Along with the development of the economy, the energy consumption issue and environmental protection have become the theme of the world. With this problem, the superlight materials have attracted much attention. Magnesium–lithium alloys are considered to be the most promising new energy materials, which have drawn more and more attention by the industry of aerospace and micro-electronic because of the advantages of the low density, high specific strength, good machinability, damping ability and high energetic particle penetration resistance. Nevertheless, the widespread use of magnesium–lithium alloys is limited by the poor mechanical properties of alloy, especially the hardness.

The definition of the whisker was given by Cevans et al., the crystal structure of the whisker is single-crystal structure, the ratio of the length to diameter is between 5 and 1000. The diameter of whisker is falling in 20 to 100 nanometer. Many researchers have adopted the whiskers to improve the mechanical properties of magnesium–lithium alloys. On account of the binding force between the whisker and the magnesium–lithium alloys substrate is limited by the adsorptive whisker, the mechanical properties of the magnesium–lithium alloys are not likely to see a great promotion. In our prior work, for the extraction of europium and formation of Al–Li–Eu alloy, most of needle-like precipitates can be formed in aluminum substrate. The needle-like precipitates grow through several grains and across grain boundaries. Such long needle-like precipitates should act as pins to increase the boundary strength and improve the properties of alloy. Therefore, the thought of whether the mechanical properties of the magnesium–lithium alloys can be improved by the formation of Al–RE intermetallic compound whiskers in magnesium–lithium alloys substrate is of crucial importance.

The traditional method of preparation magnesium–lithium based alloy is directly mixing and fusing the metallic element. However, many shortcomings exist in the production process: a complex alloy is directly mixing and fusing the metallic element. Nevertheless, the widespread use of electronic because of the advantages of the low density, high specific properties.

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liquid magnesium electrode. The micro hardness of Mg–Li–Al–La alloy with and without whiskers was characterized by Leitz micro hardness tester.

Experimental

Preparation and purification of the melts.— The electrolyte was composed of LiCl and KCl. In order to remove excess water of the electrolyte, the LiCl–KCl mixture (LiCl:KCl = 50:50 (wt%), analytical grade) was dried under vacuum condition for more than 48 h at 523 K before it was added into an alumina crucible placed in a quartz cell located in an electric furnace. The temperature of the melts was measured by the nickel–chromium thermocouple which was sheathed by an alumina tube. To remove the impurity of the molten salts, the molten salts were carefully purified by pre-electrolysis for 4 h. Lanthanum, aluminium and magnesium elements were introduced into bath in the form of dehydrated LaCl₃, AlCl₃ and MgCl₂ powder, respectively.

Electrochemical apparatus and electrodes.— All of the electrochemical measurements were performed by Autolab electrochemical work station (Zahner Co., Ltd.). The reference electrode was an Ag/AgCl electrode which composed by a Pyrex tube containing a solution of AgCl (1 wt%) in LiCl–KCl (50:50 wt%) melts. All of the potentials were referred to this Ag/AgCl couple. The counter electrode was a spectral pure graphite rod of 6 mm diameter. The tungsten wire electrode which composed by a Pyrex tube containing a solution of electrolyte, the LiCl–KCl mixture (LiCl:KCl = 50:50 wt%) melts, were carefully purified by pre-electrolysis for 4 h. Lanthanum, aluminium and magnesium elements were introduced into bath in the form of dehydrated LaCl₃, AlCl₃ and MgCl₂ powder, respectively.

Auxiliary techniques.— The preparation of Mg–Li–Al–La alloy (containing whiskers) was carried out via galvanostatic electrolysis in LiCl–KCl melts at 1023 K after the addition of LaCl₃ and AlCl₃ on liquid magnesium electrode. The deposits were analyzed by XRD (XPERT Pro; Philips Co., Ltd.) using Cu Kα radiation at 40 kV and 40 mA. Scanning electron microscopy (SEM) (JSM–6480A; JEOL Co., Ltd.) with energy dispersive spectrometer (EDS) was used to observe the microstructure and micro–zone chemical analysis of the alloys. Transmission electron microscope (TEM) (JEOL, JEM–2010) with electron diffraction was employed to investigate the crystal structure of whisker. The TEM sample preparation steps were as follows: the samples with thickness of about 0.4 mm were made by line cutting, and then were abraded and polished to about 50 um thickness with 200#, 400# and 1500# SiC paper. After that, the sample was made into circular sheet which diameter was 3 mm, and was thinned with Precision Ion Polishing System (Gatan691). The Leitz micro hardness tester with the conditions of the loading force 50 N and holding pressure time 15 s was used to measure the micro hardness of the alloy.

Results and Discussion

Cyclic voltammetry.— The cyclic voltammetry was adopted to investigate the electrochemical behavior of La(III) in chloride melts. Fig. 1 illustrates the cyclic voltammograms obtained on a tungsten electrode at 1023 K in different molten salt systems. Only one pair of cathode/anode signals A/A’ (curve 1 in Fig. 1) which correspond to the formation and dissolution of metal Li in blank LiCl–KCl melts on liquid magnesium electrode. The deposits were analyzed by X-ray diffraction (Pert Pro; Philips Co., Ltd.) using Cu Kα radiation at 40 kV and 0.322 cm² at 1023 K in different molten salt systems, curve 1: LiCl–KCl melts, curve 2: LiCl–KCl–MgCl₂ (1 wt%) melts, curve 3: LiCl–KCl–MgCl₂ (1 wt%)-AlCl₃ (1 wt%) melts. Scan rate: 0.1 V s⁻¹. The weak signal F at around −0.90 V or D appears, and the corresponding oxidation signal C’ is detected at around −0.67 V is possibly ascribed to the formation of an Al–W alloy. The oxidation signal F’ belongs to the dissolution of an Al–W alloy. The similar phenomenon occurs in the process of the electrochemical extraction of europium and ytterbium. When the potential reaches to −0.75 V, the reduction signal C appears, and the corresponding oxidation signal C’ is detected at around −0.61 V. At this point, the oxidation signal D’ does not appear. When the scanning range of cyclic voltammogram is switched from 0 V to −1.1 V. The oxidation signal D’ is detected. Therefore, the redox signals C/C’ are related to the formation and dissolution of metal aluminium, and the oxidation signal D’ corresponds to the dissolution of an Al–Mg alloy.

Fig. 1 shows the cyclic voltammogram obtained on a tungsten electrode in LiCl–KCl–MgCl₂ melts after the addition of AlCl₃ (1 wt%) at 1023 K. Except for the signals A/A’ and B/B’, a new pair of electrode–signals C/C’ at around −0.90 V or 0.58 V are detected. The electro–signal C in negative–going scan is ascribed to the reduction of Al(III) and the corresponding oxidation signal C’ is interpreted as the dissolution of metal aluminium, respectively. The reduction signal D appears or not. Therefore, the underpotential deposition can be occurred under our experiment condition.

To investigate the corresponding relationship of C and C’ or D’, the different scanning ranges of cyclic voltammograms were obtained on a tungsten electrode at 1023 K in LiCl–KCl–MgCl₂ (1 wt%)-AlCl₃ (1 wt%) melts (Fig. 2). Curve 1 illustrates the cyclic voltammogram obtained on a tungsten electrode in LiCl–KCl–MgCl₂ melts after the addition of AlCl₃ (1 wt%) at 1023 K. Except for the signals A/A’ and B/B’, a new pair of electrode–signals C/C’ at around −0.90 V or 0.58 V are detected. The electro–signal C in negative–going scan is ascribed to the reduction of Al(III) and the corresponding oxidation signal C’ is interpreted as the dissolution of metal aluminium, respectively. Apart from these redox signals, a new oxidation signal D appears and the corresponding oxidation signal C’ is detected at around −0.61 V. At this point, the oxidation signal D’ does not appear. When the scanning range of cyclic voltammogram is switched from 0 V to −1.1 V. The oxidation signal D’ is detected. Therefore, the redox signals C/C’ are related to the formation and dissolution of the metal magnesium, and the oxidation signal D’ corresponds to the dissolution of an Al–Mg alloy.

Fig. 3 shows the cyclic voltammogram obtained in LiCl–KCl–MgCl₂ (1 wt%)-AlCl₃ (1 wt%) melts after the addition of LaCl₃ (3 wt%) on a tungsten electrode at 1023 K. The same as the cyclic voltammogram obtained in LiCl–KCl–MgCl₂ (1 wt%)-AlCl₃ (1 wt%) molten salts system, the redox signals A/A’, B/B’ and C/C’ are also obtained. The reduction signals A, B and C in cathodic direction are ascribed to the formation of the metals Li, Mg and Al, respectively.
respectively. And the corresponding oxidation signals $A'$, $B'$ and $C'$ in reverse direction are related to the dissolution of the metals Li, Mg and Al, respectively. Apart from the three pairs of electrochemical signals, a new pair of redox signals $G'$/$G$ is obtained. The reduction signal $G'$, which is detected at around $-1.37$ V, may be ascribed to the formation of an Al-La intermetallic compound. And the corresponding oxidation signal $G$, which is detected at around $-1.22$ V, is related to the dissolution of an Al-La intermetallic compound. Meanwhile, in the anode direction, an oxidation signal $E'$ detected at about $-1.42$ V, between the oxidation signals $B'$ and $G'$, is probably caused by the dissolution of another kind of Al-La intermetallic compound. Nevertheless, the corresponding reduction signal $E$ is not detected. The reasons for this phenomenon may be as follows: the reduction potential of signal $E$ is very close to the reduction potential of the magnesium ions. Consequently, the signal $E$ is covered by signal $B$. It is easy to find signal $G$ in Fig. 3 is too wide. Therefore, another possibility is that the signal $E$ is covered by signal $G$. It is worth noticing that the redox signals of the Mg-La intermetallic compound are not observed between the reduction/oxidation signals $A'$/$A'$ and $B$/$B'$. This interesting phenomenon can be explained by the electronegativity difference, which can be used to predict the formation of the intermetallic compound, between the two kinds of different elements. With the electronegativity difference increasing between the two elements, the formation of intermetallic compound will be easier. Therefore, the Al-La intermetallic compound will be formed under this experiment condition when the electronegativity difference between aluminum and lanthanum is larger than that between magnesium and lanthanum.

Some voltammetric data were also employed to illustrate the Al-La alloy formation directly. Fig. 4a shows the typical cyclic voltammograms obtained on a tungsten electrode ($S = 0.322$ cm$^2$) at 1023 K in different molten salt systems. Two pairs of cathode/anode signals $A'$/$A'$ and $H/H'$ (curve 1 in Fig. 4a) which correspond to the formation and dissolution of metal Li and La in LiCl−KCl−LaCl$_3$ (3 wt%) melts on a tungsten electrode. Curve 2 exhibits the cyclic voltammogram obtained in LiCl−KCl−LaCl$_3$−MgCl$_2$ melts on a tungsten electrode, and Fig. 4b shows the partial enlarged view of curve 2. The different scanning ranges of cyclic voltammograms obtained on a tungsten electrode ($S = 0.322$ cm$^2$) at 1023 K in different molten salt systems (a) curve 1: LiCl−KCl−LaCl$_3$ (3 wt%) melts, curve 2: LiCl−KCl−LaCl$_3$ (3 wt%)-MgCl$_2$ (1 wt%) melts, curve 3: LiCl−KCl−LaCl$_3$ (3 wt%)-MgCl$_2$ (1 wt%)-AlCl$_3$ (1 wt%) melts (b) the partial enlarged view of curve 2. Scan rate: 0.1 V·s$^{-1}$. 

![Figure 2. The different scanning ranges of cyclic voltammograms obtained on a tungsten electrode ($S = 0.322$ cm$^2$) at 1023 K in LiCl−KCl−MgCl$_2$ (1 wt%)-AlCl$_3$ (1 wt%)-LaCl$_3$ (3 wt%) melts. Scan rate: 0.1 V·s$^{-1}$.

![Figure 3. The typical cyclic voltammogram obtained on a tungsten electrode ($S = 0.322$ cm$^2$) at 1023 K in LiCl−KCl−MgCl$_2$ (1 wt%)-AlCl$_3$ (1 wt%)-LaCl$_3$ (3 wt%) melts. Scan rate: 0.1 V·s$^{-1}$.

![Figure 4. The typical cyclic voltammograms obtained on a tungsten electrode ($S = 0.322$ cm$^2$) at 1023 K in different molten salt systems (a) curve 1: LiCl−KCl−LaCl$_3$ (3 wt%) melts, curve 2: LiCl−KCl−LaCl$_3$ (3 wt%)-MgCl$_2$ (1 wt%) melts, curve 3: LiCl−KCl−LaCl$_3$ (3 wt%)-MgCl$_2$ (1 wt%)-AlCl$_3$ (1 wt%) melts (b) the partial enlarged view of curve 2. Scan rate: 0.1 V·s$^{-1}$.](image-url)
Therefore, the peak potential of signal B from curve 2 is larger than that in curve 1. This phenomenon may be caused by the reason that the numbers of free ions in the electrolyte system increase after the addition of LaCl₃ and the conductivity of the electrolyte enhances.

**Open circuit chronopotentiometry.**— Open circuit chronopotentiometry, as an appropriate electrochemical technique to probe mechanism of the formation and dissolution of alloy,¹⁸,¹⁹,⁴⁵ was employed to survey the equilibrium potential of alloy. First, a thin layer of the specimen was synthesized by potentiostatic electrolysis for 10 s at −2.5 V on a tungsten electrode. Then, the current was cut up and a series of electrochemical curves were obtained. Fig. 6 shows a group of open circuit chronopotentiograms obtained in different molten salt systems on a tungsten electrode at 1023 K. Before the additions of AlCl₃ and LaCl₃ in LiCl−KCl−MgCl₂ melts, two potential plateaus can be observed. The first potential plateau A at around −2.27 V is ascribed to the formation potential of metal Li on a tungsten electrode. With the extension of time, a second potential plateau B at around −1.61 V corresponds to the equilibrium potential of Mg(II)/Mg. Curve 2 exhibits the open circuit chronopotentiogram obtained in LiCl−KCl−MgCl₂ melts after the addition of AlCl₃ (1 wt%) on a tungsten electrode. Two new potential plateaus F and C are obtained. The plateau F at around −1.40 V is probably associated with the open circuit potential of Al−Mg alloy, which is formed by the underpotential deposition of Li(I) on magnesium already deposited on a tungsten electrode.

Square wave voltammetry.— Square wave voltammetry, a more sensitive electrochemical method than cyclic voltammetry, was also adopted to further investigate the electrochemical behavior of La(III). Fig. 5 exhibits the comparative diagram of the square wave voltamograms obtained in LiCl−KCl−MgCl₂ (curve 1) and LiCl−KCl−MgCl₂ (1 wt%−AlCl₃ (1 wt%)−LaCl₃ (3 wt%) curve 2) melts. In curve 1, two electro−signals A and B can be observed. The signal B is associated with the reduction of magnesium ions on a tungsten electrode, which is beginning at around −1.59 V. With the increasing of the cathode potential, another electro−signal A appears. The huge cathode signal A may be caused by the formation of a Mg−Li alloy, which is in accordance with the situation of the cyclic voltammetry. From curve 1, the asymmetry of the signal B exists. This can be probably explained by the nucleation effect. An overpotential is required during a new phase formation process on a tungsten electrode, which results in the deposition potential going negative. Therefore, there is the left side of peak B is wider than the right one. Curve 2 displays square wave voltamogram in LiCl−KCl−MgCl₂ (1 wt%)−AlCl₃ (1 wt%)−LaCl₃ (3 wt%) after the addition of LaCl₃ (3 wt%) on a tungsten electrode at 1023 K. Four new electro−signals (E, G, C and F) are obtained, which are in accordance with these obtained in cyclic voltamogram. In addition, the peak potential of signal B (curve 2) is more negative than that in curve 1. The reason is that the volume of the electrolyte increases after the addition of the LaCl₃. Therefore, the concentration of the Mg(II) decreases and results in the reduction potential going negative. Furthermore, the current density of the signal B from curve 2 is larger than that in curve 1. This phenomenon may be caused by the reason that the numbers of free ions in the electrolyte system increase after the addition of LaCl₃ and the conductivity of the electrolyte enhances.

**Figure 5.** Square wave voltammograms obtained on a tungsten electrode (S = 0.322 cm²) at 1023 K in different melts: 1: LiCl−KCl−MgCl₂ (1 wt%) melts; 2: LiCl−KCl−MgCl₂ (1 wt%−AlCl₃ (1 wt%−LaCl₃ (3 wt% melts, with the conditions of pulse height: 25 mV; potential step: 1 mV; frequency: 10 Hz.

**Figure 6.** Open circuit chronopotentiograms obtained in different molten salt systems: 1: LiCl−KCl−MgCl₂ (1 wt%) melts; 2: LiCl−KCl−MgCl₂ (1 wt%−AlCl₃ (1 wt%)−LaCl₃ (1 wt%)−LaCl₃ (3 wt%) melts; 3: LiCl−KCl−MgCl₂ (1 wt%)−AlCl₃ (1 wt%)−LaCl₃ (3 wt%) melts, with the conditions of potentiostatic electrolysis 10 s at −2.5 V on a tungsten electrode (S = 0.322 cm²) at 1023 K.
tively. And the equilibrium potentials of H and I are in accordance with the equilibrium potential of E and G, which are obtained in LiCl–KCl–MgCl₂–AlCl₃–LaCl₃ melts. With changing the current intensity, five plateaus are obtained. When the current intensity is –15 mA, first plateau C appears, which is associated with the reduction of aluminum ions on a tungsten electrode. When the current intensity reaches to –30 mA and –35 mA, the plateaus G and E are obtained, which are ascribed to the formation of two different Al–La intermetallic compounds, respectively. When the current intensity is 40 mA, the plateau B which is related to the reduction of Mg(II) appears. The last plateau A is obtained when the current intensity is more negative than –190 mA. This plateau is attributed to the reduction of Li(I). That is to say, the co-deposition of the Mg(II), Li(I), Al(III) and La(III) ions will be realized when the current intensity is more negative than –190 mA. From the chronopotentiograms, with the increasing of the current intensity, the transition time of the plateaus C and B decreases. This phenomenon indicates that the reduction of aluminum and magnesium ions is controlled by the mass transfer.35,41,47

**Chronopotentiometry.**—Chronopotentiometry is a suitable method to investigate the co-deposition mechanism of Mg(II), Li(I), Al(III) and La(III) ions in LiCl–KCl melts on a tungsten electrode in our experiment condition.46 Fig. 8 illustrates a series of chronopotentiograms obtained on a tungsten electrode at 1023 K under the different current intensities in LiCl–KCl–MgCl₂–AlCl₃–LaCl₃ melts. With changing the current intensity, five plateaus are obtained. When the current intensity is –15 mA, first plateau C appears, which is associated with the reduction of aluminum ions on a tungsten electrode. When the current intensity reaches to –30 mA and –35 mA, the plateaus G and E are obtained, which are ascribed to the formation of two different Al–La intermetallic compounds, respectively. When the current intensity is 40 mA, the plateau B which is related to the reduction of Mg(II) appears. The last plateau A is obtained when the current intensity is more negative than –190 mA. This plateau is attributed to the reduction of Li(I). That is to say, the co-deposition of the Mg(II), Li(I), Al(III) and La(III) ions will be realized when the current intensity is more negative than –190 mA. From the chronopotentiograms, with the increasing of the current intensity, the transition time of the plateaus C and B decreases. This phenomenon indicates that the reduction of aluminum and magnesium ions is controlled by the mass transfer.35,41,47

Preparation and characterization of Mg–Li–Al–La alloy containing whiskers.—In this experiment, the main purpose is to prepare Al–La intermetallic compound whiskers in magnesium substrate and characterize the mechanical properties of the Mg–Li–Al–La alloy containing whiskers. However, it is difficult to obtain the bulk alloy during the co-deposition process. Therefore, the preparation of Mg–Li–Al–La alloy containing whisker was implemented by galvanostatic electrolysis on liquid magnesium electrode at 1023 K in LiCl–KCl–AlCl₃–LaCl₃ (3 wt%) melts. In consideration of the volatilization of AlCl₃, 2 g AlCl₃ powder was poured into the melts per 30 minutes. The current intensity for galvanostatic electrolysis was selected from chronopotentiograms. When the current intensity was more negative than –0.19 A, the co-deposition of the Mg(II), Li(I), Al(III) and La(III) ions could be realized. Thus, –0.20 A (S = 1.76 cm²) was employed for applying current. After electrolysis for 4.5 h, Mg–Li–Al–La alloy was cooled to the room temperature (the cooling rate is 2 °C/min). Then, the Mg–Li–Al–La alloy was taken out and laid in glove box until their analysis. Fig. 9 exhibits the X-ray diffraction (XRD) of Mg–Li–Al–La alloy obtained by galvanostatic electrolysis for 4.5 h on a liquid magnesium electrode. The XRD pattern illustrates that only Al₄La and Mg phases are detected in Mg–Li–Al–La alloy. In XRD pattern, the diffraction peaks of aluminum are not observed. The reason should be that the element aluminum exists in magnesium substrate in the form of the Al–La intermetallic compound.41

Fig. 10 exhibits the scanning electron microscope of the Mg–Li–Al–La alloy obtained on a liquid magnesium electrode at 1023 K after galvanostatic electrolysis for 4.5 h. Lots of needle-like precipitates orderly distribute in magnesium substrate. These needle-like precipitates probably are Al–La intermetallic compounds. The gray zone on cross-sectional may mainly be magnesium.
mainly distribute on needle-like precipitates, and the element magnesium mainly distributes on gray zone. In addition, the distribution of aluminum is similar to that of element lanthanum. It further verifies the view that element aluminum mainly distributes on needle-like precipitate in the form of Al-La intermetallic compound. The EDS quantitative analysis was also employed to further examine the distribution of the magnesium, aluminum and lanthanum elements (Fig. 11). Points 1 and 2 were selected from the needle-like precipitate and point 3 was selected from the gray zone. The quantitative analysis exhibits that the needle-like precipitates dissolve more aluminum and lanthanum elements than the gray zone. The element with atomic number less than 4 cannot be detected by EDS. Thus, inductive coupled plasma atomic emission spectrometer was directly used to examine the percentage composition of each element of Mg–Li–Al–La alloy. The result shows that the compositions of these elements are: 84.1 wt% Mg, 1.2 wt% Li, 8.4 wt% Al and 6.3 wt% La, respectively.

The crystal structure of the whisker is single-crystal structure. The ratio of length to diameter is between 10 and 1000. And the diameter of the whisker is falling in 20 to 100 nanometer. From the SEM images, all of characteristic can be satisfied, except the crystal structure. Consequently, the TEM with electron diffraction was employed to investigate whether the needle-like precipitate is single crystal structure. Fig. 12 exhibits the TEM image and electron diffraction image of Mg–Li–Al–La alloy obtained by galvanostatic electrolysis for 4.5 hours at 1023 K on liquid magnesium electrode in LiCl–KCl–AlCl3–LaCl3 (3 wt%) melts. Lots of needle-like precipitates orderly distribute in magnesium substrate in image a. The ratio of length to diameter is between 10 and 1000, and the diameter of the needle-like precipitate falling in 20 to 100 nanometer can also be observed from image a. The point A is taken from random area of needle-like precipitates for the electron diffraction experiment. Image b exhibits the electron diffraction pattern of needle-like precipitates. The electron diffraction image shows that the diffraction spots arrange in an orderly manner, which can be used to explain the fact that the crystal structure of needle-like precipitates is single-crystal structure, and needle-like precipitates are intermetallic compound whisker.
The micro hardness.— To verify the improvement of mechanical properties of alloy with the help of Al_{2}La intermetallic compound whiskers, the micro hardness of alloy was measured by the micro hardness tester. Originally, two kinds of alloys with the same compositions of Mg, Li, Al and La were prepared with the same experiment condition except for the cooling rate. Fig. 13 exhibits the comparison diagram of micro hardness of the Mg–Li–Al–La alloys with and without whiskers. The column diagram 1 shows the micro hardness of Mg–Li–Al–La alloy containing whiskers obtained in LiCl–KCl–AlCl_{3}–LaCl_{3} (3 wt%) melts at 973 K on a liquid magnesium electrode. The micro hardness is 71.25 HV. The column diagram 2 illustrates the micro hardness of Mg–Li–Al–La alloy without whiskers. The micro hardness is 63.75 HV. It is easy to find that the hardness of Mg–Li–Al–La alloy containing whiskers is higher than the alloy without whiskers.

Conclusions

The electrochemical behavior of La(III) was investigated by cyclic voltammetry, square wave voltammetry, chronopotentiometry and open circuit chronopotentiometry in LiCl–KCl–MgCl_{2}–AlCl_{3}–LaCl_{3} melts on a tungsten electrode at 1023 K. The results illustrate Mg–La intermetallic compound cannot be formed under this experiment condition. This interesting phenomenon may be caused by the electronegativity difference between the two kinds of different elements. Al–La intermetallic compound can be formed while the electronegativity difference between aluminum and lanthanum is larger than that between magnesium and lanthanum. Chronopotentiometry shows that co-deposition of the Mg(II), Li(I) Al(III) and La(III) ions occurs when the current intensity is more than ~190 mA. The Al–La intermetallic compound whiskers are formed in magnesium substrate after galvanostatic electrolysis for 4.5 h, and Al_{2}La intermetallic compound is identified via XRD. The SEM with EDS (map analysis and quantitative analysis) illustrates that elements aluminum and lanthanum mainly distribute on needle-like precipitates and element magnesium mainly distributes on gray area. The SEM and TEM show that the ratio of length to diameter is between 10 and 1000, and the diameter of the whisker is falling in 20 to 100 nanometers. The electron diffraction pattern exhibits the diffraction spots arrange in an orderly manner and the needle-like precipitates are Al–La intermetallic compound whiskers. Compared with Mg–Li–Al–La alloy without whiskers, the micro hardness of Mg–Li–Al–La alloy containing whiskers improves 11.68%.

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Figure 12. TEM image (a) and electron diffraction pattern (b) of Mg–Li–Al–La alloy containing whiskers obtained by galvanostatic electrolysis for 4.5 hours at 1023 K on liquid magnesium electrode in LiCl–KCl–AlCl_{3}–LaCl_{3} (3 wt%) melts.

Figure 13. Comparison diagram of micro hardness of Mg–Li–Al–La alloys with (column 1) and without (column 2) whiskers.
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