

High-Performance, Corrosion-Resistance Sealing Glasses for Primary Lithium Batteries: Preparation, Properties and Applications

Z. Wang¹, S.J. Hua¹, W.H. Liu¹, W.B. Yang¹, Q. Feng^{*1, 2}

¹Xi'an Seal Electronic Material Technology Co., Ltd. Xi'an, 710201 China

²Northwest Institute for Non-Ferrous Metal Research Xi'an, 710016 China

received December 15, 2022; received in revised form March 20, 2023; accepted March 27, 2023

Abstract

The $\text{SiO}_2\text{-B}_2\text{O}_3\text{-Al}_2\text{O}_3\text{-Na}_2\text{O}$ glass system was selected as the main body. The effects of MgO additions and the ratios of $\text{SiO}_2/\text{B}_2\text{O}_3$ on the performance of the glasses were investigated. The corrosion mechanism model of glass in the battery was discussed. The findings were that adding MgO can increase the characteristic temperature of the glass, it also can strengthen the glass network structure and improve the corrosion resistance of the glass in the electrolyte. Reducing the ratio of $\text{SiO}_2/\text{B}_2\text{O}_3$ can improve the performance of the glass. When the ratio of the $\text{SiO}_2/\text{B}_2\text{O}_3$ reached 3.7, the performance of the glass was best overall. Therefore, when the amount of MgO reached 2 mol% and the ratio of the $\text{SiO}_2/\text{B}_2\text{O}_3$ reached 3.7, the glass-to-metal seals for lithium primary battery lids exhibited excellent corrosion resistance, with the corroded area of the glass being close to zero, so the glass seal can meet customer and market requirements.

Keywords: Glass, sealing, performance, corrosion resistance.

1. Introduction

With the rapid development of the Internet of Things (IoT) and artificial intelligence, the market application of lithium primary batteries has been greatly improved^{1,2}. For example, shared bicycles, ETC, bracelet watches, domestic gas meters and other Internet of Things industries and equipment need lithium primary batteries to supply power^{3,4}. In the Internet of Things sensing system, the battery needs to have high output power, high capacity, high load pulse performance, no voltage hysteresis, high safety performance, a longer service life, and a wider temperature application range ($-40\text{ }^\circ\text{C} \sim +80\text{ }^\circ\text{C}$) as well as other characteristics³. The performance of lithium primary batteries is better than that of lithium-ion batteries with regard to key factors such as energy density, self-discharge rate, product maintenance, and applicable temperature range. These factors are urgently needed for IoT applications. In other scenarios, the battery needs to be used for more than several years. Obviously, ordinary lithium-ion batteries cannot meet those demands. Therefore, in some applications that require long life, zero maintenance and high reliability, lithium primary batteries will be the best choice.

The lithium primary battery is composed of metal lithium sheet as the negative electrode, carbon as the positive electrode and non-aqueous electrolyte⁵. The structure of the lithium primary battery is shown in Fig. 1. The negative lithium sheet leans against the inner wall of the stainless-steel shell, and the positive electrode is formed by us-

ing a glass-metal sealing lid and laser welding with the steel shell^{6,7}. One of the biggest shortcomings of current lithium primary batteries is leakage. The leakage caused by glass-metal sealing lids has two main aspects. On the one hand, the glass is not strong enough to prevent breaking, and on the other hand, the glass is not corrosion resistant enough to prevent leaking⁸.

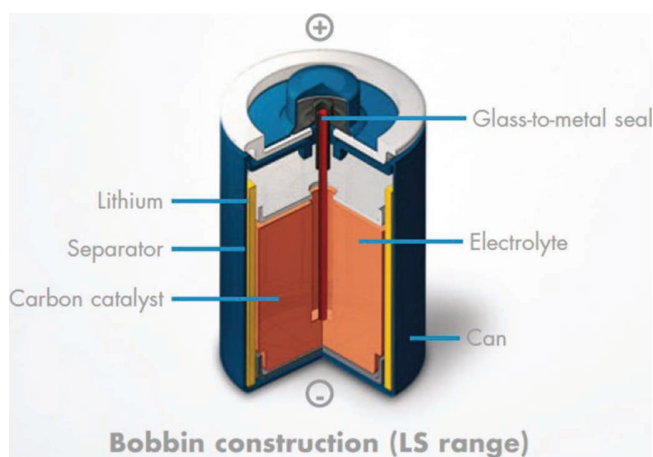


Fig. 1: The structure of the primary lithium battery.

The glass-to-metal sealing technology consists of a glass with a suitable thermal expansion coefficient, softening temperature and other properties to connect two metals of the same type or different types of metals, which is sintered at a certain temperature to form the glass-to-metal assembly with excellent airtightness, electrical insulation and other special performance, which generally consists of

* Corresponding author: 15675150713@163.com

pins, glass bead and the metal shell. According to the difference in thermal expansion coefficient, a differentiation is made between matching sealing and pressure sealing. Matching sealing refers to the coefficient of thermal expansion (α), where $\alpha(\text{pins}) \approx \alpha(\text{glass bead}) \approx \alpha(\text{shell})$. The pressure sealing refers to the coefficient of thermal expansion (α), where the $\alpha(\text{pins}) \leq \alpha(\text{glass bead}) \leq \alpha(\text{shell})$. Based on the difference in the sealing temperature, a differentiation is made between low-temperature sealing and high-temperature sealing, which is determined by the softening temperature of the glass and the melting point of the metal. Generally speaking, the current glass-to-metal sealing industry is tending to develop towards low-temperature sealing. This cannot only reduce energy consumption and improve efficiency, it also reduces the quality and appearance related problems of the sealed product caused by the complex chemical reaction on the metal surface because of the high temperature⁹.

In this paper, we detail research into the effects of different silicon-boron ratios on the physical properties, mechanical properties and electrolyte corrosion resistance of borosilicate glass, and the effect of different amounts of added MgO on the properties of borosilicate glass was further studied. At the same time, on this basis, the mixed alkali-alkaline earth effect was proposed.

The $\text{SiO}_2\text{-B}_2\text{O}_3\text{-Al}_2\text{O}_3\text{-Na}_2\text{O}$ glass system was selected as the main body. A thermal dilatometer, mechanical instruments, an ultra-depth-of-field optical microscope, SEM and other equipment were used to study it. The corrosion mechanism model of the glass in the battery was discussed.

II. Experimental

The sealing glass with a molar composition (mol%) of $65\text{SiO}_2\text{-}5\text{B}_2\text{O}_3\text{-}5\text{Al}_2\text{O}_3\text{-}20\text{Na}_2\text{O}\text{-}5$ others was prepared using the analytical reagents SiO_2 , H_3BO_3 , $\text{Al}(\text{OH})_3$, Na_2CO_3 from the China National Pharmaceutical Group Corporation. All the raw powder was sifted on 150 mesh, so the average particle size was about 106 μm . While the Al_2O_3 and Na_2O components are unchanged and SiO_2 is gradually replaced by equal components of B_2O_3 . We prepared six additional batches of glass to investigate the effect of different ratios of the $\text{SiO}_2/\text{B}_2\text{O}_3$ on the thermal, mechanical and corrosion resistance properties of seal-

ing glass. Simultaneously, a small amount (2–4 mol%) of MgO was introduced to observe the impact of MgO additions on the sealing glass' properties. The specific formula of the series glasses is shown in Table 1.

All the prepared raw materials were placed in a blender and mixed for 30 minutes in a mechanical stirring process, to ensure that the components can be quickly and evenly dispersed in the glass phase during the melting process. The mixed materials were placed in an alumina crucible and treated in an air atmosphere resistance furnace, the heating rate was 10 K/min, and the temperature was kept at 1600 °C for 80 min. The glass was discharged by means of water quenching.

The bulk glasses were machined into cylinders with the dimensions of $\varnothing 6 \times 30$ mm to enable measurement of characteristic temperatures (T_g and T_f) and CTE with a horizontal dilatometer (DIL 402 Expedit Classic, Netzsch, Germany). The mechanical machine was used to test the tensile strength of the glass-to-metal sealing terminal in the electronic universal testing machine (XWW-20KN). The sealed lid was assembled in a battery to test the corrosion resistance of the glass. An ultra-depth-of-field optical microscope (VHX-950F) and SEM (JSM-6360LV) were used to characterize the corrosion morphology. Finally, the glass corrosion mechanism model was derived.

As for the metal of primary lithium battery in this paper, its shell is made of stainless steel 304L with a CET of 17 ~ 18 ppm/K, and its core column is made of ferronickel 4J50 with a CET of 8 ~ 9 ppm/K.

III. Results and Discussion

(1) Thermal behavior

The effect of different MgO additions and the ratios of $\text{SiO}_2/\text{B}_2\text{O}_3$ on the glass characteristic temperatures (T_g and T_f) and thermal expansion coefficient is shown in Fig. 2. It can be seen from the figure that as the content of MgO increases, the coefficient of thermal expansion of the glass decreases, while the characteristic temperature of the glass increases. This is because the characteristic temperature and thermal expansion coefficient of glass are related to the structure of the glass. The alkaline earth metals can increase the expansion and softening temperature of borosilicate and decrease the expansion coefficient. As the

Table 1: Nominal and analyzed molar compositions of the melted glasses.

Number	SiO_2	B_2O_3	Al_2O_3	Na_2O	MgO	others	$\text{SiO}_2/\text{B}_2\text{O}_3$
1#	65	5	5	20	0	5	13
2#	65	5	5	18	2	5	13
3#	65	5	5	16	4	5	13
4#	60	10	5	18	2	5	6
5#	55	15	5	18	2	5	3.7
6#	50	20	5	18	2	5	2.5
7#	45	25	5	18	2	5	1.8

content of MgO increases, MgO can form the mixed alkali-alkaline earth effect with Na_2O ¹². The ions of different radius were closely packed, and the divalent alkaline earth metal oxide has a suppressing effect on the monovalent alkali metal oxide^{13,14}. In this situation, the ions in the glass can have a difficult migration. As everyone knows that the expansion and softening temperature of glass is related to the migration of ions, so the characteristic temperature of the glass increases, while the thermal expansion coefficient decreases. The coefficient of thermal expansion decreases too much to meet the requirements of matching sealing, so the amount of MgO added was only 2 mol%.

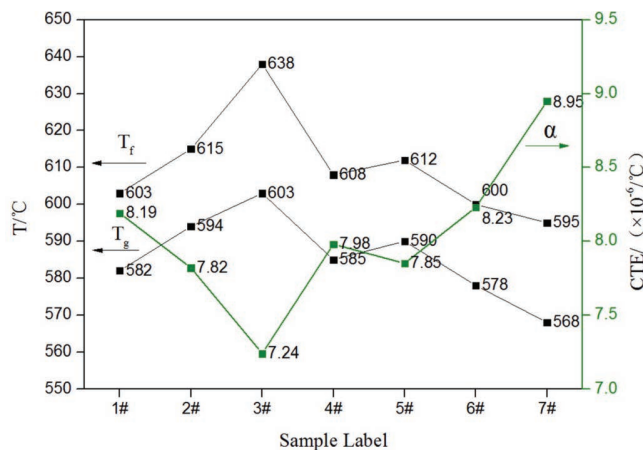


Fig. 2: The characteristic temperatures and CTE of the glass samples.

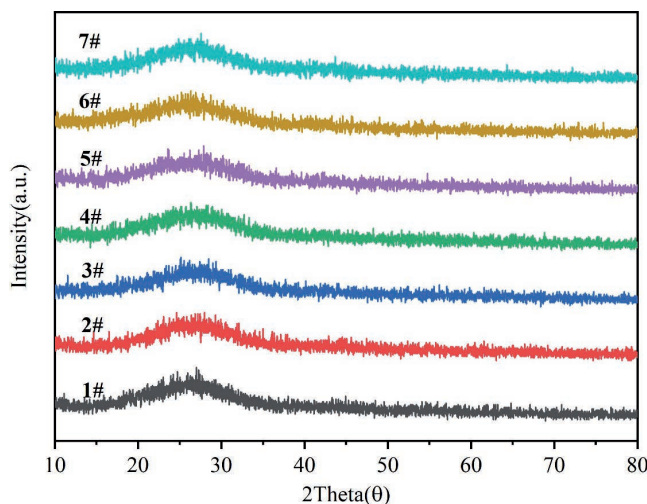


Fig. 3: The XRD of different glass-to-metal sealed battery lids.

In addition, with the decrease in the $\text{SiO}_2/\text{B}_2\text{O}_3$ ratios, the thermal expansion coefficient of the glass has a tendency to first decrease and increase, and the characteristic temperature of the glass first increases and then decreases. Owing to the decrease in the SiO_2 content of the network former, the structural density of the glass decreases¹⁵. However, with the increase in the B_2O_3 content, the free oxygen provided by the alkali metal starts transforming from the boron-oxygen triangle $[\text{BO}]_3$ to the boron-oxygen tetrahedron $[\text{BO}]_4$, which causes the glass to change from a layered structure to a frame structure^{16,17}. Therefore, the thermal expansion coefficient of the glass decreases,

and the characteristic temperature firstly increases, and then when the ratio of $\text{SiO}_2/\text{B}_2\text{O}_3$ reached 3.7, the optimum value is reached. At the same time, because the boron has the boron oxygen anomaly^{18,19}, when $\text{Na}_2\text{O}/\text{B}_2\text{O}_3$ exceeds a certain value, the quantitative change between the boron-oxygen triangle $[\text{BO}]_3$ and the boron-oxygen tetrahedron $[\text{BO}]_4$ in the glass will cause the glass properties to change suddenly, so the thermal expansion coefficient of the glass increases, and the characteristic temperature decreases again.

Fig. 3 presents all the XRD curves of series sealing glasses. It can be seen that with the change of $\text{SiO}_2/\text{B}_2\text{O}_3$ ratio and the addition of MgO, the XRD curve of corresponding glass does not change, and no new peak is formed, indicating that there is no crystal phase in any of the sealing glasses.

(2) Mechanical properties

We prepared glass beads with the glass prepared with different MgO additions and different ratios of $\text{SiO}_2/\text{B}_2\text{O}_3$ into the certain shape, and then assembled them with a metal shell and a pin and sealed them into lithium primary battery terminals in a chain furnace with a nitrogen atmosphere. We then tested its mechanical properties. The test results are shown in Fig.4. As the MgO content increases, the tensile strength of the glass decreases, which may be related to the bonding strength of the glass and metal interface. With the decrease in the ratio of the $\text{SiO}_2/\text{B}_2\text{O}_3$, the tensile strength of glass firstly increases and then decreases, which may be related to the proportion of $[\text{BO}]_3$ and $[\text{BO}]_4$ in the glass²⁰. In general, the tensile strength of glass is greater than the product's demand of 1 200 N.

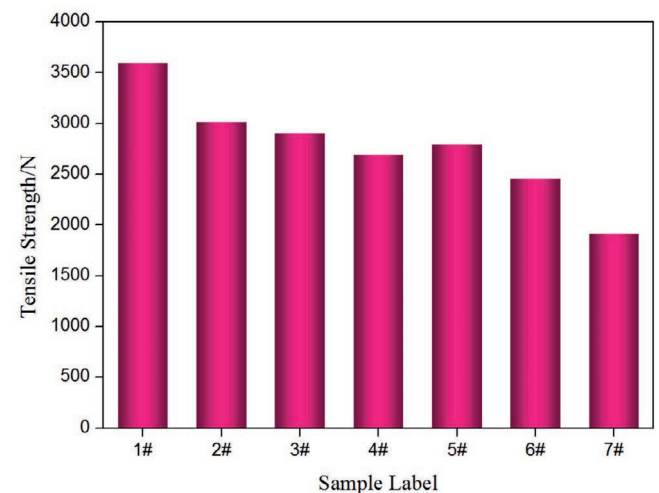


Fig. 4: The mechanical property of different glass-to-metal sealed battery lids.

(3) Corrosion resistance

(a) Photograph of the glass-to-metal sealed battery lid

The lithium primary battery lid made of glass with different amounts of added MgO and glass with different ratios of $\text{SiO}_2/\text{B}_2\text{O}_3$ ratio were assembled into a complete lithium primary battery, and the electrolyte of the battery is thionyl chloride. The assembled battery was placed in an oven at 120 °C for 7 days to test the corrosion

resistance of the glass-metal sealing terminal in the battery^{21,22}. After dissecting the insulated battery, we measured the corrosion distance of the glass along the radius to determine the corrosion resistance of the glass. This is because the greater the corrosion distance, the faster the

corrosion rate is. The results for the corrosion resistance of the glass in the battery sealing terminal are shown in Fig. 5. The specific corrosion performance was as follows: the corrosion distance of sample 1# was 35 %, the corrosion distance of sample 2# was 28 %, and the corrosion

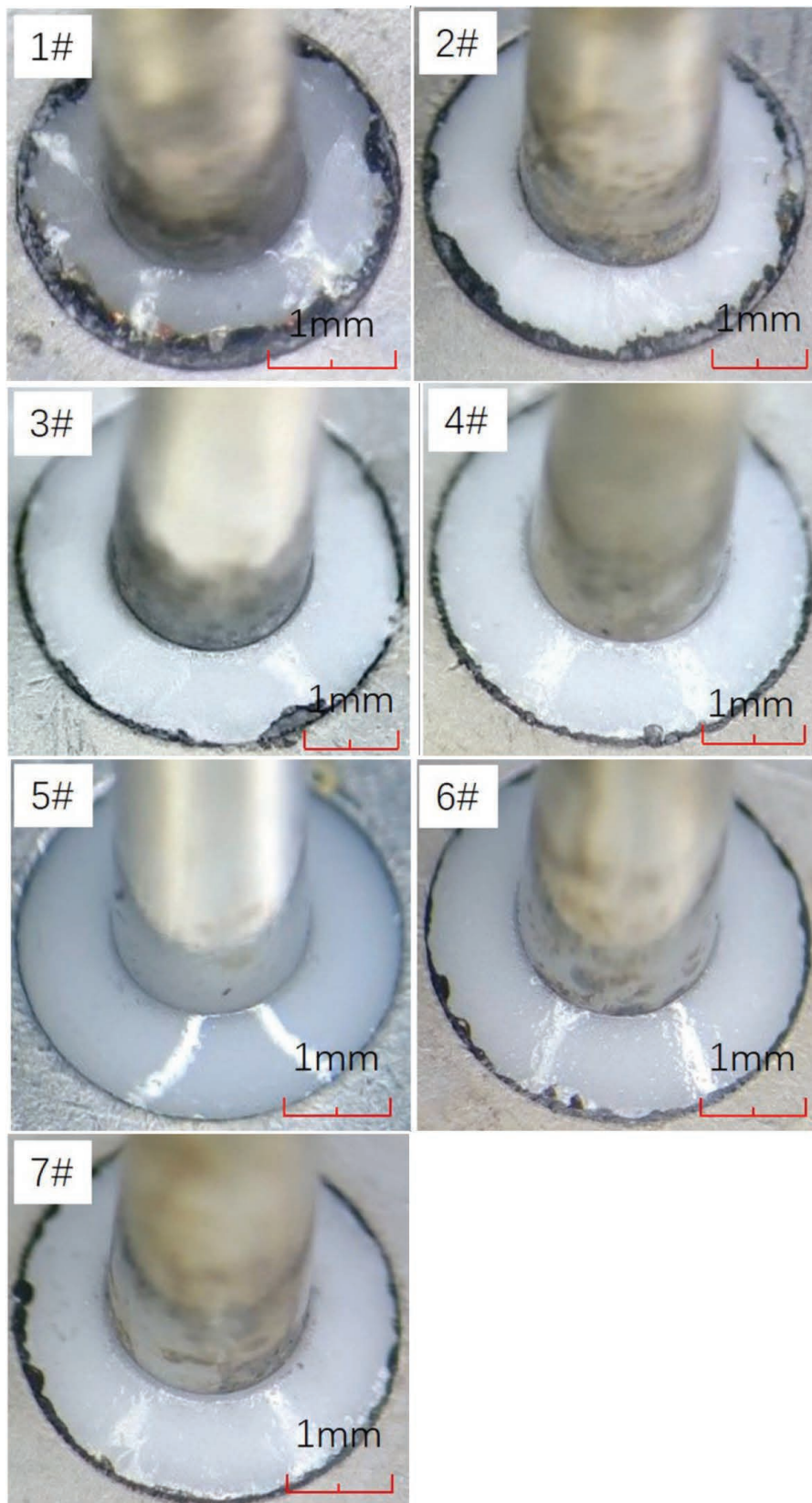


Fig. 5: Photographs of corrosion of the glasses after battery lid dissection.

distance of sample 3# was 20 % (maximum corrosion distance shall prevail), the corrosion distance of sample 4# was 10 %, the corrosion distance of sample 5# was 0, the corrosion distance of sample 6# was 8 %, the corrosion distance of sample 7# was 12 %. The corrosion distance of the sample glass of 1#, 2#, 3# gradually decreases, indicating that the introduction of MgO can form the mixed alkali-alkaline earth effect with Na_2O . The radius of Mg^{2+} is 0.65 Å, and the radius of Na^+ is 0.95 Å. The formation of close packing can improve the Li^+ corrosion resistance of the glass structure. In addition, the radius of Mg^{2+} 0.65 Å is close to that of Li^+ 0.60 Å. Mg^{2+} can fill the voids in the glass network structure and can prevent Li^+ from directly entering and corroding the glass structure²³. The corrosion distance of the sample 4#, 5#, 6#, 7# glass decreases first and then increases, but the corrosion distance is generally smaller than that of the 3# sample glass. Because of the decrease in the ratio of the $\text{SiO}_2/\text{B}_2\text{O}_3$ and the increase in the content of $[\text{BO}]_4$ in the glass, the corrosion distance of the glass decreases. In other words, the corrosion resistance of the glass is improved. The bond energy

of B-O with 515 kJ/mol is higher than the bond energy of Si-O with 460 kJ/mol, which can improve the chemical stability of the glass, strength, and resistance to the corrosion of the Li^+ ion.^{23,24} The increase in the corrosion distance of glass is due to the increase in B_2O_3 content, and the content of $[\text{BO}]_3$ in the glass also increases due to the boron oxygen anomaly, and $[\text{BO}]_3$ mainly exists in a layered structure, so the strength of the glass is reduced.

(b) *SEM of the glass-to-metal-sealed battery lid*

The corroded glass-to-metal-sealed terminal is shown in Fig. 6. Picture (a) is the SEM of glass in contact with the electrolyte, and picture (b) is the SEM of glass in contact with the air. Among them, the glass was obviously corroded after contact with the electrolyte, and the degree of corrosion from the surface of the glass to the inside of the glass is gradually reduced. Fig.(c) and (d) show enlarged views of the glass after corrosion. The glass becomes loose, with many cracks and large gaps. As time goes by, the glass will eventually be corroded by the electrolyte and cause electrolyte leakage, which will result in the battery failing.

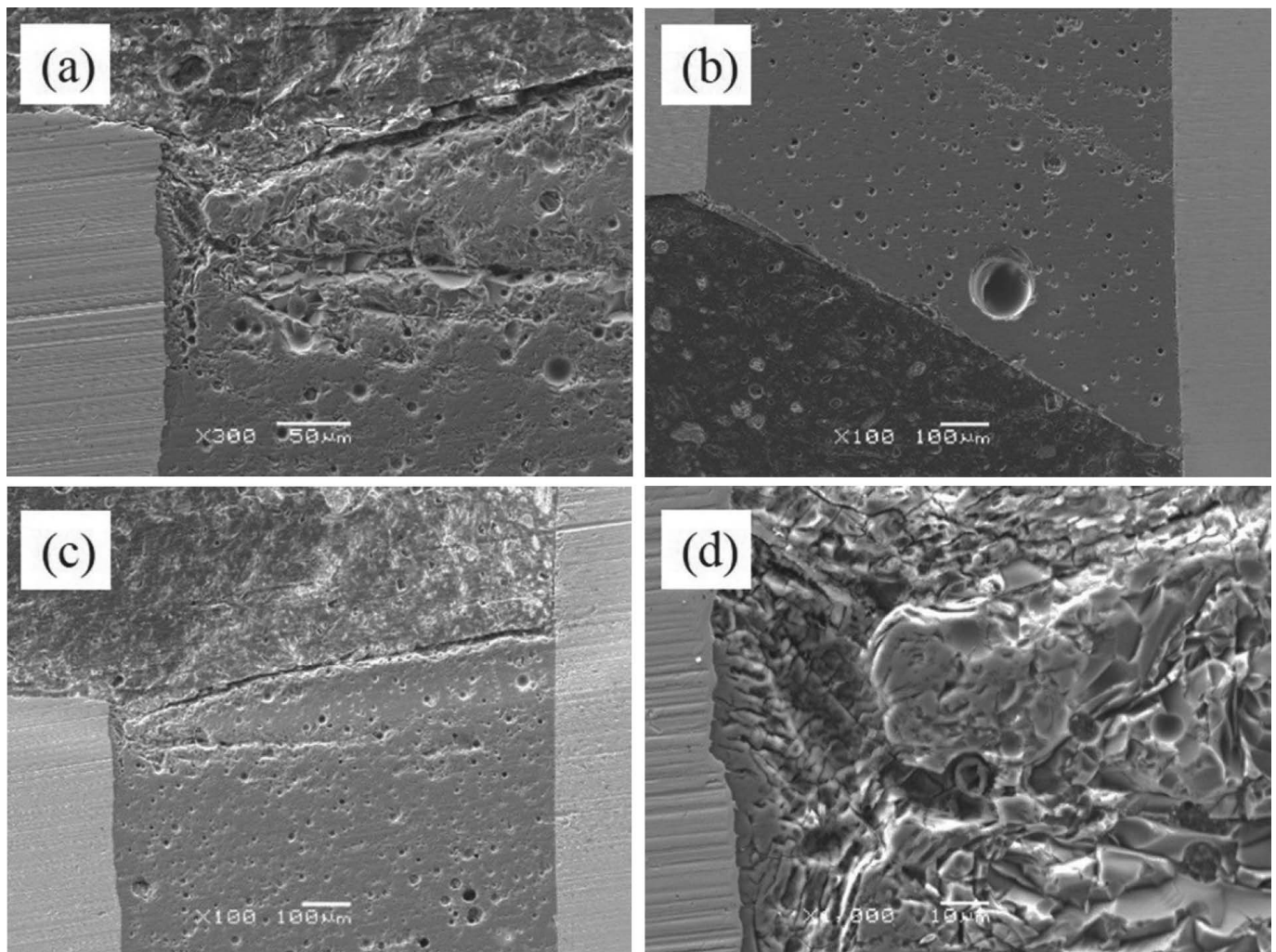
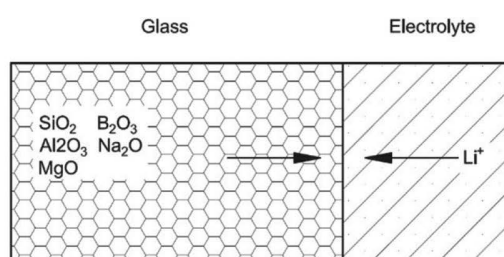


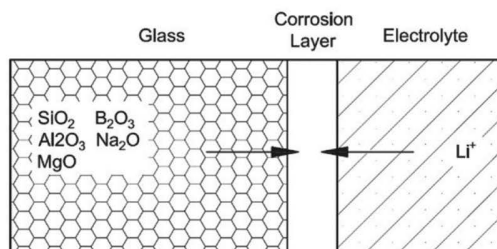
Fig. 6: The SEM of the glass-to-metal sealed battery lid.

(c) Corrosion mechanism model

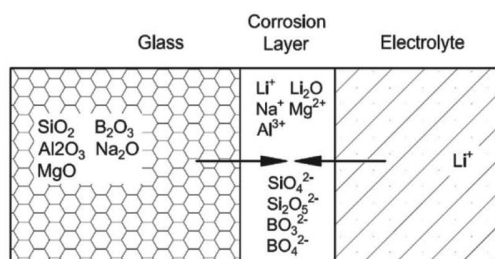
According to the experimental results, the corrosion mechanism model of glass in electrolyte can be summarized as shown in Fig. 7. The first stage: diffusion. The Li^+ ion in the electrolyte diffuses to the glass surface, and the rate is affected by time and temperature. The second stage: the dissolution of the glass network structure. Under the action of electrolyte and Li^+ ion, the surface of the glass is eroded, and the network structure begins to dissolve^{21–24}. The following chemical reaction occurs: $4\text{Li} + \text{SiO}_2 \rightarrow 2\text{Li}_2\text{O} + \text{Si}$, $4\text{Li} + 5\text{SiO}_2 \rightarrow 2\text{Li}_2\text{Si}_2\text{O}_5 + \text{Si}$. The third stage: the formation of the glass corrosion layer and its spread into the glass. Once the glass is corroded, it becomes loose and porous. The electrolyte and Li^+ ion quickly enter the inside of the glass and corrode it, making the thickness of the corrosion layer gradually expand²².



Stage 1. The diffusion process



Stage 2. The glass network dissolution



Stage 3. Formation and expansion of the corrosion layer

Fig. 7: The corrosion mechanism model of the glasses in the battery's electrolyte.

The corrosion often occurs where the glass is in contact with the negative electrode, and the corrosion product grows from the anode to the cathode until it covers the entire glass surface. When the pin is used as an anode, point-like corrosion products tend to radiate outward from the pin instead of forming concentric rings. The corrosion

products have high conductivity. Glass corrosion can also cause glass cracks and consequently electrolyte leakage. Owing to the volume change accompanying the chemical reaction, a large surface stress is generated at the interface between the corrosion product and the glass. The cracks produced by this mechanism are often shallow surface cracks under the corrosion products, causing the glass to spall rather than seal failure. The most serious cracks are related to changes in the stress distribution of the entire glass-metal seal, which are caused by glass removal due to corrosion²¹.

VI. Conclusions

The SiO_2 - B_2O_3 - Al_2O_3 - Na_2O sealing glass was prepared, and the effects of different MgO addition and the ratio of $\text{SiO}_2/\text{B}_2\text{O}_3$ on the characteristic temperature, thermal expansion coefficient, mechanical properties and corrosion resistance of the glass were investigated.

(1) MgO can increase the characteristic temperature of the glass, reduce the thermal expansion coefficient and mechanical properties of the glass, and at the same time can strengthen the glass network structure and improve the glass' resistance to electrolyte corrosion. This is because it can form the mixed alkali-alkaline earth effect with Na^+ and Mg^{2+} .

(2) Reducing the ratio of $\text{SiO}_2/\text{B}_2\text{O}_3$ can improve the performance of the glass. When the ratio of $\text{SiO}_2/\text{B}_2\text{O}_3$ reached 3.7, the overall performance of the glass was best, especially the corrosion resistance is best, and the corrosion distance of the glass was almost zero. This is because it is related to the boron-oxygen anomalies.

(3) According to the corrosion results, the corrosion model mechanism model was given. In summary, when the amount of MgO introduced was 2 mol% and the ratio of $\text{SiO}_2/\text{B}_2\text{O}_3$ reached 3.7 mol%, the glass used for the glass-to-metal sealing of the lithium primary battery lid exhibits the best corrosion resistance, which can satisfy customers and market requirements.

References

- Zhang, L., Liang, Y.C., Niyato, D.: 6G Visions: Mobile Ultra-Broadband, Super Internet-of-Things and Artificial Intelligence, *China Commun.*, **16** [8], 1–14, (2019). doi: <https://doi.org/10.23919/JCC.2019.08.001>.
- Sethi, P., Sarangi, S.R.: Internet of Things: Architectures, Protocols, and Applications, *J Electr. Comput. Eng.*, **1**, 1–25, (2017). doi: <https://doi.org/10.1155/2017/9324035>.
- Osuwa, A.A., Ekhorgbon, E.B., Fat, L.T.: Application of artificial intelligence in Internet of Things, *International Conference on Computational Intelligence & Communication Networks(CICN)*, 169–173, (2017).
- Pramanik, P.K.D., Pal, S., Choudhury, P.: Beyond Automation: The Cognitive IoT. Artificial Intelligence Brings Sense to the Internet of Things, *Cognitive Computing for Big Data Systems Over IoT*, **14**, (2018). doi: https://doi.org/10.1007/978-3-319-70688-7_1.
- Yoko, S., Yanagimoto, T.: Negative electrode for lithium primary battery and lithium primary battery, U.S. Patent. No. 8,236,451, 2012.
- Yang, Z.G., Stevenson, J.W., Meinhardt, K.D.: Chemical interactions of barium-calcium-aluminosilicate-based sealing glass-

- es with oxidation resistant alloys, *Solid State Ionics*, **160** [3–4], 213–225, (2003).
doi: [https://doi.org/10.1016/S0167-2738\(03\)00160-7](https://doi.org/10.1016/S0167-2738(03)00160-7).
- 7 Komatsu, T., Inoue, T., Tasheva, T., et al.: Correlation between thermal expansion coefficient and interionic interaction parameter in $\text{ZnO-Bi}_2\text{O}_3\text{-B}_2\text{O}_3$ glasses, *J. Ceram. Soc. Jpn.*, **126** [1], 8–15, (2018). doi: <https://doi.org/10.2109/jcersj2.17176>.
- 8 Reis, S.T., Brow, R.K.: Designing sealing glasses for solid oxide fuel cells, *J. Mater. Eng. Perform.*, **15** [4], 410–413, (2006).
- 9 Rulon, R.M.: *Glass To Metal Seals*, Introduction to Glass Science, Springer US, 1972.
- 10 Keding, R., Rüssel, C., Pascual, M.J., et al.: Corrosion mechanism of borosilicate sealing glasses in molten carbonates studied by impedance spectroscopy, *J. Electroanal. Chem.*, **528** [1–2], 184–189, (2002).
doi: [https://doi.org/10.1016/S0022-0728\(02\)00714-3](https://doi.org/10.1016/S0022-0728(02)00714-3).
- 11 Wang, Q.Y., Wang, S., Zhou, G., et al.: Progress on the failure analysis of lithium battery, *Acta. Phys. Sin.-ch. Ed.*, **67** [12], 128501, (2018). doi: <https://doi.org/10.7498/aps.67.20180757>.
- 12 Kim, B.S., Lim, E.S., Lee, J.H., et al.: Effect of structure change on thermal and dielectric characteristics in low-temperature firing $\text{Bi}_2\text{O}_3\text{-B}_2\text{O}_3\text{-ZnO}$ glasses, *J. Mater. Sci.*, **42** [12], 4260–4264, (2007).
- 13 Brow, R.K., Tallant, D.R.: Structural design of sealing glasses, *J. Non-cryst. Solids*, **222**, 396–406, (1997).
- 14 Wang, X., Ou, D.R., Shang, L., et al.: Sealing Performance and Chemical Compatibility of $\text{SrO-La}_2\text{O}_3\text{-Al}_2\text{O}_3\text{-SiO}_2$ Glasses with Bare and Coated Ferritic Alloy, *Ceram. Int.*, **42** [12], 14168–14174, (2016).
doi: <https://doi.org/10.1016/j.ceramint.2016.06.040>.
- 15 Furuyama, T., Yonehara, M., Arimoto, S., et al.: Development of Highly Chemoselective Bulky Zincate Complex, $\text{tBu}_4\text{ZnLi}_2$: Design, Structure, and Practical Applications in Small-/Macromolecular Synthesis, *Chemistry*, **14** [33], 10348–10356, (2008).
doi: <https://doi.org/10.1002/chem.200800536>.
- 16 Nie, H., Zhang, J., Qi, Y., et al.: Influence of composition on the structure and properties of $\text{SrO-Sb}_2\text{O}_3\text{-P}_2\text{O}_5$ low-melting sealing glasses, *Mater. Sci-Poland.*, **33** [4], 862–866, (2015).
doi: <https://doi.org/10.1515/msp-2015-0117>.
- 17 Hülsenberg, D., Harnisch, A., Bismarck, A.: *Microstructuring of Glasses*, Springer Series in Materials Science, **87**, (2008).
- 18 Cheng, Y., Xiao, H.N., Guo, W.M.: Influence of compositions on sealing temperature and properties of lead borate non-crystallizing sealing glasses, *Mater. Sci. Eng.: A*, **464** [1–2], 210–215, (2007).
doi: <https://doi.org/10.1016/j.msea.2007.01.146>.
- 19 Kim, Y., Morita, K.: Thermal Conductivity of Molten B_2O_3 , $\text{B}_2\text{O}_3\text{-SiO}_2$, $\text{Na}_2\text{O-B}_2\text{O}_3$, and $\text{Na}_2\text{O-SiO}_2$ Systems, *J. Am. Ceram. Soc.*, **98** [5], 1588–1595, (2015).
doi: <https://doi.org/10.1111/jace.13490>.
- 20 Zhou, D., Jones, B.G.: Boron Concentration Model and Effects of Boron Holdup on Axial Offset Anomaly (AOA) in PWRs, American Society of Mechanical Engineers, 35987, 829–834, 2002.
doi: <https://doi.org/10.1115/ICONE10-22636>.
- 21 Bunker, B.C., Douglas, S.C., Quinn, R.K.: Glass corrosion in ambient temperature lithium battery headers, *J. Mater. Res.*, **2** [2], 182–194, (1987).
doi: <https://doi.org/10.1557/JMR.1987.0182>.
- 22 Pascual, M.J., Pascual, L., Valle, F.J., et al.: Corrosion of Borosilicate Sealing Glasses for Molten Carbonate Fuel Cells, *J. Am. Ceram. Soc.*, **86** [11], 1918–1926, (2003).
doi: <https://doi.org/10.1111/j.1151-2916.2003.tb03582.x>.
- 23 Brow, R.K., Watkins, R.D.: High expansion, lithium corrosion resistant sealing glasses, U.S. Patent. No. 5021307, (1991).
- 24 Theis, C.D., Fleming, D.A., Osenbach, J.W.: The corrosion behavior of BK-7 glasses for use in non-hermetic electro-optic devices, *IEEE Transactions on Components & Packaging Technologies*, **23** [4], 638–645, (2000).
doi: <https://doi.org/10.1109/6144.888847>.

