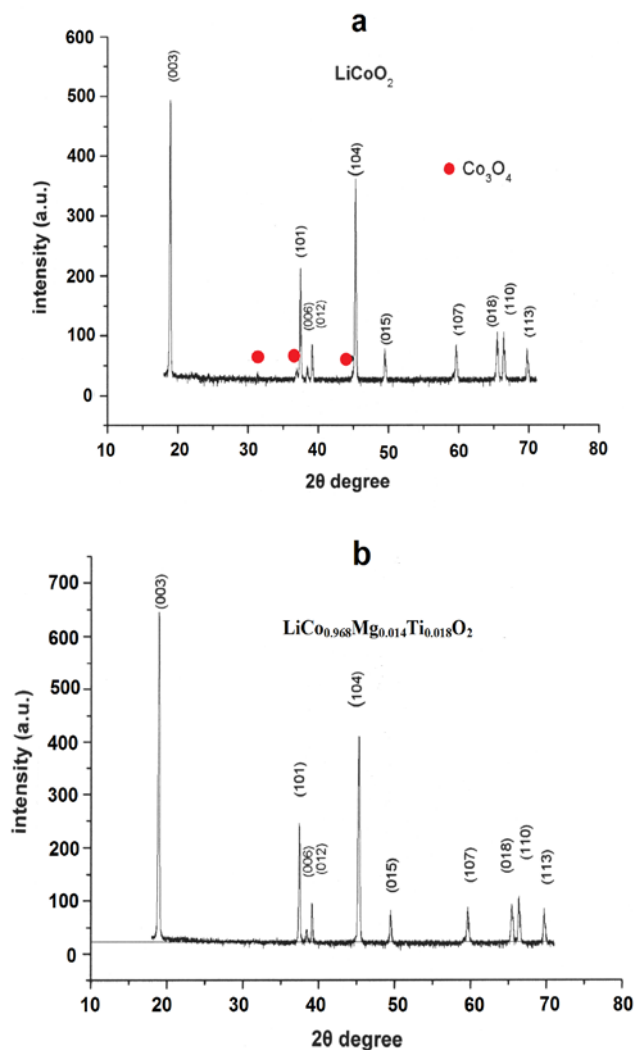


Fig. 1. XRD patterns for LiCoO<sub>2</sub> (a) and LiCo<sub>0.968</sub>Mg<sub>0.014</sub>Ti<sub>0.018</sub>O<sub>2</sub> (b)

According to [5] and [14, 15] substitution of magnesium ions for cobalt ions is accompanied by increase of constants of hexagonal lattice. The results of the present work demonstrate that LiCoO<sub>2</sub> doping by magnesium, titanium or both also results in the increase of the lattice constants. It is considered that ratio *I*<sub>(003)</sub>/*I*<sub>(104)</sub> directly influences on electrochemical behavior of the system. This ratio could be used as some indicator of cation mixing in doped layered systems [16]. As one can see in the Table 1 all doped samples possess higher ratio *I*<sub>(003)</sub>/*I*<sub>(104)</sub> than

plain  $\text{LiCoO}_2$ . This fact points on high cation ordering in doped materials.

Table 1. Composition and structure parameters of the samples studied

Sample $\text{LiCo}_{1-x-y}\text{Mg}_x\text{Ti}_y\text{O}_2$	$a_{\text{hex}}$ , Å	$c_{\text{hex}}$ , Å	c/a	$I_{003}/$ $I_{104}$
$\text{LiCoO}_2$	2.8139	14.052	4.994	1.38
$\text{LiCo}_{0.99}\text{Ti}_{0.01}\text{O}_2$	2.8148	14.054	4.993	1.38
$\text{LiCo}_{0.98}\text{Ti}_{0.02}\text{O}_2$	2.8141	14.051	4.993	1.42
$\text{LiCo}_{0.99}\text{Mg}_{0.01}\text{O}_2$	2.8139	14.055	4.995	1.55
$\text{LiCo}_{0.98}\text{Mg}_{0.02}\text{O}_2$	2.8161	14.056	4.991	1.50
$\text{LiCo}_{0.984}\text{Mg}_{0.007}\text{Ti}_{0.009}\text{O}_2$	2.8153	14.055	4.992	1.44
$\text{LiCo}_{0.982}\text{Mg}_{0.007}\text{Ti}_{0.011}\text{O}_2$	2.8149	14.057	4.994	1.63
$\text{LiCo}_{0.968}\text{Mg}_{0.014}\text{Ti}_{0.018}\text{O}_2$	2.8146	14.053	4.993	1.47
$\text{LiCo}_{0.948}\text{Mg}_{0.034}\text{Ti}_{0.018}\text{O}_2$	2.8153	14.052	4.993	1.43
$\text{LiCo}_{0.946}\text{Mg}_{0.034}\text{Ti}_{0.020}\text{O}_2$	2.8146	14.053	4.993	1.28
$\text{LiCo}_{0.936}\text{Mg}_{0.036}\text{Ti}_{0.026}\text{O}_2$	2.8139	14.043	4.991	1.22

### 3.2. Electrochemical performances of $\text{LiCo}_{1-x-y}\text{Mg}_x\text{Ti}_y\text{O}_2$ ( $0 \leq x \leq 0.36$ ; $0 \leq y \leq 0.26$ ).

The effect of doping on electrochemical performances of  $\text{LiCoO}_2$  is vividly seen in Table 2 and Fig. 2.

Table 2. Composition and electrochemical performances of the samples studied

Sample $\text{LiCo}_{1-x-y}\text{Mg}_x\text{Ti}_y\text{O}_2$	$x + y$	$x/y$	Average fading rate, $\text{mAh g}^{-1}$ per cycle	Initial capacity, $\text{mAh g}^{-1}$
$\text{LiCoO}_2$	0	-	0.74	142
$\text{LiCo}_{0.99}\text{Ti}_{0.01}\text{O}_2$	0.01	-	0.70	143
$\text{LiCo}_{0.98}\text{Ti}_{0.02}\text{O}_2$	0.02	-	0.54	143
$\text{LiCo}_{0.99}\text{Mg}_{0.01}\text{O}_2$	0.01	-	0.50	151
$\text{LiCo}_{0.98}\text{Mg}_{0.02}\text{O}_2$	0.02	-	0.42	150

$\text{LiCo}_{0.984}\text{Mg}_{0.007}\text{Ti}_{0.009}\text{O}_2$	0.016	0.78	0.16	148
$\text{LiCo}_{0.982}\text{Mg}_{0.007}\text{Ti}_{0.011}\text{O}_2$	0.018	0.64	0.13	147
$\text{LiCo}_{0.968}\text{Mg}_{0.014}\text{Ti}_{0.018}\text{O}_2$	0.032	0.78	0.10	146
$\text{LiCo}_{0.948}\text{Mg}_{0.034}\text{Ti}_{0.018}\text{O}_2$	0.052	1.89	0.10	140
$\text{LiCo}_{0.946}\text{Mg}_{0.034}\text{Ti}_{0.020}\text{O}_2$	0.054	1.70	0.10	140
$\text{LiCo}_{0.936}\text{Mg}_{0.036}\text{Ti}_{0.026}\text{O}_2$	0.062	1.90	0.24	131

The Figure compares charge and discharge curves for plain and doped  $\text{LiCoO}_2$ . The effect of doping violently manifests in the course of cycling. Charge-discharge curves of the first cycle for non-doped and doped samples barely differ.

Discharge capacity in this case is equal to  $142 \text{ mAh g}^{-1}$  and mean discharge potential is close to 3.95 V. After 80 charge-discharge cycles discharge capacity of non-doped sample lowered to  $83 \text{ mAh g}^{-1}$  whereas that for doped sample ( $\text{LiCo}_{0.968}\text{Mg}_{0.014}\text{Ti}_{0.018}\text{O}_2$ ) is equal to  $136.6 \text{ mAh g}^{-1}$ . Mean discharge potential for these samples is equal to 3.62 and 3.88 V, correspondingly.

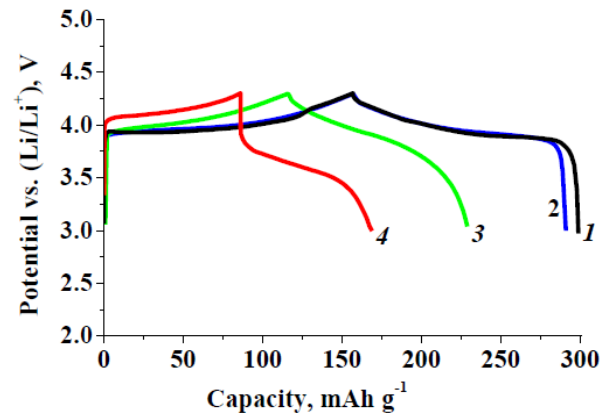


Fig. 2. Charge and discharge curves for electrodes from  $\text{LiCo}_{0.968}\text{Mg}_{0.014}\text{Ti}_{0.018}\text{O}_2$  (curves 1, 3) and plain  $\text{LiCoO}_2$  (curves 2, 4) for the 1st (curves 1, 2) and 100<sup>th</sup> (curves 3, 4) cycles.

Capacity diminishing upon cycling electrode with non-doped  $\text{LiCoO}_2$  was  $0.74 \text{ mAh g}^{-1}$  per cycle.  $\text{LiCoO}_2$  doping with small amounts of titanium (sample  $\text{LiCo}_{0.99}\text{Ti}_{0.01}\text{O}_2$ ) seems to have no impact on initial discharge capacity as well as on capacity fading. Increase

of titanium content up to  $y = 0.02$  (sample  $\text{LiCo}_{0.98}\text{Ti}_{0.02}\text{O}_2$ ) allowed to decrease degradation rate up to  $0.54 \text{ mAh g}^{-1}$  per cycle without change in initial capacity. Doping of  $\text{LiCoO}_2$  by magnesium improved both initial capacity and cycling stability. The initial discharge capacity of the  $\text{LiCo}_{0.99}\text{Mg}_{0.01}\text{O}_2$  and  $\text{LiCo}_{0.98}\text{Mg}_{0.02}\text{O}_2$  amounted to  $150\text{--}151 \text{ mAh g}^{-1}$ , and capacity fading was equal to  $0.50$  and  $0.42 \text{ mAh g}^{-1}$  per cycle, correspondingly. Samples doped with both Mg and Ti could be divided into four groups. The first group includes low-doped samples  $\text{LiCo}_{0.984}\text{Mg}_{0.007}\text{Ti}_{0.009}\text{O}_2$  and  $\text{LiCo}_{0.982}\text{Mg}_{0.007}\text{Ti}_{0.011}\text{O}_2$ . In this case a sum  $x + y$  was equal to  $0.016$  and  $0.018$ , and ratio  $x/y = 0.78$  and  $0.64$ . The second group consists of samples  $\text{LiCo}_{0.968}\text{Mg}_{0.014}\text{Ti}_{0.018}\text{O}_2$  ( $x + y = 0.032$  and  $x/y = 0.78$ ). The third group contains samples  $\text{LiCo}_{0.948}\text{Mg}_{0.034}\text{Ti}_{0.018}\text{O}_2$ ,  $\text{LiCo}_{0.946}\text{Mg}_{0.034}\text{Ti}_{0.020}\text{O}_2$ , and  $\text{LiCo}_{0.949}\text{Mg}_{0.036}\text{Ti}_{0.017}\text{O}_2$ . For this group  $x + y$  lies in the range  $0.052\text{--}0.054$  and  $x/y$  in the range  $1.70\text{--}1.89$ . And finally, samples  $\text{LiCo}_{0.936}\text{Mg}_{0.036}\text{Ti}_{0.026}\text{O}_2$  ( $x + y = 0.062$  and  $x/y = 1.38$ ) present the fourth group.

Capacity fading for the samples of the first group amounted from  $0.13$  to  $0.16 \text{ mAh g}^{-1}$  per cycle. Doubling of magnesium and titanium content with invariant ratio  $x/y$  (the second group) led to decrease capacity fading. Samples of the third group had unexpectedly modest initial discharge capacity, specifically  $140 \text{ mAh g}^{-1}$  however their degradation upon cycling was rather slow ( $0.099\text{--}0.10 \text{ mAh g}^{-1}$  per cycle). The following increase of doping level (samples of the fourth group) resulted in worsening electrode performances, namely decrease of initial capacity and increase of degradation upon cycling.

The effect of doping on degradation of cobaltite-based electrodes is shown also in Fig. 3. This Figure depicts a cycling history of electrodes with plain  $\text{LiCoO}_2$  and electrodes with doped samples  $\text{LiCo}_{0.98}\text{Mg}_{0.02}\text{O}_2$ ,  $\text{LiCo}_{0.98}\text{Ti}_{0.02}\text{O}_2$ , and  $\text{LiCo}_{0.968}\text{Mg}_{0.014}\text{Ti}_{0.018}\text{O}_2$ . It is clear that effect of doping tells mainly upon degradation rate.

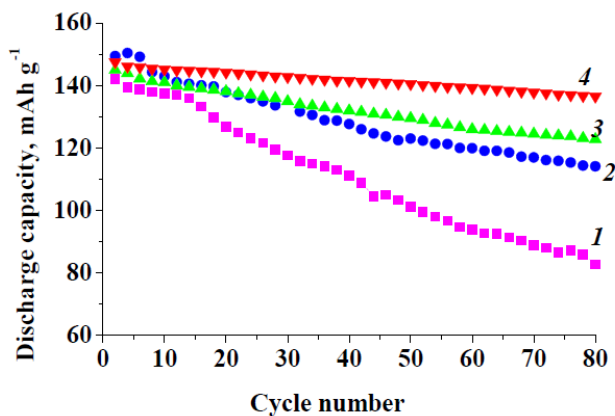


Fig. 3. Discharge capacity diminution upon cycling for electrodes with plain  $\text{LiCoO}_2$  (curve 1) and for electrodes with  $\text{LiCoO}_2$  doped by

magnesium (sample  $\text{LiCo}_{0.98}\text{Mg}_{0.02}\text{O}_2$ , curve 2), titanium (sample  $\text{LiCo}_{0.98}\text{Ti}_{0.02}\text{O}_2$ , curve 3), and both (sample  $\text{LiCo}_{0.968}\text{Mg}_{0.014}\text{Ti}_{0.018}\text{O}_2$ , curve 4).

Fig. 4 depicts degradation rate vs. doping level ( $x + y$ ).

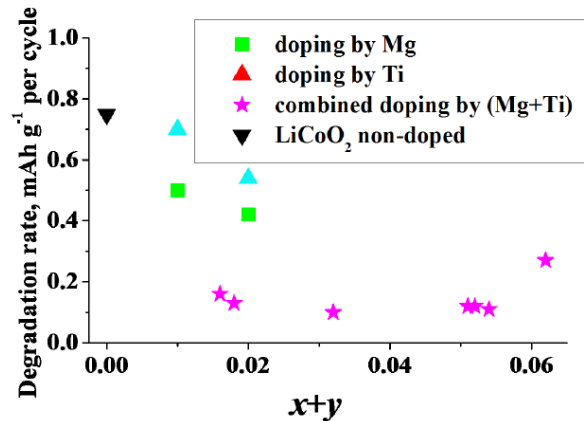


Fig.4. Capacity fading vs. doping level ( $x + y$ )

One can see that the doping effect becomes noticeable at total dopant content about  $0.02$ . As a whole, the dependence of degradation rate on doping level passes through minimum at  $x + y \approx 0.03\text{--}0.05$ .

## 4. Conclusions

A number of  $\text{LiCoO}_2$  samples doped with magnesium and/or titanium was synthesized by solid-state method from  $\text{Li}_2(\text{CO}_3)$ ,  $\text{MgO}$ ,  $\text{Co}_3\text{O}_4$  and  $\text{TiO}_2$ . Such a doping was shown to result in some increase of lattice parameters. The main effect of the doping consists in notable decrease in capacity fading upon cycling. The degradation rate of electrodes made from non-doped  $\text{LiCoO}_2$  amounts to  $0.74 \text{ mAh g}^{-1}$  per cycle, whereas that for doped samples  $\text{LiCo}_{1-x-y}\text{Mg}_x\text{Ti}_y\text{O}_2$  with  $(x + y) \approx 0.03\text{--}0.05$  is as low as  $0.10 \text{ mAh g}^{-1}$  per cycle.

## Acknowledgments

Researches were carried out with the financial support of the state represented by the Ministry of Education and Science of the Russian Federation. Agreement no. 14.604.21.0126. 26 Aug. 2014. Unique project Identifier: RFMEFI60414X0126.

## References

- [1] V.S. Bagotsky, A.M. Skundin, Yu.M. Volkovich. Electrochemical Power Sources: Batteries, Fuel Cells, and Supercapacitors. Wiley, 2015, ISBN: 978-1-118-46023-8, 400 pages.

- [2] C. Julien, G.A. Nazir, A. Rougier, "Electrochemical performances of layered  $\text{LiM}_{1-y}\text{M}_y\text{O}_2$  (M=Ni, Co; M'=Mg, Al, B) oxides in lithium batteries", *Solid State Ionics*, Vol.135, 2000, pp. 121-130.
- [3] T.-S.Kim, T.-K. Ko, B.-K. Na, W.I. Cho, B.W. Chao, "Electrochemical properties of  $\text{LiM}_x\text{Co}_{1-x}\text{O}_2$  [M = Mg, Zr] prepared by sol-gel process", *J. Power Sources*, Vol.138, 2004, pp. 232-239.
- [4] H. Tukamoto, A.R. West, "Electronic Conductivity of  $\text{LiCoO}_2$  and Its Enhancement by Magnesium Doping", *J. Electrochem. Soc.*, Vol. 144, 1997, pp. 3164-3168.
- [5] H.-J. Kim, Y.-U. Jeong, J.-H. Lee, J.-J. Kim, "Crystal structures, electrical conductivities and electrochemical properties of  $\text{LiCo}_{1-x}\text{Mg}_x\text{O}_2$  ( $0 \leq x \leq 0.11$ )", *J. Power Sources*, Vol. 159, 2006, pp. 233-236.
- [6] Elumalai P., Vasani H.N., N. Munichandraiah, "Microwave synthesis and electrochemical properties of  $\text{LiCo}_{1-x}\text{M}_x\text{O}_2$  (M = Al and Mg) cathodes for Li-ion rechargeable batteries", *J. Power Sources*, Vol. 125, 2004, pp. 77-84.
- [7] S. Frangini, S. Scaccia, M. Carewska, "A voltammetric study concerning the structural stability of Li-overstoichiometric Mg-doped  $\text{LiCoO}_2$  powders", *Electrochimica Acta*, Vol. 48, 2003, pp. 3473-3479.
- [8] M. Mladenov, R. Stoyanova, E. Zhecheva, S. Vassilev, "Effect of Mg doping and MgO-surface modification on the cycling stability of  $\text{LiCoO}_2$  electrodes", *Electrochemistry Communications*, Vol. 3, 2001, pp. 410-416.
- [9] G.T.K. Fey, J.G. Chen, V. Subramanian, "Electroanalytical and thermal stability studies of multi-doped lithium nickel cobalt oxides", *J. Power Sources*, Vol. 119-121, 2003, pp. 658-663.
- [10] S. Shi, C. Ouyang, M. Lei, W. Tang, "Effect of Mg-doping on the structural and electronic properties of  $\text{LiCoO}_2$ : A first-principles investigation", *J. of Power Sources*, Vol. 171, 2007, pp. 908-912.
- [11] W.-S.Yoon, K.-K.Lee, K.-B. Kim, "Synthesis of  $\text{LiAl}_y\text{Co}_{1-y}\text{O}_2$  using acrylic acid and its electrochemical properties for Li rechargeable batteries", *J. Power Sources*, Vol. 97-98, 2001, pp. 303-307.
- [12] J. Shim, J. Lee, S. Y. Han, S. Lee, "Synergistic effects of coating and doping for lithium ion battery cathode materials: synthesis and characterization of lithium titanate-coated  $\text{LiCoO}_2$  with Mg doping", *Electrochimica Acta*, Vol. 186, 2015, pp. 201-208.
- [13] X. Zhu, K. Shang, X. Jiang, X. Ai, H. Yang, Y. Cao, "Enhanced electrochemical performance of Mg-doped  $\text{LiCoO}_2$  synthesized by a polymer-pyrolysis method", *Ceramics International*, Vol. 40, Issue 7, Part B, pp. 11245-11249.
- [14] S. Levasseur, M. Menetrier, C. Delmas, "On the Dual Effect of Mg Doping in  $\text{LiCoO}_2$  and  $\text{Li}_{1+\delta}\text{CoO}_2$ : Structural, Electronic Properties, and  $^7\text{Li}$  MAS NMR Studies", *Chem. Mater*, Vol. 14, 2002, pp. 3584-3590.
- [15] M.V. Reddy, T.W. Jie, C.J. Jafta, K.I. Ozoemena, M.K. Mathe, A.S. Nair, S.S. Peng, M.S. Idris, G. Balakrishna, F.I. Ezema, B.V.R. Chowdari, "Studies on Bare and Mg-doped  $\text{LiCoO}_2$  as a cathode material for Lithium ion Batteries", *Electrochimica Acta*, Vol. 128, 2014, pp. 192-197.
- [16] Y. Gao, M.V. Yakovleva, W.B. Ebner, "Novel  $\text{LiNi}_{1-x}\text{Ti}_{x/2}\text{Mg}_{x/2}\text{O}_2$  Compounds as Cathode Materials for Safer Lithium-Ion Batteries", *Electrochem. Solid State Lett.*, Vol. 1, 1998, pp. 117-119.

**First Author** 1996 - Ph.D. (Chemistry), 2011 - Doctor of Chemical Sciences. 1986 - Engineer-electrochemist, 1991 - Researcher, 2003 - Senior researcher, 2011 - present time - Head of Laboratory of Power Sources of Frumkin Institute of Physical Chemistry and Electrochemistry, Russian Academy of Sciences, Moscow. Membership: A member of The International Society of Electrochemistry. Subject of research work: The investigation of catalysts for fuel cells, electrocatalysis in thionyl chloride cells, processes of lithium and sodium intercalation, nanostructures in electrochemistry. Publications: About 200 publications including about 160 papers in reputed Russian and International Journals and 15 patent applications.

**Second Author** 1967 - Ph.D. (Chemistry), 1986 - Doctor of Chemical Sciences. 2010 – Professor. Membership: A member of The International Society of Electrochemistry. Awards: 1995 - The premium of Government of Russian Federation for the development of the electrochemical methods of detoxification for medicinal application. Subject of research work: The kinetics of electrochemical processes in melts, the main processes in hydrogen-oxygen fuel cells, electrocatalysis of simple electrochemical processes, electrosynthesis of organic substances, size effects in electrochemistry, binary systems in electrocatalysis, structural factors in electrocatalysis, processes of lithium intercalation, nanostructures in electrochemistry. Publications: About 375 publications including about 285 papers in reputed Russian and International Journals and about 35 patent applications.