# 锂电池背景

【锂电池优点、应用】

## 【锂电池优点、应用】

[1] C. Jo, A.S. Groombridge, J. De La Verpilliere, J.T. Lee, Y. Son, H.-L. Liang, A.M. Boies, M. De Volder, Continuous-Flow Synthesis of Carbon-Coated Silicon/Iron Silicide Secondary Particles for Li-Ion Batteries, ACS NANO, 14 (2020) 698-707.

Because of their high energy and power density, lithium ion batteries (LIBs) are currently the most promising energy storage technology for mobile devices, electric vehicles, and large-scale energy storage. 【为提升锂电池能量密度，发展新电极材料和配方】

【锂电池是最快发展的储能器件，应用】

## 【锂电池是最快发展的储能器件，应用】

[5] F. Wang, M. Gao, R. Hong, X. Lu, Magnetoelectric Plasma Preparation of Silicon-Carbon Nanocomposite as Anode Material for Lithium Ion Batteries, APPLIED SCIENCES-BASEL, 10 (2020).

Nowadays, lithium-ion batteries (LIB) are the fastest developing energy storage systems, and have widespread application in mobile phones, laptops, electric vehicles, etc. [1–3]. 【石墨材料的问题】

【锂电池优点，占据主导】

## 【锂电池优点，占据主导】

[6] S. Zhou, C. Fang, X. Song, G. Liu, Highly Ordered Carbon Coating Prepared with Polyvinylidene Chloride Precursor for High-Performance Silicon Anodes in Lithium-Ion Batteries, BATTERIES & SUPERCAPS, 4 (2021) 240-247.

Lithium-ion batteries (LIBs) have long cycling life, high energy density, and high power capability, thus dominating the current energy storage market.[1,2]【下一代电池，满足快速发展的储能需求，石墨容量有限】

【锂电池主导市场，优点】

## 【锂电池主导市场，优点】

[7] J. Wu, Y. Cao, H. Zhao, J. Mao, Z. Guo, The critical role of carbon in marrying silicon and graphite anodes for high-energy lithium-ion batteries, CARBON ENERGY, 1 (2019) 57-76.

Lithium‐ion batteries (LIBs) have been dominant in the market for powering the portable electronic devices since they were first commercialized, due to their desirable energy and power densities. 【需要提高锂电池能量密度】

【锂电池是一些领域电气化的关键】

## 【锂电池是一些领域电气化的关键】

[10] X. Zhou, H. Xie, X. He, Z. Zhao, Q. Ma, M. Cai, H. Yin, Annihilating the Formation of Silicon Carbide: Molten Salt Electrolysis of Carbon–Silica Composite to Prepare the Carbon–Silicon Hybrid for Lithium-Ion Battery Anode, Energy and Environmental Materials, 3 (2020) 166-176.

Lithium-ion batteries (LIBs) are the key to underpinning the electrification of modern transportation and using intermittent renewable energies such as solar and wind. [1–3] 【需要提高锂电池的能量密度】

【锂电池是消费电子中的主要能源，原因。以及电动车中的应用】

## 【锂电池是消费电子中的主要能源，原因。以及电动车中的应用】

[15] Z.P. Guo, E. Milin, J.Z. Wang, J. Chen, H.K. Liu, Silicon/disordered carbon nanocomposites for lithium-ion battery anodes, JOURNAL OF THE ELECTROCHEMICAL SOCIETY, 152 (2005) A2211-A2216.

Lithium-ion batteries have become the power source of choice for consumer electronic devices such as cell phones and laptop computers due to their high energy density and long cycle life. In addition, lithium-ion batteries are expected to be a major breakthrough in the hybrid vehicle field. 【尽快取得成功商业化应用，还需要进一步性能提升】

## 【锂电池主导市场】

[22] K. Feng, W. Ahn, G. Lui, H.W. Park, A.G. Kashkooli, G. Jiang, X. Wang, X. Xiao, Z. Chen, Implementing an in-situ carbon network in Si/reduced graphene oxide for high performance lithium-ion battery anodes, NANO ENERGY, 19 (2016) 187-197.

Lithium ion batteries (LIBs) have been dominating the market for electronic devices due to its relatively higher working potential, higher specific power and energy densities, and better environmentally friendliness compared to previous battery technologies such as lead acid, nickel cadmium, and nickel metal hydride batteries [1,2]. 【锂电池发展落后于消费电子器件的发展，后者遵循摩尔定律】

【锂电池是最重要的储能器件，优点】

## 【锂电池是最重要的储能器件，优点】

[24] J. Lu, D. Wang, J. Liu, G. Qian, Y. Chen, Z. Wang, Hollow double-layer carbon nanocage confined Si nanoparticles for high performance lithium-ion batteries, NANOSCALE ADVANCES, 2 (2020) 3222-3230.

Lithium-ion batteries (LIBs) have been considered as one of the most important energy storage devices owing to their high energy density and lack of the memory effect.1,2 【商业负极的问题，容量】

## 【锂电池背景】

[25] B. Li, F. Yao, J.J. Bae, J. Chang, M.R. Zamfir, L. Duc Toan, P. Duy Tho, H. Yue, Y.H. Lee, Hollow carbon nanospheres/silicon/alumina core-shell film as an anode for lithium-ion batteries, SCIENTIFIC REPORTS, 5 (2015).

The lithium-ion battery (LIB) has become one of the most promising energy storage devices because of its relatively high energy density and reasonable rate capability 1,2. 【石墨电极背景】

【石油价格，全球变暖引出锂电池，应用】

## 【石油价格，全球变暖引出锂电池，应用】

[26] L.Y. Yang, H.Z. Li, J. Liu, Z.Q. Sun, S.S. Tang, M. Lei, Dual yolk-shell structure of carbon and silica-coated silicon for high-performance lithium-ion batteries, SCIENTIFIC REPORTS, 5 (2015).

Recently, the rapidly rising price of petroleum and growing concerns about global warming have brought a great deal of attention to lithium-ion batteries with high capacity and energy density for future electric vehicles and portable electronics1–6. 【锂电池性能需要进一步提高】

# 商业锂电池目前广泛基于石墨负极，存在什么样的问题

## 【商业锂电基于石墨，容量数据】

[1] C. Jo, A.S. Groombridge, J. De La Verpilliere, J.T. Lee, Y. Son, H.-L. Liang, A.M. Boies, M. De Volder, Continuous-Flow Synthesis of Carbon-Coated Silicon/Iron Silicide Secondary Particles for Li-Ion Batteries, ACS NANO, 14 (2020) 698-707.

Commercial LIB anodes typically rely on Li-ion intercalation in graphite (372 mAh/g) or lithium titanate (175 mAh/g).5 【然而，合金化或转化机理可获得更高的能量密度】

## 【锂电池通常使用石墨】

[2] R.F.H. Hernandha, P.C. Rath, B. Umesh, J. Patra, C.-Y. Huang, W.-W. Wu, Q.-F. Dong, J. Li, J.-K. Chang, Supercritical CO2-Assisted SiOx/Carbon Multi-Layer Coating on Si Anode for Lithium-Ion Batteries, ADVANCED FUNCTIONAL MATERIALS, 31 (2021).

LIBs commonly use a conventional carbonaceous anode (e.g., graphite). [3]【石墨容量限制，无法满足逐步提升的应用需求】

## 【石墨容量限制，无法满足逐步提升的应用需求】

[2] R.F.H. Hernandha, P.C. Rath, B. Umesh, J. Patra, C.-Y. Huang, W.-W. Wu, Q.-F. Dong, J. Li, J.-K. Chang, Supercritical CO2-Assisted SiOx/Carbon Multi-Layer Coating on Si Anode for Lithium-Ion Batteries, ADVANCED FUNCTIONAL MATERIALS, 31 (2021).

However, a graphite anode, whose theoretical capacity is limited to 372 mAh g −1 ,cannot meet the escalating application requirements.【为提高锂电池性能，研究高容量负极】

## 【石墨材料的问题】

[5] F. Wang, M. Gao, R. Hong, X. Lu, Magnetoelectric Plasma Preparation of Silicon-Carbon Nanocomposite as Anode Material for Lithium Ion Batteries, APPLIED SCIENCES-BASEL, 10 (2020).

However, the commercial graphite anode material has a limited theoretical capacity of 372 mAh g−1, which cannot meet the energy density requirements in certain applications [4,5]. 【寻找高能量密度的材料】

## 【然而，传统使用碳负极的锂电池接近理论能量密度】

[7] J. Wu, Y. Cao, H. Zhao, J. Mao, Z. Guo, The critical role of carbon in marrying silicon and graphite anodes for high-energy lithium-ion batteries, CARBON ENERGY, 1 (2019) 57-76.

Nevertheless, the conventional LIBs using carbonaceous anode and lithium transition‐metal oxide cathode are approaching their theoretical energy density.

【锂电池的能量密度与电极材料的容量有关】

## 【石墨的问题】

[11] Z. Wu, J. Luo, J. Peng, H. Liu, B. Chang, X. Wang, Rational architecture design of yolk/double-shells Si-based anode material with double buffering carbon layers for high performance lithium-ion battery, GREEN ENERGY & ENVIRONMENT, 6 (2021) 517-527.

Especially, nowadays commercialized graphite anodes are hard to meet the ever-increasing need of higher energy and power densities for LIBs, which will restrict the further development of consumer electronics and electric vehicles [1,2]. 【硅的优点】

【锂电池使用碳电极的问题】

## 【锂电池使用碳电极的问题】

[12] L. Zhang, H. Guo, R. Rajagopalan, X. Hu, Y. Huang, S.X. Dou, H.K. Liu, One-step synthesis of a silicon/hematite@carbon hybrid nanosheet/silicon sandwich-like composite as an anode material for Li-ion batteries, JOURNAL OF MATERIALS CHEMISTRY A, 4 (2016) 4056-4061.

Conventional lithium ion batteries (LIBs) based on carbon anodes, such as commercial graphite microspheres and mesophase carbon microbeads (MCMBs), with a theoretical capacity ofabout 372 mAh g1, have now reached their limits in terms of meeting the need for high energy storage.1–4【为提高能量密度，需要高容量，低成本的电极】

## 【石墨被广泛使用】

[15] Z.P. Guo, E. Milin, J.Z. Wang, J. Chen, H.K. Liu, Silicon/disordered carbon nanocomposites for lithium-ion battery anodes, JOURNAL OF THE ELECTROCHEMICAL SOCIETY, 152 (2005) A2211-A2216.

Graphitic or graphitization carbons have been used extensively as negative electrode materials for lithium-ion batteries. 【石墨的问题】

## 【石墨的问题】

[15] Z.P. Guo, E. Milin, J.Z. Wang, J. Chen, H.K. Liu, Silicon/disordered carbon nanocomposites for lithium-ion battery anodes, JOURNAL OF THE ELECTROCHEMICAL SOCIETY, 152 (2005) A2211-A2216.

However, the lithium storage capacity of graphite as associated with its maximum LiC 6 stage 1 is limited to 372 mAh/g. 【锂合金引起兴趣。举例】

【石墨的缺点】

## 【石墨的缺点】

[18] Z. He, X. Wu, Z. Yi, X. Wang, Y. Xiang, Silicon/graphene/carbon hierarchical structure nanofibers for high performance lithium ion batteries, MATERIALS LETTERS, 200 (2017) 128-131.

The capacity of the commercial graphite has reached its limit, which prevent lithium ion batteries to meet the increasing demand of higher energy density. Besides, the commercial or indevelopment cathode materials also display a low specific capacity [1–8]. 【因此需要寻找新的负极，替代商业石墨】

## 【石墨理论容量低，无法满足这些需要高能量密度的应用】

[23] J. Yang, Y.-X. Wang, S.-L. Chou, R. Zhang, Y. Xu, J. Fan, W.-x. Zhang, H.K. Liu, D. Zhao, S.X. Dou, Yolk-shell silicon-mesoporous carbon anode with compact solid electrolyte interphase film for superior lithium-ion batteries, NANO ENERGY, 18 (2015) 133-142.

The traditional graphite anode with its limited theoretical capacity of $372 mA h g-1 is unable to meet the high energy needs of such applications. 【探索了不同的负极材料和方法，提升容量】

## 【商业负极的问题，容量】

[24] J. Lu, D. Wang, J. Liu, G. Qian, Y. Chen, Z. Wang, Hollow double-layer carbon nanocage confined Si nanoparticles for high performance lithium-ion batteries, NANOSCALE ADVANCES, 2 (2020) 3222-3230.

However, the commercial anode material, graphite, has got a low theoretical specific capacity (LiC6, 372 mA h g-1), and it is challenging to meet the ever-growing demands of portable electronics and electric vehicles.3,4 【需要发展替代商业负极的高容量电极材料】

## 【石墨电极背景】

[25] B. Li, F. Yao, J.J. Bae, J. Chang, M.R. Zamfir, L. Duc Toan, P. Duy Tho, H. Yue, Y.H. Lee, Hollow carbon nanospheres/silicon/alumina core-shell film as an anode for lithium-ion batteries, SCIENTIFIC REPORTS, 5 (2015).

Since the development of the first commercial LIB in the early 1990s by Sony Energytech 3, graphite has been widely used as the anode material. 【石墨的缺点】

## 【石墨的缺点】

[25] B. Li, F. Yao, J.J. Bae, J. Chang, M.R. Zamfir, L. Duc Toan, P. Duy Tho, H. Yue, Y.H. Lee, Hollow carbon nanospheres/silicon/alumina core-shell film as an anode for lithium-ion batteries, SCIENTIFIC REPORTS, 5 (2015).

However, the specific capacity of graphite is relatively low due to its intercalation mechanism 4. 【为提高能量密度，需要高容量电极材料】

# 锂电池的发展趋势，引出需要发展高容量负极

## 【发展新电极材料和配方，提升锂电池能量密度】

[1] C. Jo, A.S. Groombridge, J. De La Verpilliere, J.T. Lee, Y. Son, H.-L. Liang, A.M. Boies, M. De Volder, Continuous-Flow Synthesis of Carbon-Coated Silicon/Iron Silicide Secondary Particles for Li-Ion Batteries, ACS NANO, 14 (2020) 698-707.

To further increase the energy density of LIBs, relentless research efforts have been invested in the development of new electrode materials and optimizing the electrode formulation.1−5 【商业锂电基于石墨，容量数据】

## 【下一代电池，满足快速发展的储能需求，石墨容量有限】

[6] S. Zhou, C. Fang, X. Song, G. Liu, Highly Ordered Carbon Coating Prepared with Polyvinylidene Chloride Precursor for High-Performance Silicon Anodes in Lithium-Ion Batteries, BATTERIES & SUPERCAPS, 4 (2021) 240-247.

Significant research efforts have been devoted to development of next-generation rechargeable batteries to meet the demand of the rapidly growing energy storage market,[3–7]as the graphite anodes in current LIBs have a rather limited theoretical capacity of 372 mAh/g.【硅的优点】

## 【需要提高锂电池能量密度】

[7] J. Wu, Y. Cao, H. Zhao, J. Mao, Z. Guo, The critical role of carbon in marrying silicon and graphite anodes for high-energy lithium-ion batteries, CARBON ENERGY, 1 (2019) 57-76.

To meet the market demand for lighter batteries with longer service life, the energy densities of LIBs have to be continually increased. The recent development of electrical vehicles and their widespread use also call for LIBs with high energy. Therefore, there is always constant pressure on the relevant academic and industry communities to improve the energy density of LIBs.1-3 【然而，传统使用碳负极的锂电池接近理论能量密度】

【锂电池被广泛使用，但需要进一步提升能量和功率密度】

## 【锂电池被广泛使用，但需要进一步提升能量和功率密度】

[9] J.-C. Kim, K.-J. Kim, S.-M. Lee, Preparation and Characterization of Core-Shell Structure Hard Carbon/Si-Carbon Composites with Multiple Shell Structures as Anode Materials for Lithium-Ion Batteries, ENERGIES, 14 (2021).

Lithium-ion batteries (LIBs) are widely used in many applications but there is an increasing demand for higher energy and power density.【能量和功率密度取决于用什么样的正极负极材料】

## 【需要提高锂电池的能量密度】

[10] X. Zhou, H. Xie, X. He, Z. Zhao, Q. Ma, M. Cai, H. Yin, Annihilating the Formation of Silicon Carbide: Molten Salt Electrolysis of Carbon–Silica Composite to Prepare the Carbon–Silicon Hybrid for Lithium-Ion Battery Anode, Energy and Environmental Materials, 3 (2020) 166-176.

To fulfill the requirements of batteries for electric vehicles and grid energy storage, it is necessary to increase the energy densities of LIBs. [4,5] 【使用高容量电极材料是有效方法】

【为满足xxx，需要发展新的锂电池负极材料】

## 【为满足xxx，需要发展新的锂电池负极材料】

[13] D. Nan, Z.-H. Huang, R. Lv, Y. Lin, L. Yang, X. Yu, L. Ye, W. Shen, H. Sun, F. Kang, Silicon-Encapsulated Hollow Carbon Nanofiber Networks as Binder-Free Anodes for Lithium Ion Battery, JOURNAL OF NANOMATERIALS, 2014 (2014).

To meet the increasing demands of rapidly developing market from cell phone to electric vehicles for the Li-ion batteries (LIBs), new anode materials with higher capacity have attracted significant attention. 【石墨的问题】

【近年来，高能量密度的锂电池的需求提升】

## 【近年来，高能量密度的锂电池的需求提升】

[16] J. Ha, H. Park, M. Kim, Y.T. Kim, J. Choi, Liquefied-Natural-Gas-Derived Vertical Carbon Layer Deposited on SiO as Cost-Effective Anode for Li-Ion Batteries, JOURNAL OF THE ELECTROCHEMICAL SOCIETY, 169 (2022).

Recently, the demand for Li-ion batteries (LIBs) with high energy density has increased.【硅的优点，容量，和其他材料对比】

【随着xxx，锂电池发展被越来越重视】

## 【随着xxx，锂电池发展被越来越重视】

[20] S. Song, J. Li, A. Zheng, Y. Yang, K. Yin, Facile Synthesis of Sponge-Like Porous Nano Carbon-Coated Silicon Anode with Tunable Pore Structure for High-Stability Lithium-Ion Batteries, MOLECULES, 26 (2021).

With the rapid growth of energy demand in mobile devices and electric vehicles, etc., the development of lithium-ion batteries with a high capacity, long cycle life, and low cost has been paid much more attention around the world [1]. 【硅可替代，碳，容量】

## 【需要更高能量密度的锂电池】

[21] J. Chang, X. Huang, G. Zhou, S. Cui, S. Mao, J. Chen, Three-dimensional carbon-coated Si/rGO nanostructures anchored by nickel foam with carbon nanotubes for Li-ion battery applications, NANO ENERGY, 15 (2015) 679-687.

As the power demands in consumer electronics, transportation, and large-scale renewable energy storage continue to increase, LIBs with a greater power and a higher energy density are urgently needed [1–4].【硅可替代石墨；容量；因此被认为有前途】

【需要高性能电池。】

## 【需要高性能电池。】

[22] K. Feng, W. Ahn, G. Lui, H.W. Park, A.G. Kashkooli, G. Jiang, X. Wang, X. Xiao, Z. Chen, Implementing an in-situ carbon network in Si/reduced graphene oxide for high performance lithium-ion battery anodes, NANO ENERGY, 19 (2016) 187-197.

The ever soaring market of portable electronic devices has triggered significant demand and unprecedented research interests for high performance batteries. 【锂电池主导市场】

【发展高能量密度和长循环寿命的锂电池，应用】

## 【发展高能量密度和长循环寿命的锂电池，应用】

[4] B. Chen, L. Zu, Y. Liu, R. Meng, Y. Feng, C. Peng, F. Zhu, T. Hao, J. Ru, Y. Wang, J. Yang, Space-Confined Atomic Clusters Catalyze Superassembly of Silicon Nanodots within Carbon Frameworks for Use in Lithium-Ion Batteries, ANGEWANDTE CHEMIE-INTERNATIONAL EDITION, 59 (2020) 3137-3142.

There is considerable demand to develop rechargeable lithium-ion batteries (LIBs) with high energy capacity and long cycle life for applications in portable electronic devices and electrical/hybrid vehicles. [1,2] 【硅被认为有前途，高容量】

## 【尽快取得成功商业化应用，还需要进一步性能提升】

[15] Z.P. Guo, E. Milin, J.Z. Wang, J. Chen, H.K. Liu, Silicon/disordered carbon nanocomposites for lithium-ion battery anodes, JOURNAL OF THE ELECTROCHEMICAL SOCIETY, 152 (2005) A2211-A2216.

Despite their successful commercial application, further performance improvement of the lithium-ion battery is still required.

【石墨被广泛使用】

## 【发展具有xxx性能特点的锂电池很重要】

[23] J. Yang, Y.-X. Wang, S.-L. Chou, R. Zhang, Y. Xu, J. Fan, W.-x. Zhang, H.K. Liu, D. Zhao, S.X. Dou, Yolk-shell silicon-mesoporous carbon anode with compact solid electrolyte interphase film for superior lithium-ion batteries, NANO ENERGY, 18 (2015) 133-142.

Developing rechargeable lithium ion batteries (LIBs) with a long cycling life, high energy density, and excellent ratecapability is of critical importance for electric vehicles and renewable energy storage [1–4]. 【石墨理论容量低，无法满足这些需要高能量密度的应用】

# 硅的优点

## 【硅的优点】

[1] C. Jo, A.S. Groombridge, J. De La Verpilliere, J.T. Lee, Y. Son, H.-L. Liang, A.M. Boies, M. De Volder, Continuous-Flow Synthesis of Carbon-Coated Silicon/Iron Silicide Secondary Particles for Li-Ion Batteries, ACS NANO, 14 (2020) 698-707.

Si is a promising active material because of its high theoretical capacity (>3500 mAh/g), low reaction potential (∼0.35 V), and low cost.29−32 【硅已在石墨电极中混合少量，作为商业电动车应用】

## 【硅的优点】

[2] R.F.H. Hernandha, P.C. Rath, B. Umesh, J. Patra, C.-Y. Huang, W.-W. Wu, Q.-F. Dong, J. Li, J.-K. Chang, Supercritical CO2-Assisted SiOx/Carbon Multi-Layer Coating on Si Anode for Lithium-Ion Batteries, ADVANCED FUNCTIONAL MATERIALS, 31 (2021).

Among them, Si is a promising anode material due to its high gravimetric capacity (theoretically 3579 mAh g −1 ), earth abundance, and low toxicity. [5] Moreover, its relatively high lithiation/delithiation potential compared to that of graphite makes it safer to operate(i.e., lower risk of Li metal plating). [6]Thus, Si-based anodes have the potential for application in high-performance, ecofriendly, and low-cost LIBs. 【硅的缺点】

## 【硅被认为是有前途的负极材料，可替代石墨】

[3] H. Su, A.A. Barragan, L. Geng, D. Long, L. Ling, K.N. Bozhilov, L. Mangolini, J. Guo, Colloidal Synthesis of Silicon–Carbon Composite Material for Lithium-Ion Batteries, Angewandte Chemie - International Edition, 56 (2017) 10780-10785.

Silicon is recognized as the most promising anode material to replace or complement graphite in lithium-ion (Li-ion) batteries.[1]【硅的缺点】

## 【硅被认为有前途，高容量】

[4] B. Chen, L. Zu, Y. Liu, R. Meng, Y. Feng, C. Peng, F. Zhu, T. Hao, J. Ru, Y. Wang, J. Yang, Space-Confined Atomic Clusters Catalyze Superassembly of Silicon Nanodots within Carbon Frameworks for Use in Lithium-Ion Batteries, ANGEWANDTE CHEMIE-INTERNATIONAL EDITION, 59 (2020) 3137-3142.

Si is recognized as one of the most promising anode candidates because of its high theoretical lithium-storage capacity (4200 mAhg @1 for Li 22 Si 5 ) and moderate Li-uptake potential (0.4 V vs. Li/Li + ). [3–6] 【硅的缺点】

## 【硅被认为有前途，高容量】

[5] F. Wang, M. Gao, R. Hong, X. Lu, Magnetoelectric Plasma Preparation of Silicon-Carbon Nanocomposite as Anode Material for Lithium Ion Batteries, APPLIED SCIENCES-BASEL, 10 (2020).

Among these, Si-based material is considered as a promising candidate owing to its high theoretical capacity of 4200 mAh g−1 [13,14].【硅的挑战，问题】

## 【硅的优点】

[6] S. Zhou, C. Fang, X. Song, G. Liu, Highly Ordered Carbon Coating Prepared with Polyvinylidene Chloride Precursor for High-Performance Silicon Anodes in Lithium-Ion Batteries, BATTERIES & SUPERCAPS, 4 (2021) 240-247.

Silicon materials, with a nearly 10-fold higher theoretical capacity of 3579 mAh/g, relatively low discharge potential (<0.5 V vs. Li/Li+ considered as promising anode materials for LIBs.[8–10]), and abundant resource, have been considered as promising anode materials for LIBs.[8–10]【硅的缺点】

## 【使用硅可限制提升能量密度】

[7] J. Wu, Y. Cao, H. Zhao, J. Mao, Z. Guo, The critical role of carbon in marrying silicon and graphite anodes for high-energy lithium-ion batteries, CARBON ENERGY, 1 (2019) 57-76.

With the same cathode material, replacing graphite with Si can significantly improve the energy density of LIBs. 【因此，硅被认为最有前途的，优点】

## 【因此，硅被认为最有前途的，优点】

[7] J. Wu, Y. Cao, H. Zhao, J. Mao, Z. Guo, The critical role of carbon in marrying silicon and graphite anodes for high-energy lithium-ion batteries, CARBON ENERGY, 1 (2019) 57-76.

Therefore, Si has been considered as one of the most‐promising next‐generation anodes towards high‐energy LIBs because of its high theoretical capacity (3572 mAh/g), low working voltage (~0.2 V vs Li/Li+), and abundance in the earth’s crust.7【硅的缺点】

【硅的优点。有吸引力的锂电池负极】

## 【硅的优点。有吸引力的锂电池负极】

[8] E.H. Chung, J.P. Kim, H.G. Kim, J.-M. Chung, S.-J. Lee, J.-S. Bae, E.D. Jeong, The Synthesis and Electrochemical Performance of Si Composite with Hollow Carbon Microtubes by the Carbonization of Milkweed from Nature as Anode Template for Lithium Ion Batteries, ENERGIES, 13 (2020).

It has been known Silicon (Si) has many advantages such as high theoretical capacity (4200 mAh/g),non-toxic, low cost, and abundant reserve [1–6]. Therefore, Si is the one of the most attractive materials as an anode for lithium ion battery. 【硅的问题】

## 【硅的优点】

[9] J.-C. Kim, K.-J. Kim, S.-M. Lee, Preparation and Characterization of Core-Shell Structure Hard Carbon/Si-Carbon Composites with Multiple Shell Structures as Anode Materials for Lithium-Ion Batteries, ENERGIES, 14 (2021).

Among various anode materials, silicon has been investigated as one of the most promising alternatives to conventional graphite anodes because of its high theoretical specific capacity (about 4200 mAh/g) [1].

【硅的缺点】

## 【硅的优点】

[10] X. Zhou, H. Xie, X. He, Z. Zhao, Q. Ma, M. Cai, H. Yin, Annihilating the Formation of Silicon Carbide: Molten Salt Electrolysis of Carbon–Silica Composite to Prepare the Carbon–Silicon Hybrid for Lithium-Ion Battery Anode, Energy and Environmental Materials, 3 (2020) 166-176.

Si is an earth-abundant element and of a theoretical gravimetrical capacity of 3579 mAh g-1 ,which is ten-fold of the commercially used graphite anode (372 mAh g-1 ). [6] 【硅的缺点】

【硅在锂电池中有前途】

## 【硅在锂电池中有前途】

[11] Z. Wu, J. Luo, J. Peng, H. Liu, B. Chang, X. Wang, Rational architecture design of yolk/double-shells Si-based anode material with double buffering carbon layers for high performance lithium-ion battery, GREEN ENERGY & ENVIRONMENT, 6 (2021) 517-527.

Silicon (Si)-based anode materials as a glaring star among the all currently reported anode materials, and it has attracted more and more attention in the industry of LIBs. 【石墨的问题】

## 【硅的优点】

[11] Z. Wu, J. Luo, J. Peng, H. Liu, B. Chang, X. Wang, Rational architecture design of yolk/double-shells Si-based anode material with double buffering carbon layers for high performance lithium-ion battery, GREEN ENERGY & ENVIRONMENT, 6 (2021) 517-527.

Generally speaking, the Si-based anode materials in LIBs have many merits, such as the great rich in the earth, theoretical specific capacity（3580 mA h g1）is ten times higher than that of graphite, and the relatively low potential of 0.3 V vs. Liþ/Li, which can avoid the formation of lithium dendrites [3–5]. 【硅的缺点】

## 【硅和氧化铁被认为有吸引力】

[12] L. Zhang, H. Guo, R. Rajagopalan, X. Hu, Y. Huang, S.X. Dou, H.K. Liu, One-step synthesis of a silicon/hematite@carbon hybrid nanosheet/silicon sandwich-like composite as an anode material for Li-ion batteries, JOURNAL OF MATERIALS CHEMISTRY A, 4 (2016) 4056-4061.

Silicon (Si) and hematite (a-Fe2O3) have long been regarded as appealing anode materials for LIBs because of their much higher theoretical capacities ($4200 and 1007 mA h g1, respectively) than those of the commercially used ones, as well as their nontoxicity and natural abundance.3,6–14【硅和氧化铁的缺点】

## 【硅的优点，容量，和其他材料对比】

[16] J. Ha, H. Park, M. Kim, Y.T. Kim, J. Choi, Liquefied-Natural-Gas-Derived Vertical Carbon Layer Deposited on SiO as Cost-Effective Anode for Li-Ion Batteries, JOURNAL OF THE ELECTROCHEMICAL SOCIETY, 169 (2022).

Si-based materials are the most promising candidates for LIB anode materials because of their high theoretical capacity (∼4200 mAh g−1 for Si, ∼2400 mAh g−1 for silicon monoxide (SiO), and ∼1680 mAh g−1 for silicon dioxide (SiO2)) compared to transition metal oxide1,2 and organic based electrode3 adequate lithium alloying–dealloying potential (∼0.5 V vs Li/Li+), and abundance in the Earth’s crust (15.1 wt%).4,5 【硅的缺点】

【硅的优点，相对石墨，锂电池的候选负极】

## 【硅的优点，相对石墨，锂电池的候选负极】

[17] J. Kong, Y. Wei, Silicon Nanoparticles Confined in Thin Carbon Network: The Free-Standing Anode of Lithium Ion Batteries with High Performance and Easy Recyclability, JOURNAL OF THE ELECTROCHEMICAL SOCIETY, 166 (2019) A2013-A2020.

As the one with exceptionally high gravimetric and volumetric capacity, low discharge voltage as well as abundant resource, silicon (Si) is a promising anode candidate as potential alternative to current commercial graphite in lithium ion batteries (LIBs). 【硅被广泛探索，过去15年几百篇文章】

## 【硅有前途，优点】

[18] Z. He, X. Wu, Z. Yi, X. Wang, Y. Xiang, Silicon/graphene/carbon hierarchical structure nanofibers for high performance lithium ion batteries, MATERIALS LETTERS, 200 (2017) 128-131.

Silicon is a promising candidate for anode material because of its high theoretical capacity (about 4200 mAh g-1), low discharge voltage and natural abundance [9–14].【硅的问题】

【纳米硅在锂电池中展现巨大潜力】

## 【纳米硅在锂电池中展现巨大潜力】

[21] J. Chang, X. Huang, G. Zhou, S. Cui, S. Mao, J. Chen, Three-dimensional carbon-coated Si/rGO nanostructures anchored by nickel foam with carbon nanotubes for Li-ion battery applications, NANO ENERGY, 15 (2015) 679-687.

Nanostructured silicon (Si) electrodes have shown great potential as lithium-ion battery (LIB) anodes. 【需要更高能量密度的锂电池】

## 【硅可替代石墨；容量；因此被认为有前途】

[21] J. Chang, X. Huang, G. Zhou, S. Cui, S. Mao, J. Chen, Three-dimensional carbon-coated Si/rGO nanostructures anchored by nickel foam with carbon nanotubes for Li-ion battery applications, NANO ENERGY, 15 (2015) 679-687.

Sianodes [5–9] offer an alternative to commercial graphite, with Li storage capacity ten times higher than that of the graphite (372 mAh g-1)usedincommercialLIBs; thus, Si has been considered as a promising candidate for an anode material for next-generation LIBs.【硅的缺点】

## 【硅被认为是下一代负极材料】

[22] K. Feng, W. Ahn, G. Lui, H.W. Park, A.G. Kashkooli, G. Jiang, X. Wang, X. Xiao, Z. Chen, Implementing an in-situ carbon network in Si/reduced graphene oxide for high performance lithium-ion battery anodes, NANO ENERGY, 19 (2016) 187-197.

Silicon (Si) has been regarded as a promising candidate anode material for next-generation LIBs due to its outstanding properties.【硅的优点】

## 【硅的优点】

[22] K. Feng, W. Ahn, G. Lui, H.W. Park, A.G. Kashkooli, G. Jiang, X. Wang, X. Xiao, Z. Chen, Implementing an in-situ carbon network in Si/reduced graphene oxide for high performance lithium-ion battery anodes, NANO ENERGY, 19 (2016) 187-197.

The theoretical gravimetric capacity of Si is approximately 4200 mAh g-1 – more than ten times that of the commercial graphite (372 mAh g-1) [6]. In addition, Si's high natural abundance, environmental compatibility, low working potential (0–0.4 V vs. Li/Li+), and maturity in the Si semiconductor industry all make it highly desirable as an anode material for LIBs [7–9]. 【硅的缺点】

## 【硅的特点，被认为有前途】

[23] J. Yang, Y.-X. Wang, S.-L. Chou, R. Zhang, Y. Xu, J. Fan, W.-x. Zhang, H.K. Liu, D. Zhao, S.X. Dou, Yolk-shell silicon-mesoporous carbon anode with compact solid electrolyte interphase film for superior lithium-ion batteries, NANO ENERGY, 18 (2015) 133-142.

Due to its high theoretical capacity (Li4.4Si=4200 mA h g-1) and low discharge potential ($0.5 V versus Li/Li+), silicon has been considered as an attractive and promising candidate for LIBs [8]. 【硅的缺点】

## 【硅被认为有前途，的优点】

[24] J. Lu, D. Wang, J. Liu, G. Qian, Y. Chen, Z. Wang, Hollow double-layer carbon nanocage confined Si nanoparticles for high performance lithium-ion batteries, NANOSCALE ADVANCES, 2 (2020) 3222-3230.

Among the emerging anode materials, silicon (Si) is a promising candidate for next-generation LIB anodes due to its high specific capacity (Li15Si4, 3579 mA h g-1), low Li-uptake voltage (-0.5 V vs. Li/Li+) and natural abundance (second largest resource).5–7 【硅的缺点】

## 【硅的容量优势，相比石墨】

[25] B. Li, F. Yao, J.J. Bae, J. Chang, M.R. Zamfir, L. Duc Toan, P. Duy Tho, H. Yue, Y.H. Lee, Hollow carbon nanospheres/silicon/alumina core-shell film as an anode for lithium-ion batteries, SCIENTIFIC REPORTS, 5 (2015).

Silicon is an exciting and promising alternative anode material to replace graphite due to its highest theoretical specific capacity of 3579 mA h g -1 among all of the alloy type anodes, which is almost ten times that of graphite anode (372 mA h g -1) 5. 【硅的问题】

## 【硅的优点】

[26] L.Y. Yang, H.Z. Li, J. Liu, Z.Q. Sun, S.S. Tang, M. Lei, Dual yolk-shell structure of carbon and silica-coated silicon for high-performance lithium-ion batteries, SCIENTIFIC REPORTS, 5 (2015).

Among the various anode materials, silicon is one of the most promising candidates due to its high theoretical capacity (~3580 mA h g−1, Li15Si4) among alloy type anode materials and relatively low discharge potential (~0.4 V vs. Li/Li+)4,5. 【硅的缺点】

## 【各类硅纳米结构。优点】

[17] J. Kong, Y. Wei, Silicon Nanoparticles Confined in Thin Carbon Network: The Free-Standing Anode of Lithium Ion Batteries with High Performance and Easy Recyclability, JOURNAL OF THE ELECTROCHEMICAL SOCIETY, 166 (2019) A2013-A2020.

Firstly, introducing “nano-effect” by reducing at least one dimension of Si to normally less than 100 nm, such as Si nanoparticles/nanospheres/nanoflowers,8–10 nanocubes,11 mesoporous Si,12–14 Si nanowires,.15–18 The nanoscale dimension of the Si realizes faster and more complete alloying and de-alloying with lithium ions, and meanwhile suppresses the volume expansion during the process. 【硅复合物】

# 引入硅，但由于硅的缺点，限制了添加量，限制了容量的进一步提升，未能充分发挥潜力等。

## 【硅已在石墨电极中混合少量，作为商业电动车应用】

[1] C. Jo, A.S. Groombridge, J. De La Verpilliere, J.T. Lee, Y. Son, H.-L. Liang, A.M. Boies, M. De Volder, Continuous-Flow Synthesis of Carbon-Coated Silicon/Iron Silicide Secondary Particles for Li-Ion Batteries, ACS NANO, 14 (2020) 698-707.

Because of these properties, Si is already mixed in very small amounts with graphite electrodes for commercial automotive applications.5【本文，体系选取理由】

## 【硅的缺点】

[2] R.F.H. Hernandha, P.C. Rath, B. Umesh, J. Patra, C.-Y. Huang, W.-W. Wu, Q.-F. Dong, J. Li, J.-K. Chang, Supercritical CO2-Assisted SiOx/Carbon Multi-Layer Coating on Si Anode for Lithium-Ion Batteries, ADVANCED FUNCTIONAL MATERIALS, 31 (2021).

Nevertheless, the practical implementation of Si anodes is hindered by its fast capacity decay. [7] The severe volume change (i.e., ≈400%) of Si during lithiation/delithiation causes the mechanical degradation and pulverization of Si particles. Repeated volume expansion/contraction also results in an unstable solid electrolyte interphase (SEI). Low Coulombic efficiency (CE) and SEI accumulation gradually increase the interfacial resistance, leading to electrode performance decay. [8]

【为缓解硅的快速劣化，提出的一些策略】

【硅被认为是有前途的负极材料，可替代石墨】

[3] H. Su, A.A. Barragan, L. Geng, D. Long, L. Ling, K.N. Bozhilov, L. Mangolini, J. Guo, Colloidal Synthesis of Silicon–Carbon Composite Material for Lithium-Ion Batteries, Angewandte Chemie - International Edition, 56 (2017) 10780-10785.

1、intoroduction

## 【硅的缺点】

[3] H. Su, A.A. Barragan, L. Geng, D. Long, L. Ling, K.N. Bozhilov, L. Mangolini, J. Guo, Colloidal Synthesis of Silicon–Carbon Composite Material for Lithium-Ion Batteries, Angewandte Chemie - International Edition, 56 (2017) 10780-10785.

However, the large volume change associated with lithiation/delithiation of Si causes significant challenges to practical Si-based anodes.[2]【】【】 【虽然采用纳米化硅后，粉化可能不再是主要问题，但是频繁的体积变化会带来副作用】

## 【硅的缺点】

[4] B. Chen, L. Zu, Y. Liu, R. Meng, Y. Feng, C. Peng, F. Zhu, T. Hao, J. Ru, Y. Wang, J. Yang, Space-Confined Atomic Clusters Catalyze Superassembly of Silicon Nanodots within Carbon Frameworks for Use in Lithium-Ion Batteries, ANGEWANDTE CHEMIE-INTERNATIONAL EDITION, 59 (2020) 3137-3142.

However, the serious volume variation (ca. 400%) of Si electrodes, coupled with poor conductivity, often cause electrode pulverization and active material loss, resulting in overall deterioration of battery performance. [7–11] 【将硅融入碳基体被认为是一个有效方法提升性能】

## 【硅的挑战，问题】

[5] F. Wang, M. Gao, R. Hong, X. Lu, Magnetoelectric Plasma Preparation of Silicon-Carbon Nanocomposite as Anode Material for Lithium Ion Batteries, APPLIED SCIENCES-BASEL, 10 (2020).

At present, the main challenge is the enormous volumetric change of the Si during the cycle process, leading to structural failure and pulverization [15,16], and the low electronic conductivity of silicon also induces severe irreversible capacity loss.

【目前工作聚焦在发展新的硅基结构解决体积变化问题，举例】

## 【硅的缺点】

[6] S. Zhou, C. Fang, X. Song, G. Liu, Highly Ordered Carbon Coating Prepared with Polyvinylidene Chloride Precursor for High-Performance Silicon Anodes in Lithium-Ion Batteries, BATTERIES & SUPERCAPS, 4 (2021) 240-247.

However, a major obstacle for silicon anodes is the dramatic volume change of silicon that occurs during lithiation and de-lithiation, which undermines the electrode’s integrity and disrupts the solid electrolyte interface (SEI). The breakdown of the SEI layers during cycling results in a range of problems, such as low Coulombic efficiency (CE), quick capacity fading and poor cycling stability.[11,12]

【为克服硅的问题，提出许多策略，举例】

## 【硅的缺点】

[7] J. Wu, Y. Cao, H. Zhao, J. Mao, Z. Guo, The critical role of carbon in marrying silicon and graphite anodes for high-energy lithium-ion batteries, CARBON ENERGY, 1 (2019) 57-76.

However, unlike the intercalation‐type anodes (eg, graphite), the alloying/dealloying reaction of Si with Li induces huge volume changes (>300%). Such huge volume changes during electrochemical cycling will lead to repeated cracking and pulverization of Si, and hence the disintegration and fracturing of the Si electrode, accompanied by electrical isolation. The repeated cracking and pulverization will also lead to the continual breaking up of the solid electrolyte interphase (SEI) layer and the explosion of new surface, which will quickly consume the electrolyte and Li ions.【单独使用硅负极的缺陷】

## 【单独使用硅负极的缺陷】

[7] J. Wu, Y. Cao, H. Zhao, J. Mao, Z. Guo, The critical role of carbon in marrying silicon and graphite anodes for high-energy lithium-ion batteries, CARBON ENERGY, 1 (2019) 57-76.

Therefore, the use of sole Si anode suffers from extremely fast capacity decay and low coulombic efficiency (CE) as a result of the severe volume changes and unstable SEI films. 【使用纳米材料，发展复合物以提升循环性能】

## 【硅的问题】

[8] E.H. Chung, J.P. Kim, H.G. Kim, J.-M. Chung, S.-J. Lee, J.-S. Bae, E.D. Jeong, The Synthesis and Electrochemical Performance of Si Composite with Hollow Carbon Microtubes by the Carbonization of Milkweed from Nature as Anode Template for Lithium Ion Batteries, ENERGIES, 13 (2020).

Two main problems should be solved for Si to be used as an anode commercially, which are low electrical conductivity and significant volume expansion (~300%) during Li insertion/extraction [7–12].【为提升导电性，硅表面包覆碳材料】

## 【硅的缺点】

[9] J.-C. Kim, K.-J. Kim, S.-M. Lee, Preparation and Characterization of Core-Shell Structure Hard Carbon/Si-Carbon Composites with Multiple Shell Structures as Anode Materials for Lithium-Ion Batteries, ENERGIES, 14 (2021).

However, the practical application of Si as an anode material is currently impeded by its large volume change (~300%) during lithiation and delithiation, resulting in capacity fading and a limited lifecycle. Moreover, the rate capability of Si electrodes is limited by the low electronic conductivity of Si and low lithium diffusion rates in Si [ 2 – 4 ]. 【大量工作提升结构稳定性和电学性能】

## 【硅的缺点】

[10] X. Zhou, H. Xie, X. He, Z. Zhao, Q. Ma, M. Cai, H. Yin, Annihilating the Formation of Silicon Carbide: Molten Salt Electrolysis of Carbon–Silica Composite to Prepare the Carbon–Silicon Hybrid for Lithium-Ion Battery Anode, Energy and Environmental Materials, 3 (2020) 166-176.

This means that one Si atom can accommodate around four Li + to form Li 15 Si 4 at a fully charged state, resulting in a vast volume expansion (~300%) of Si. [7] During discharge, Li + ions will be extracted out from the Si and subsequently incur a significant volume shrinkage thus causing the collapse of Si framework. [8] After repeated charge and discharge cycles, pulverization of the Si anode becomes severe along with the continual formation of solid electrolyte interface (SEI) layers, so that the active electrode materials gradually lose contact from current collectors and consequently the capacity of the electrode decays. [9]【因此，高容量硅负极发展的焦点是降低体积变化引起的性能衰减】

## 【硅的缺点】

[11] Z. Wu, J. Luo, J. Peng, H. Liu, B. Chang, X. Wang, Rational architecture design of yolk/double-shells Si-based anode material with double buffering carbon layers for high performance lithium-ion battery, GREEN ENERGY & ENVIRONMENT, 6 (2021) 517-527.

However, Si-based anode materials undergo the large volume expansion (300%) in lithiation/delithiation process, which will lead to the collapsing and pulverization of the active material, corresponded to the active materials break away from the current collectors [6,7]. Besides, the repeated fracture and formation of solid electrolyte interface (SEI) results in the irreversible consumption of Liþ and electrolyte [8,9], and it causes the low coulombic efficiency and large irreversible capacity loss [6]. In addition, the performance of Sibased anode materials is restricted by sluggish electrochemical kinetics due to the inherent low conductivity [10].

【提出很多策略解决硅的问题。举例，纳米化。】

## 【硅和氧化铁的缺点】

[12] L. Zhang, H. Guo, R. Rajagopalan, X. Hu, Y. Huang, S.X. Dou, H.K. Liu, One-step synthesis of a silicon/hematite@carbon hybrid nanosheet/silicon sandwich-like composite as an anode material for Li-ion batteries, JOURNAL OF MATERIALS CHEMISTRY A, 4 (2016) 4056-4061.

Despite all these advantages, the full utilization of silicon- or a-Fe2O3-based batteries to date has been hindered by a series of obstacles, including poor cycle life and rate performance, that resulted from their large volumetric expansion during cycling and low ionic/electronic conductivity.15–19【为改善硅和氧化铁缺点做了大量努力，举例】

## 【硅的挑战和问题】

[13] D. Nan, Z.-H. Huang, R. Lv, Y. Lin, L. Yang, X. Yu, L. Ye, W. Shen, H. Sun, F. Kang, Silicon-Encapsulated Hollow Carbon Nanofiber Networks as Binder-Free Anodes for Lithium Ion Battery, JOURNAL OF NANOMATERIALS, 2014 (2014).

However, there still exist several challenges which restrict the commercialization of such silicon anodes. Firstly, the large volumetric expansion (∼400%) of silicon anodes upon the lithiation results in high internal stress, causes mechanical fracture and pulverization of electrode and subsequent losses of electrical contact between the active material and current collector, and leads to poor reversibility and rapid fading of capacity. Secondly, the huge and repeated volume change during the charge/discharge process prevents the formation of a layer of stable solid electrolyte interface (SEI). Hence it can easily continuously grow through the cracks till being too thick for Li-ions to diffuse through, and in turn results in a low Coulombic efficiency and a decrease in capacity. Moreover, silicon anodes possess poor electrical conductivity [2, 3]. Such drawbacks lead to serious capacity fade during cycles and thus hinder the practical applications of silicon anodes.

【为解决以上硅的问题，需要xxx】

## 【但是，还没有利用大容量硅负极的实际应用】

[14] N. Kobayashi, Y. Inden, M. Endo, Silicon/soft-carbon nanohybrid material with low expansion for high capacity and long cycle life lithium-ion battery, JOURNAL OF POWER SOURCES, 326 (2016) 235-241.

Thus, no practical application of LIB, taking advantage of large capacity of Si, has been performed.【硅电极的最大挑战，寿命短，原因】

## 【硅电极的最大挑战，寿命短，原因】

[14] N. Kobayashi, Y. Inden, M. Endo, Silicon/soft-carbon nanohybrid material with low expansion for high capacity and long cycle life lithium-ion battery, JOURNAL OF POWER SOURCES, 326 (2016) 235-241.

The greatest challenges that obstruct the practical use of silicon-based materials for LIB is their short cycle life that arises from the alloying of silicon and lithium during their charging and discharging processes and the change in their big volume through large expansion and contraction during the repeated desorption of lithium from the alloy. In previous studies, these effects have been well documented to adversely affect the cycle life of LIB.【电动车的寿命需要15年，接近燃油车】

## 【硅的缺点】

[16] J. Ha, H. Park, M. Kim, Y.T. Kim, J. Choi, Liquefied-Natural-Gas-Derived Vertical Carbon Layer Deposited on SiO as Cost-Effective Anode for Li-Ion Batteries, JOURNAL OF THE ELECTROCHEMICAL SOCIETY, 169 (2022).

However, because of their low conductivity and high-volume expansion rate during cycling (∼400%) leading to loss of electric contact via pulverization and electrolyte decomposition, Si-based electrodes exhibit poor cycling properties and fast capacity fading.6,7【因此，为克服缺点，活性材料表面碳涂层，可解决什么问题】

## 【尽管取得进展，硅的问题】

[17] J. Kong, Y. Wei, Silicon Nanoparticles Confined in Thin Carbon Network: The Free-Standing Anode of Lithium Ion Batteries with High Performance and Easy Recyclability, JOURNAL OF THE ELECTROCHEMICAL SOCIETY, 166 (2019) A2013-A2020.

Despite the great potential, several issues of Si as anode severely hinder its practical use, including large volume expansion (more than 300% upon full lithiation) that irreversibly breaks the structural integrity, poor intrinsic electrical conductivity that causes sluggish electrochemical kinetics, as well as gradual pulverization of the anode along with lithiation/delithiation cycles.

## 【硅的问题】

[18] Z. He, X. Wu, Z. Yi, X. Wang, Y. Xiang, Silicon/graphene/carbon hierarchical structure nanofibers for high performance lithium ion batteries, MATERIALS LETTERS, 200 (2017) 128-131.

But a significant volume expansion and unstable solid electrolyte interphase (SEI) films occurred during the electrode process and results in particle fracture and loss of capacity with cycling [15–20]. 【硅纳米颗粒包裹在碳材料中，是个有效策略】

## 【硅的缺点】

[20] S. Song, J. Li, A. Zheng, Y. Yang, K. Yin, Facile Synthesis of Sponge-Like Porous Nano Carbon-Coated Silicon Anode with Tunable Pore Structure for High-Stability Lithium-Ion Batteries, MOLECULES, 26 (2021).

However, the extremely large volume expansion of silicon anode as high as 280% (vs. Li15Si4)~417% (vs. Li22Si5) causes severe problems such as pulverization, unstable solid electrolyte interface (SEI) film, etc. [5,6]. These issues lead to the rapid irreversible capacity decay of silicon anodes during the cycling, and then result in poor cycling stability.

【结构设计是提高硅基负极稳定性的主要策略】

## 【硅的缺点】

[21] J. Chang, X. Huang, G. Zhou, S. Cui, S. Mao, J. Chen, Three-dimensional carbon-coated Si/rGO nanostructures anchored by nickel foam with carbon nanotubes for Li-ion battery applications, NANO ENERGY, 15 (2015) 679-687.

Unfortunately, practical applications of Si as an anode material are not yet a reality due to the huge volume change (4300%) during the lithiation/delithiation process, which leads to dramatic destruction of the initial particle morphology and the loss of electrical contact between active materials and the electrode framework. In addition, the low intrinsic electrical conductivity of Si leads to dramatic pulverization of the Si anode material, rapid capacity decay, and poor cyclability, and thus should be addressed before its practical application [10,11].

【许多努力改善硅的问题，方法举例】

## 【硅的缺点】

[22] K. Feng, W. Ahn, G. Lui, H.W. Park, A.G. Kashkooli, G. Jiang, X. Wang, X. Xiao, Z. Chen, Implementing an in-situ carbon network in Si/reduced graphene oxide for high performance lithium-ion battery anodes, NANO ENERGY, 19 (2016) 187-197.

However, several intrinsic drawbacks of Si have prevented it from being widely commercialized as LIB anodes. One of the critical challenges is that the large volume expansion of Si upon lithiation (up to 400% of its original volume) can cause it to crack and pulverize, resulting in the loss of contact points between the active material and the current collector [10–12]. This large volume change also leads to the continuous formation of an unstable solid electrolyte interphase (SEI) which consumes a considerable amount of electrolyte and lithium in a battery [13]. Columbic efficiency and electrode capacity are hence lowered due to these continuous side reactions. Furthermore, the repetitive growth of the SEI may severely block the conductive pathway of electrons between Si and the current collector. These phenomena significantly decrease the electrode's integrity and electron conductivity and, ultimately, the battery's rate performance [14]. Although the pulverization of Si can be prevented by engineering nano-sized structures, the severe volume variation can still lead to the displacement and the detachment of Si from the electrode's original conductive network during cycling [15]. The above disadvantages consequently result in poor cycling and rate performance of Si electrodes. 【为解决以上硅的问题，学者提出一些策略】

## 【硅的缺点】

[23] J. Yang, Y.-X. Wang, S.-L. Chou, R. Zhang, Y. Xu, J. Fan, W.-x. Zhang, H.K. Liu, D. Zhao, S.X. Dou, Yolk-shell silicon-mesoporous carbon anode with compact solid electrolyte interphase film for superior lithium-ion batteries, NANO ENERGY, 18 (2015) 133-142.

The practical application of Si-based anodes, however, is still hindered by two critical problems: the relatively low electric conductivity and the huge volume expansion ($400%) upon lithium insertion and extraction [9]. These often cause fracturing, pulverization, and loss of electrical contact, leading to rapid capacity fading and poor cycling performance [10].

【一个有效的策略，使用不同形貌的纳米硅。与块体硅相比的优点】

## 【纳米硅的缺点】

[23] J. Yang, Y.-X. Wang, S.-L. Chou, R. Zhang, Y. Xu, J. Fan, W.-x. Zhang, H.K. Liu, D. Zhao, S.X. Dou, Yolk-shell silicon-mesoporous carbon anode with compact solid electrolyte interphase film for superior lithium-ion batteries, NANO ENERGY, 18 (2015) 133-142.

Nanostructured silicon materials, however, still suffer from poor electric conduction [18].【优化纳米硅，将纳米硅和不同导电基体融合，举例】

## 【硅的缺点】

[24] J. Lu, D. Wang, J. Liu, G. Qian, Y. Chen, Z. Wang, Hollow double-layer carbon nanocage confined Si nanoparticles for high performance lithium-ion batteries, NANOSCALE ADVANCES, 2 (2020) 3222-3230.

Unfortunately, the application of Si-based anodes has been impeded because of its inferior intrinsic conductivity and large volume effect (~300%) during lithiation.8,9 The huge volume variation produces high mechanical stress that causes the powdering of the electrode materials and formation of an unstable solid electrolyte interphase (SEI), resulting in fast capacity fading and poor coulombic efficiency.10

【发展大量策略解决硅的问题】

## 【硅的问题】

[25] B. Li, F. Yao, J.J. Bae, J. Chang, M.R. Zamfir, L. Duc Toan, P. Duy Tho, H. Yue, Y.H. Lee, Hollow carbon nanospheres/silicon/alumina core-shell film as an anode for lithium-ion batteries, SCIENTIFIC REPORTS, 5 (2015).

However, two major scientific and technical challenges have hindered its practical applications. First, due to the alloying mechanism, a large number of lithium atoms are inserted into Si and chemical bonds between Si atoms are broken. The structural pulverization induced by the large volume change (>300% at room temperature) during Li insertion and extraction leads to the loss of electrical contact between the active material and the current collector, eventually resulting in capacity fading and short battery lifetime 6,7. Second, due to the volume expansion and shrink, a thick solid-electrolyte interphase (SEI) layer can be formed deriving from the irreversible side reactions with the organic electrolyte 8. This causes the degradation of battery performance due to the consumption of electrolyte and lithium ions, the electrically insulating nature and the rather long lithium diffusion length through the thick SEI 9. 【因此，需要解决硅的问题】

## 【硅的缺点】

[26] L.Y. Yang, H.Z. Li, J. Liu, Z.Q. Sun, S.S. Tang, M. Lei, Dual yolk-shell structure of carbon and silica-coated silicon for high-performance lithium-ion batteries, SCIENTIFIC REPORTS, 5 (2015).

Despite these advantages, silicon anodes have two major disadvantages that have prevented their widespread use. First, the large volume changes (~300%) in silicon upon insertion and extraction of lithium-ions lead to severe electrode pulverization, which results in the loss of contact between the active materials and the current collector, leading to rapid capacity fading. Second, the continual pulverization of silicon during cycling causes the electrode surface to be cyclically exposed to the electrolyte. This generates continual formation of solid-electrolyte interphase (SEI) films, contributing to capacity fading and poor coulombic efficiency.

【为解决硅的这些问题，许多工作致力于发展硅纳米结构，举例，硅复合物】

# 诸多策略被提出以改善硅的缺点

## 【目前研究正在发展策略以解决问题】

[1] C. Jo, A.S. Groombridge, J. De La Verpilliere, J.T. Lee, Y. Son, H.-L. Liang, A.M. Boies, M. De Volder, Continuous-Flow Synthesis of Carbon-Coated Silicon/Iron Silicide Secondary Particles for Li-Ion Batteries, ACS NANO, 14 (2020) 698-707.

Ongoing research is developing strategies to alleviate some of these challenges.13−15 【吸引人的策略，改善导电性，碳包覆。文献举例，缓冲体积膨胀，但降低振实密度】

## 【为克服硅的问题，提出许多策略，举例】

[6] S. Zhou, C. Fang, X. Song, G. Liu, Highly Ordered Carbon Coating Prepared with Polyvinylidene Chloride Precursor for High-Performance Silicon Anodes in Lithium-Ion Batteries, BATTERIES & SUPERCAPS, 4 (2021) 240-247.

To address these challenges, many strategies have been proposed, including nanostructured silicon particles, coating of buffer layers, conductive binders, etc. 【设计出各类纳米硅，可缓解体积膨胀，但还是存在其他缺点】

## 【许多策略被提出提升硅负极寿命，举例】

[10] X. Zhou, H. Xie, X. He, Z. Zhao, Q. Ma, M. Cai, H. Yin, Annihilating the Formation of Silicon Carbide: Molten Salt Electrolysis of Carbon–Silica Composite to Prepare the Carbon–Silicon Hybrid for Lithium-Ion Battery Anode, Energy and Environmental Materials, 3 (2020) 166-176.

To increase the life span of the Si anode, various approaches have been employed such as

designing nanostructured Si materials, [10–12] preparing Si-C hybrid materials, [13–18] using

buffering matrixes, [19,20] and engineering electrolytes and binders. [21–23] 【纳米硅降低应力，碳层的作用】

## 【提出很多策略解决硅的问题。举例，纳米化。】

[11] Z. Wu, J. Luo, J. Peng, H. Liu, B. Chang, X. Wang, Rational architecture design of yolk/double-shells Si-based anode material with double buffering carbon layers for high performance lithium-ion battery, GREEN ENERGY & ENVIRONMENT, 6 (2021) 517-527.

To overcome these thorny problems, many improvement strategies have been adopted. For instance, a variety of nanosized Si particles with different morphology and structures (nanoparticles [11,12], nanowires [13,14], nanosheets [15,16], hollow nanoparticles [17,18], and nanoporous networks [19,20]) have been designed and prepared. 【硅纳米化的优势】

## 【为改善硅和氧化铁缺点做了大量努力，举例】

[12] L. Zhang, H. Guo, R. Rajagopalan, X. Hu, Y. Huang, S.X. Dou, H.K. Liu, One-step synthesis of a silicon/hematite@carbon hybrid nanosheet/silicon sandwich-like composite as an anode material for Li-ion batteries, JOURNAL OF MATERIALS CHEMISTRY A, 4 (2016) 4056-4061.

Hence, great efforts have been made to further improve their electrochemical performance by using various silicon-containing (silicon nanowires,10,20,21Fe2O3 nanotubes,26 Fe2O3 and graphene@Fe2O3 composite9) materials. silicon nanotubes,22 porous structured silicon,23 and carbon coated silicon24,25)or aFe2O3-containing (Fe2O3 nanorods,15 nanosheets,6【其中，多孔carbon@Si或孔carbon@a-Fe2O3有前途，原因。文献】

## 【为解决以上硅的问题，需要xxx】

[13] D. Nan, Z.-H. Huang, R. Lv, Y. Lin, L. Yang, X. Yu, L. Ye, W. Shen, H. Sun, F. Kang, Silicon-Encapsulated Hollow Carbon Nanofiber Networks as Binder-Free Anodes for Lithium Ion Battery, JOURNAL OF NANOMATERIALS, 2014 (2014).

In order to address abovementioned challenges, it would be crucial to release the mechanical strains, as well as reducing the diffusion length of Li-ions in Si electrode materials during charge/discharge process. 【纳米硅是一个解决方案。举例，发展了许多纳米硅。】

## 【许多努力改善硅的问题，方法举例】

[21] J. Chang, X. Huang, G. Zhou, S. Cui, S. Mao, J. Chen, Three-dimensional carbon-coated Si/rGO nanostructures anchored by nickel foam with carbon nanotubes for Li-ion battery applications, NANO ENERGY, 15 (2015) 679-687.

Significant efforts have been made towards mitigating the adverse mechanical effects of Si anodes and improving their overall electrochemical performance through diverse strategies, including engineering active material, current collector, binder and/or their interfaces [12–14]. 【一个特别吸引人的策略是形成双功能共形涂层。体系展开描述】

## 【发展大量策略解决硅的问题】

[24] J. Lu, D. Wang, J. Liu, G. Qian, Y. Chen, Z. Wang, Hollow double-layer carbon nanocage confined Si nanoparticles for high performance lithium-ion batteries, NANOSCALE ADVANCES, 2 (2020) 3222-3230.

Researchers have developed various strategies to resolve simple and multi-strategic coupling methods to mitigate the volume change of Si and form a stable SEI layer. 【金属有机框架材料如何制备的，在储能中的应用潜力。MOFs 的文献报道。MOFs 的优点。因此，硅可以和MOFs zuhe 】

## 【很多工作被开展以解决硅的问题】

[25] B. Li, F. Yao, J.J. Bae, J. Chang, M.R. Zamfir, L. Duc Toan, P. Duy Tho, H. Yue, Y.H. Lee, Hollow carbon nanospheres/silicon/alumina core-shell film as an anode for lithium-ion batteries, SCIENTIFIC REPORTS, 5 (2015).

Numerous works have been conducted on the research of silicon anode to meet the above challenges. 【降低尺寸到纳米级别消除机械破裂。纳米结构举例。这些纳米结构优点。】

## 【为解决硅的这些问题，许多工作致力于发展硅纳米结构，举例，硅复合物】

[26] L.Y. Yang, H.Z. Li, J. Liu, Z.Q. Sun, S.S. Tang, M. Lei, Dual yolk-shell structure of carbon and silica-coated silicon for high-performance lithium-ion batteries, SCIENTIFIC REPORTS, 5 (2015).

In an attempt to overcome these limitations of silicon, much attention has been devoted to the design and fabrication of silicon nanostructures, such as silicon nanowires6–8 and nanotubes9,10, three-dimensional (3D) porous silicon11–14, and silicon in composites with carbon or oxides15–20. 【取得了令人鼓舞的结果。举例，硅复合物。性能提升原因】

## 【为解决以上硅的问题，学者提出一些策略】

[22] K. Feng, W. Ahn, G. Lui, H.W. Park, A.G. Kashkooli, G. Jiang, X. Wang, X. Xiao, Z. Chen, Implementing an in-situ carbon network in Si/reduced graphene oxide for high performance lithium-ion battery anodes, NANO ENERGY, 19 (2016) 187-197.

To circumvent the aforementioned problems with Si electrodes, several strategies have been proposed by researchers. 【一个有效策略是设计不同的纳米硅电极。纳米硅的优点。体系举例。】

# 包括硅纳米化，作用描述。

## 【提升电子/离子传输，缓解应力，前人的纳米化工作】

[1] C. Jo, A.S. Groombridge, J. De La Verpilliere, J.T. Lee, Y. Son, H.-L. Liang, A.M. Boies, M. De Volder, Continuous-Flow Synthesis of Carbon-Coated Silicon/Iron Silicide Secondary Particles for Li-Ion Batteries, ACS NANO, 14 (2020) 698-707.

To improve the ion and electron transport, as well as to alleviate mechanical stress, previous researchers have looked into nanostructuring these active materials.【纳米化的缺点】

## 【为缓解硅的快速劣化，提出的一些策略】

[2] R.F.H. Hernandha, P.C. Rath, B. Umesh, J. Patra, C.-Y. Huang, W.-W. Wu, Q.-F. Dong, J. Li, J.-K. Chang, Supercritical CO2-Assisted SiOx/Carbon Multi-Layer Coating on Si Anode for Lithium-Ion Batteries, ADVANCED FUNCTIONAL MATERIALS, 31 (2021).

To prevent the fast degradation of Si anode, several strategies have been investigated, including size and morphology control, [9] nano-architecture design, [10] application of composites/hybrids, [11] and binder optimization. [12]【硅表面包覆碳的作用】

## 【目前工作聚焦在发展新的硅基结构解决体积变化问题，举例】

[5] F. Wang, M. Gao, R. Hong, X. Lu, Magnetoelectric Plasma Preparation of Silicon-Carbon Nanocomposite as Anode Material for Lithium Ion Batteries, APPLIED SCIENCES-BASEL, 10 (2020).

At present, research has mainly focused on finding new Si-based structures to solve the problems of the volumetric changes. The utility of nanoparticles, nanosheets, nanohollows, nanowires, and nano-core-shells has been studied as well [17–21]. 【硅碳复合物被认为是有效结构，硅和碳所起的作用，对SEI的作用】

## 【设计出各类纳米硅，可缓解体积膨胀，但还是存在其他缺点】

[6] S. Zhou, C. Fang, X. Song, G. Liu, Highly Ordered Carbon Coating Prepared with Polyvinylidene Chloride Precursor for High-Performance Silicon Anodes in Lithium-Ion Batteries, BATTERIES & SUPERCAPS, 4 (2021) 240-247.

Recently, various delicate nanostructures have been designed and fabricated, such as nanotubes,[13,14] structures.[17–19] hollow sphere,[15,16] and yolk-shell. These void-containing nanostructures can effectively alleviate the large volume change and improve the cycling performance, but they also suffer from additional demerits such as low tap density, large surface area, complicated synthesis process, and relatively poor electrical properties due to the high inter-particle resistance.[20]

【导电聚合物和碳涂层对提升硅性能有利，文献举例】

## 【使用纳米材料，发展复合物以提升循环性能】

[7] J. Wu, Y. Cao, H. Zhao, J. Mao, Z. Guo, The critical role of carbon in marrying silicon and graphite anodes for high-energy lithium-ion batteries, CARBON ENERGY, 1 (2019) 57-76.

Design strategies for advanced materials, such as employing unique nanostructures (nanowire, nanotube, core/shell, yolk shell, nanoporous materials, etc) and forming composites with electrochemically inactive/less active materials, such as carbon, conductive polymer, and so forth, have been applied as academic approaches to significantly improve the cycle life.8-10 【然而，体积能量密度和负载量太低，无法满足工业需求】

## 【硅的缺点可通过降低硅的尺寸实现】

[9] J.-C. Kim, K.-J. Kim, S.-M. Lee, Preparation and Characterization of Core-Shell Structure Hard Carbon/Si-Carbon Composites with Multiple Shell Structures as Anode Materials for Lithium-Ion Batteries, ENERGIES, 14 (2021).

Numerous studies have demonstrated that the drawbacks of Si as an anode material could be mitigated by reducing the size of the Si particle.【碳基体中分散纳米硅的优势】

## 【纳米硅降低应力，碳层的作用】

[10] X. Zhou, H. Xie, X. He, Z. Zhao, Q. Ma, M. Cai, H. Yin, Annihilating the Formation of Silicon Carbide: Molten Salt Electrolysis of Carbon–Silica Composite to Prepare the Carbon–Silicon Hybrid for Lithium-Ion Battery Anode, Energy and Environmental Materials, 3 (2020) 166-176.

It has been proven that the nanostructured Si can reduce the mechanical stress caused by the volume expansion, and a carbon layer on Si could remarkably stabilize the SEI layers and avoid the disconnection of the Si from the current collector. [24,25] 【传统制备纳米硅的方法举例。制备方法的问题。】

## 【硅纳米化的优势】

[11] Z. Wu, J. Luo, J. Peng, H. Liu, B. Chang, X. Wang, Rational architecture design of yolk/double-shells Si-based anode material with double buffering carbon layers for high performance lithium-ion battery, GREEN ENERGY & ENVIRONMENT, 6 (2021) 517-527.

These solutions can buffer the huge volume change and enhance the mechanical integrity of Si electrodes to some degree. 【另一方面，提升寿命，硅基复合物】

## 【小于150nm的硅，可以首次嵌锂过程中，缓解体积变化】

[11] Z. Wu, J. Luo, J. Peng, H. Liu, B. Chang, X. Wang, Rational architecture design of yolk/double-shells Si-based anode material with double buffering carbon layers for high performance lithium-ion battery, GREEN ENERGY & ENVIRONMENT, 6 (2021) 517-527.

It is generally considered that the volume expansion of Si anodes can be limited in the initial lithiation process, when the diameter of particles is less than 150 nm [9]. 【但是，进一步降低硅颗粒尺寸的问题】

## 【典型的解决以上问题的策略主要依赖于稳定硅纳米结构】

[17] J. Kong, Y. Wei, Silicon Nanoparticles Confined in Thin Carbon Network: The Free-Standing Anode of Lithium Ion Batteries with High Performance and Easy Recyclability, JOURNAL OF THE ELECTROCHEMICAL SOCIETY, 166 (2019) A2013-A2020.

Typical strategies to tackle the above issues mainly rely on stabilizing the Si nanostructure while maintaining its morphology/structure integrity during lithiation/de-lithiation.【各类硅纳米结构。优点】

## 【一个有效策略是设计不同的纳米硅电极。纳米硅的优点。体系举例。】

[22] K. Feng, W. Ahn, G. Lui, H.W. Park, A.G. Kashkooli, G. Jiang, X. Wang, X. Xiao, Z. Chen, Implementing an in-situ carbon network in Si/reduced graphene oxide for high performance lithium-ion battery anodes, NANO ENERGY, 19 (2016) 187-197.

One of the potential solutions is to design various nanostructured Si electrodes. Nano-sized Si can better accommodate mechanical strain during lithiation and delithiation processes, and avoid cracking and fragmentation [16]. Improved cycling stability has been demonstrated with mechanically-milled nanostructured particles, [17] and chemically synthesized nanostructures including nanowires, [18] nanotubes, [19] nanoporous structures, [20] and core– shell nanostructures [21].【另一个有效提升硅的策略是构建导电网络，举例。】

## 【一个有效的策略，使用不同形貌的纳米硅。与块体硅相比的优点】

[23] J. Yang, Y.-X. Wang, S.-L. Chou, R. Zhang, Y. Xu, J. Fan, W.-x. Zhang, H.K. Liu, D. Zhao, S.X. Dou, Yolk-shell silicon-mesoporous carbon anode with compact solid electrolyte interphase film for superior lithium-ion batteries, NANO ENERGY, 18 (2015) 133-142.

It is a common and effective strategy to adopt nanoscale silicon materials with various morphologies, including nanoparticles [11,12], nanowires [13], nanotubes [14,15], and hollow spheres [16,17]. Compared to bulk silicon, such nanostructured Si is able to accommodate elevated mechanical stress, resulting in prolonged cycling stability. 【纳米硅的缺点】

## 【降低尺寸到纳米级别消除机械破裂。纳米结构举例。这些纳米结构优点。】

[25] B. Li, F. Yao, J.J. Bae, J. Chang, M.R. Zamfir, L. Duc Toan, P. Duy Tho, H. Yue, Y.H. Lee, Hollow carbon nanospheres/silicon/alumina core-shell film as an anode for lithium-ion batteries, SCIENTIFIC REPORTS, 5 (2015).

Reducing the size of active materials into nanoscale could be one efficient way to alleviate the mechanical fracture. Various structures synthesized by different methods have been proposed, including nanoparticles 10,11 , nanotubes 12,13, nanowires 14,15, nanospheres 16, core-shell nanofibers 17,18 and thin films 19. These nanostructures have demonstrated superior performance compared to bulk silicon because of their ability to release the strain. Moreover, nanostructured silicon has settled the issue of the active material detachment from the current collector, resulting in significant improvement of electrochemical cycling. 【硅的缺点，和SEI相关】

## 【硅的缺点，和SEI相关】

[25] B. Li, F. Yao, J.J. Bae, J. Chang, M.R. Zamfir, L. Duc Toan, P. Duy Tho, H. Yue, Y.H. Lee, Hollow carbon nanospheres/silicon/alumina core-shell film as an anode for lithium-ion batteries, SCIENTIFIC REPORTS, 5 (2015).

In spite of this, the surface of silicon is still directly exposed to the electrolyte and therefore unstable SEI is still formed.

【为解决硅直接接触形成SEI这个问题，表面涂层】

# 碳包覆，作用描述。

## 【吸引人的策略，改善导电性，碳包覆。文献举例，缓冲体积膨胀，但降低振实密度】

[1] C. Jo, A.S. Groombridge, J. De La Verpilliere, J.T. Lee, Y. Son, H.-L. Liang, A.M. Boies, M. De Volder, Continuous-Flow Synthesis of Carbon-Coated Silicon/Iron Silicide Secondary Particles for Li-Ion Batteries, ACS NANO, 14 (2020) 698-707.

In particular, attractive strategies have been proposed to address the poor conductivity of high capacity materials by advanced carbon coating processes. For instance, a number of promising carbon cages have been proposed to buffer the volume change of active materials,16−18 but these further reduce the tapped density of the electrodes. 【石墨烯和碳纳米管被研究。存在的问题。产生问题的原因及后果】

## 【硅表面包覆碳的作用】

[2] R.F.H. Hernandha, P.C. Rath, B. Umesh, J. Patra, C.-Y. Huang, W.-W. Wu, Q.-F. Dong, J. Li, J.-K. Chang, Supercritical CO2-Assisted SiOx/Carbon Multi-Layer Coating on Si Anode for Lithium-Ion Batteries, ADVANCED FUNCTIONAL MATERIALS, 31 (2021).

A thin, uniform, and conformal carbon layer on the Si surface is highly desirable to boost Si conductivity and stabilize the interface.【但是，湿法碳包覆方法无法形成高质量表面涂层，原因】

## 【硅碳复合物被认为是有效结构，硅和碳所起的作用，对SEI的作用】

[5] F. Wang, M. Gao, R. Hong, X. Lu, Magnetoelectric Plasma Preparation of Silicon-Carbon Nanocomposite as Anode Material for Lithium Ion Batteries, APPLIED SCIENCES-BASEL, 10 (2020).

Among them, silicon/carbon composites are regarded as effective structures to alleviate the volumetric changes of the silicon. In them, the silicon acts as the active material to provide lithium storage capacity, and the carbon material acts as a buffer to resist the volumetric changes of silicon during the cycle process. In addition, the drastic capacity fading of the Si-based anode corresponds to the solid electrolyte interphase (SEI) films repeatedly formed during the cycles. It has been proved that the surrounding carbon material avoids direct contact between the silicon and the electrolyte, preventing repeated SEI formation [22–24].

【文献，纳米硅被碳包裹，固定在石墨烯上。三明治结构纳米硅/空心石墨纤维/碳涂层】

## 【导电聚合物和碳涂层对提升硅性能有利，文献举例】

[6] S. Zhou, C. Fang, X. Song, G. Liu, Highly Ordered Carbon Coating Prepared with Polyvinylidene Chloride Precursor for High-Performance Silicon Anodes in Lithium-Ion Batteries, BATTERIES & SUPERCAPS, 4 (2021) 240-247.

Conductive polymer and carbon coating have proven to be a practical approach to enhance the electrochemical performance of the silicon materials for LIBs.[21] layers not only can improve the electrical conductivity, but also can serve as an electrolyte layer on the surface of silicon to alleviate the side reactions and minimize the volume changes. For example, Wu et al.[22] Conductive coating reported a stable Si/C anode material by in-situ polymerization of polyaniline (PANi) to conformally coat silicon nanoparticles with conducting polymer, delivering a capacity of 550 mAh/g after 5000 cycles at 6 A/g with a mass loading of 0.2–0.3 mg/cm2. The average CE of the Si/C electrode from the 2nd to 5,000th cycle was 99.8%. Lee et al.[23] investigated the pyrolysis of polyacrylonitrile (PAN) at the temperature of 300–500°C to attain the cyclization of PAN, which was achieved without carbonization while maintaining PAN’s polymeric properties. This Si/C material with homogeneous coating layer on the surface of Si nanoparticles could provide superior performance of ~1500 mAh/g after 150 cycles with a CE approaching 100% at a current rate of 0.1 C. Choi et al.[18] used sucrose as a precursor via spray drying process to attain Si/C composite particles in which silicon nanoparticles (~ 70 nm) were embedded in porous carbon particles. The composite electrodes exhibited excellent electrochemical performance of 1243 mAh/g after 150 cycles at 4 A/g with a mass loading of 1 mg/cm2. In the cycling range from first cycle to fifth cycle, the average CE was 98.5%. 【然而，需要更高的库伦效率和循环稳定性】

## 【为提升导电性，硅表面包覆碳材料】

[8] E.H. Chung, J.P. Kim, H.G. Kim, J.-M. Chung, S.-J. Lee, J.-S. Bae, E.D. Jeong, The Synthesis and Electrochemical Performance of Si Composite with Hollow Carbon Microtubes by the Carbonization of Milkweed from Nature as Anode Template for Lithium Ion Batteries, ENERGIES, 13 (2020).

In order to enhance electronic conductivity, many researchers have been studied on several of Si-based electrodes. Carbon materials, including artificial graphite, natural graphite, and hard carbon are widely applied for Si coating and the mixture of high carbon Si/carbon composite was synthesized [13–15]. 【循环性有限。原因。】

## 【另一方面，提升寿命，硅基复合物】

[11] Z. Wu, J. Luo, J. Peng, H. Liu, B. Chang, X. Wang, Rational architecture design of yolk/double-shells Si-based anode material with double buffering carbon layers for high performance lithium-ion battery, GREEN ENERGY & ENVIRONMENT, 6 (2021) 517-527.

On the other hand, in order to improve the long cycling stability of Sibased anodes, the Si-based composites with different composite structures have also been designed, such as Si/carbon [21,22], Si/metallic oxide [23,24], and Si/carbon/metal oxide [25,26].【和其他改性方法相比，核壳蛋黄结构硅碳纳米结构复合物的优点】

## 【其中，多孔carbon@Si或孔carbon@a-Fe2O3有前途，原因。文献】

[12] L. Zhang, H. Guo, R. Rajagopalan, X. Hu, Y. Huang, S.X. Dou, H.K. Liu, One-step synthesis of a silicon/hematite@carbon hybrid nanosheet/silicon sandwich-like composite as an anode material for Li-ion batteries, JOURNAL OF MATERIALS CHEMISTRY A, 4 (2016) 4056-4061.

Among them, porous carbon@Si or carbon@a-Fe2O3 composites in which the active particles are coated or embedded in a porous conductive carbon skeleton are quite promising, because the void space allows the expansion of silicon and a-Fe2O3 during the lithiation/delithiation processes, thus maintaining the structural and electrical integrity.7a For instance, Cui et al. Demonstrated a carbon@void@Si (yolk–shell) composite system having a high capacity of $2800 mA h g1.27 a-Fe2O3/reduced graphene oxide (rGO) nanocomposites ($1100 mA h g-1) in which the a-Fe2O3 nanoparticles were uniformly anchored on the graphene nanosheets were fabricated by Zhang et al.28 through a facile microwave hydrothermal method. 【（之前是结合文献）因此，硅和氧化铁的最主要问题可如何被解决】

## 【因此，为克服缺点，活性材料表面碳涂层，可解决什么问题】

[16] J. Ha, H. Park, M. Kim, Y.T. Kim, J. Choi, Liquefied-Natural-Gas-Derived Vertical Carbon Layer Deposited on SiO as Cost-Effective Anode for Li-Ion Batteries, JOURNAL OF THE ELECTROCHEMICAL SOCIETY, 169 (2022).

Therefore, to overcome these shortcomings, recently, researchers have increasingly focused on coating the active material surface with a carbon layer that increases electrical conductivity and suppresses volume expansion by inducing the formation of a stable solid electrolyte interface (SEI).8–10 【cvd是大规模在活性材料表面生长碳的最有效方法。文献】

## 【硅复合物】

[17] J. Kong, Y. Wei, Silicon Nanoparticles Confined in Thin Carbon Network: The Free-Standing Anode of Lithium Ion Batteries with High Performance and Easy Recyclability, JOURNAL OF THE ELECTROCHEMICAL SOCIETY, 166 (2019) A2013-A2020.

Secondly, combining with structurally stable and electrically conductive components to produce Si-based composites. 【诸多候选物中，碳最有前途，原因】

## 【诸多候选物中，碳最有前途，原因】

[17] J. Kong, Y. Wei, Silicon Nanoparticles Confined in Thin Carbon Network: The Free-Standing Anode of Lithium Ion Batteries with High Performance and Easy Recyclability, JOURNAL OF THE ELECTROCHEMICAL SOCIETY, 166 (2019) A2013-A2020.

Among all the candidates (metals, polymers, etc.),19–22 carbon is the most promising one, acting as host/support of Si, that is capable of buffering/accommodating the volume change of Si during charging/discharging, as well as providing good electrical conduction to the composites. In addition, the carbon phase is also electrochemically active and contributes to the overall battery performance. 【碳在硅中的应用】

## 【碳在硅中的应用】

[17] J. Kong, Y. Wei, Silicon Nanoparticles Confined in Thin Carbon Network: The Free-Standing Anode of Lithium Ion Batteries with High Performance and Easy Recyclability, JOURNAL OF THE ELECTROCHEMICAL SOCIETY, 166 (2019) A2013-A2020.

So far, carbon nanofibers/carbon nanotubes,23–25 graphene/graphite,26–31 amorphous/doped carbon32–36 have been synergistically introduced into Si nanostructures. 【硅碳比和硅碳之间交互的有效性是决定性能的关键因素】

## 【硅碳比和硅碳之间交互的有效性是决定性能的关键因素】

[17] J. Kong, Y. Wei, Silicon Nanoparticles Confined in Thin Carbon Network: The Free-Standing Anode of Lithium Ion Batteries with High Performance and Easy Recyclability, JOURNAL OF THE ELECTROCHEMICAL SOCIETY, 166 (2019) A2013-A2020.

The ratio of Si/carbon in the composites and the effectiveness of the interaction between Si and carbon are the critical factors that determine the properties. 【通过优化胶粘剂等，提升制备过程】

## 【硅纳米颗粒包裹在碳材料中，是个有效策略】

[18] Z. He, X. Wu, Z. Yi, X. Wang, Y. Xiang, Silicon/graphene/carbon hierarchical structure nanofibers for high performance lithium ion batteries, MATERIALS LETTERS, 200 (2017) 128-131.

Si nanoparticles (NPs) wrapped in carbon materials is an effective way to strengthen the electrochemical properties.【近年来，各种碳被用来缓冲硅纳米颗粒的体积变化，作用】

## 【碳包硅的优点。文献】

[20] S. Song, J. Li, A. Zheng, Y. Yang, K. Yin, Facile Synthesis of Sponge-Like Porous Nano Carbon-Coated Silicon Anode with Tunable Pore Structure for High-Stability Lithium-Ion Batteries, MOLECULES, 26 (2021).

Carbon-coated silicon’s design exhibits improved structural stability and higher cycling stability due to the protection of silicon by the carbon coating layer [7–9]. For example, Liu et al. [10] proposed a hierarchical structure design inspired by the structure of pomegranate through a evaporation-driven self-assembly method combined with coating and etching processes. In this structure, the silicon nanoparticles are encapsulated by a conductive carbon layer that leaves enough room for expansion during lithiation. Owing to the more stable SEI film and relieved stress, this pomegranate-like silicon-based anode exhibited a superior cyclability (97% capacity retention after 1000 cycles). Ryu et.al. [11] introduced a two-dimensional silicon nanosheet coated with a thin carbon layer through chemical vapor deposition. This carbon-coated silicon nanosheet formed ripples upon delithiation, which effectively releases the induced stress, rendering the electrode much more stable and durable than the uncoated counterparts.【但是，虽然这些碳包硅设计展现高循环稳定性，合成复杂、甚至结构设计不可控限制实际应用】

## 【碳在锂电池中常用，优点】

[21] J. Chang, X. Huang, G. Zhou, S. Cui, S. Mao, J. Chen, Three-dimensional carbon-coated Si/rGO nanostructures anchored by nickel foam with carbon nanotubes for Li-ion battery applications, NANO ENERGY, 15 (2015) 679-687.

Carbon is a commonly used conductive additive in lithium-ion electrode materials, which can enhance electrical conductivity and constrain the large volume change of Si to maintain structural integrity by coating the Si surface with carbon [23– 27]. 【从电极结构角度，我们选择的是将硅纳米颗粒嵌入石墨烯薄膜中。这一方法的优点和缺点。】

## 【优化纳米硅，将纳米硅和不同导电基体融合，举例】

[23] J. Yang, Y.-X. Wang, S.-L. Chou, R. Zhang, Y. Xu, J. Fan, W.-x. Zhang, H.K. Liu, D. Zhao, S.X. Dou, Yolk-shell silicon-mesoporous carbon anode with compact solid electrolyte interphase film for superior lithium-ion batteries, NANO ENERGY, 18 (2015) 133-142.

Further optimization is achieved by incorporating nano-silicon materials with various conductive matrixes, such as graphene [19,20], carbon nanotubes [21], and carbon [22,23] to form core-shell and yolk-shell nanocomposites [24]. The most promising carbon coating strategy has been explored to promote the electrochemical performance [25–28]. The obvious advantage of carbon shells is intensive improving the overall electrical conductivity of the Si-based anodes. In addition, the introduction of such a carbon shell plays a key role in alleviating the agglomeration of nano-silicon particles [29,30]. 【但是，目前包碳方法哪些，存在什么问题。导致硅纳米颗粒的倍率不行】

## 【为解决硅直接接触形成SEI这个问题，表面涂层】

[25] B. Li, F. Yao, J.J. Bae, J. Chang, M.R. Zamfir, L. Duc Toan, P. Duy Tho, H. Yue, Y.H. Lee, Hollow carbon nanospheres/silicon/alumina core-shell film as an anode for lithium-ion batteries, SCIENTIFIC REPORTS, 5 (2015).

To tackle this problem, conformal coatings on silicon anode have been explored. 【无定形碳的优点】

## 【取得了令人鼓舞的结果。举例，硅复合物。性能提升原因】

[26] L.Y. Yang, H.Z. Li, J. Liu, Z.Q. Sun, S.S. Tang, M. Lei, Dual yolk-shell structure of carbon and silica-coated silicon for high-performance lithium-ion batteries, SCIENTIFIC REPORTS, 5 (2015).

Encouraging results have been achieved through these efforts. In particular, Si/SiOx composites21,22, Si/SiO2/C23–25, and yolk-shell structured Si/C26–28 have demonstrated excellent electrochemical performance. These performances can be ascribed to the C or SiOx shell on the outside of the silicon, which can offer a static surface for the formation of a thin and stable SEI, preserving the anode from irreversible reaction with the electrolyte29–31. Additionally, the existing hollow structures in the yolk-shell structure can provide extra space for the volume expansion of silicon, which guarantees the structural integrity of the electrode29–31. These distinguishing features provide enlightened guidance for nanostructured design of high-performance silicon batteries.

【本文，硅表面包裹SiO2，随后包裹碳层】

# 工业应用需要关注压实密度、同时纳米级别带来的sei方面的问题，因此希望活性物质颗粒是微米级别的。

## 【纳米化的缺点】

[1] C. Jo, A.S. Groombridge, J. De La Verpilliere, J.T. Lee, Y. Son, H.-L. Liang, A.M. Boies, M. De Volder, Continuous-Flow Synthesis of Carbon-Coated Silicon/Iron Silicide Secondary Particles for Li-Ion Batteries, ACS NANO, 14 (2020) 698-707.

However, nanostructuring often introduces problems of its own such as low tapped and electrode density as well as irreversible reactions taking place on the high surface area of the nanostructured materials. 【目前研究正在发展策略以解决问题】

## 【然而，体积能量密度和负载量太低，无法满足工业需求】

[7] J. Wu, Y. Cao, H. Zhao, J. Mao, Z. Guo, The critical role of carbon in marrying silicon and graphite anodes for high-energy lithium-ion batteries, CARBON ENERGY, 1 (2019) 57-76.

Nevertheless, the volumetric energy density of these materials and the areal mass loading on electrodes are generally too low for industrial implementation. 【高性能负极的商业指标，容量，循环性，库伦效率，负载量，膨胀率】

## 【高性能负极的商业指标，容量，循环性，库伦效率，负载量，膨胀率】

[7] J. Wu, Y. Cao, H. Zhao, J. Mao, Z. Guo, The critical role of carbon in marrying silicon and graphite anodes for high-energy lithium-ion batteries, CARBON ENERGY, 1 (2019) 57-76.

The commercial goal of achieving high‐performance anodes to replace the existing commercial graphite materials in the near future, involves reaching a specific capacity of 500 mAh/g or higher with a capacity retention of 80% after 500 cycles, while the initial CE and average CE should exceed 90% and 99.8%, respectively (Figure 1). Accordingly, the pressing density should reach ~1.65 g/cm3, and electrode swelling should be restricted to ~10%.11

【硅和石墨一起使用】

## 【但是，进一步降低硅颗粒尺寸的问题】

[11] Z. Wu, J. Luo, J. Peng, H. Liu, B. Chang, X. Wang, Rational architecture design of yolk/double-shells Si-based anode material with double buffering carbon layers for high performance lithium-ion battery, GREEN ENERGY & ENVIRONMENT, 6 (2021) 517-527.

However, with the decrease of the particles size, the price of commercial nanosized Si increases obviously, and the manufacturing technique of commercial nanosized Si particles is complex.【硅的选择影响了生产硅的成本】

# 进一步的，碳包覆的形貌理应也对性能有影响，但目前这方面的研究很有限。

## 语法【然而很少研究关注提升倍率性能】

[9] J.-C. Kim, K.-J. Kim, S.-M. Lee, Preparation and Characterization of Core-Shell Structure Hard Carbon/Si-Carbon Composites with Multiple Shell Structures as Anode Materials for Lithium-Ion Batteries, ENERGIES, 14 (2021).

However, little attention has been paid to an approach for improving their rate performance.

【本文，组合了以上提到的几方面，核壳结构硬碳/硅碳复合物】

# 最相关文献点评，关于包碳的形貌研究。但不清楚这些不同形貌对于xxx的影响

## 【本文，SiO表面沉积直立碳，用液化天然气】

[16] J. Ha, H. Park, M. Kim, Y.T. Kim, J. Choi, Liquefied-Natural-Gas-Derived Vertical Carbon Layer Deposited on SiO as Cost-Effective Anode for Li-Ion Batteries, JOURNAL OF THE ELECTROCHEMICAL SOCIETY, 169 (2022).

Herein, we deposited a vertical carbon layer on SiO as an anode material for LIBs via CVD using liquefied natural gas (LNG, 0.27 USD/L, based on the retail price in 2021, South Korea), which was 13 times less expensive than high-purity CH4 (3.52 USD/L, based on the retail price in 2021, South Korea). Furthermore, the physicochemical properties and electrochemical performance of the carboncoated SiO electrode prepared using inexpensive LNG (denoted as C-SiO-LNG) were compared with those of a carbon-coated SiO electrode prepared using high-purity CH4 (denoted as C-SiO-CH4).【】【】

2. Experimental

## 【本文，Si@介孔碳，包含大量孔洞】

[23] J. Yang, Y.-X. Wang, S.-L. Chou, R. Zhang, Y. Xu, J. Fan, W.-x. Zhang, H.K. Liu, D. Zhao, S.X. Dou, Yolk-shell silicon-mesoporous carbon anode with compact solid electrolyte interphase film for superior lithium-ion batteries, NANO ENERGY, 18 (2015) 133-142.

Here, aiming at outstanding cycling stability and ratecapability, we report a novel large-void-containing Si@mesoporous carbon yolk-shell structure from commercial silicon NPs for LIB anodes. This unique design has multiple attractive advantages: (i) the special design of the void spaces (10 and 50 nm) between the silicon NPs and the mesoporous carbon shells highlights the superiority of the unique yolk-shell structure and allows us to optimize the cycling stability while maintaining a reasonable storage capacity; (ii) the open-ended mesoporous carbon shells with accessible channels are able to facilitate the fast diffusion of Li+ ions, and guarantee the full immersion of active materials in the electrolyte, thus contributing to excellent rate capability; (iii) the mesoporous carbon shells are beneficial for the formation of a homogeneous and compact SEI-layer film on the external surface, retaining the internal void space for silicon yolk expansion and rendering superior capacity retention at a high current density. With this design, such elegant mesoporous carbon-encapsulated Si yolk-shell NPs address the challenges of rapid capacity decay and unsatisfied rate capability for Si-anodes, and deliver a high reversible capacity of $1000 mA h g-1 with outstanding cyclability during 400 long-deep cycles, as well as superior rate-capability at a very high current density of 8.4 A g-1.【】

## 【镁热反应。硅的结构完整性和SiO2纳米颗粒的尺寸有关。文献，Si在MgO基体中。】

[11] Z. Wu, J. Luo, J. Peng, H. Liu, B. Chang, X. Wang, Rational architecture design of yolk/double-shells Si-based anode material with double buffering carbon layers for high performance lithium-ion battery, GREEN ENERGY & ENVIRONMENT, 6 (2021) 517-527.

The magnesiothermic reduction reaction is an exothermic process, and the obtained Si is melted and aggregated at high temperature. Therefore, the structural integrality of the reduced Si particles is related to the size of SiO2 nanoparticles. Besides, Yoo et al. reported that the Si nanoparticles (10 nm) were uniformly dispersed in MgO matrix via magnesiothermic reduction reaction, and Mg2Si still exists in the inner of product [32]. Moreover, the MgO matrix will contribute to form the ordered mesoporous structure, which will facilitate to enhance the electrochemical stability of Si.

【本文，介孔Si，来自SiO2镁热反应】

# 本文

# 融合了几方面的xxx

## 【本文，组合了以上提到的几方面，核壳结构硬碳/硅碳复合物】

[9] J.-C. Kim, K.-J. Kim, S.-M. Lee, Preparation and Characterization of Core-Shell Structure Hard Carbon/Si-Carbon Composites with Multiple Shell Structures as Anode Materials for Lithium-Ion Batteries, ENERGIES, 14 (2021).

In this study, by combining several of the abovementioned aspects, a unique core-shell structure hard carbon/Si-carbon composites with multiple shell structures were synthesized to be applied as anode materials for LIBs. The concept was to improve the power density and energy efficiency by adopting a hard carbon with a high-rate capability as a core material and distributing Si nanoparticles in the shell layer. Thereby, it was expected that the utilization of active electrode materials would increase. In particular, we investigated the effect of the shell structure in the composite material on its electrochemical performance as an anode material for LIBs, in which we employed three types of shell structure: Si-carbon, Si-carbon black-carbon and Si-carbon black-carbon/graphite nanosheet. The resultant composite materials are denoted as Hard carbon/Si-carbon composite, Hard carbon/Si-carbon black-carbon composite and Hard carbon/Si-carbon black-carbon/graphite nano-sheet composite, respectively.【】【】

# 硅融入SiO2基体中

## 【将硅融入碳基体中可提高性能】

[3] H. Su, A.A. Barragan, L. Geng, D. Long, L. Ling, K.N. Bozhilov, L. Mangolini, J. Guo, Colloidal Synthesis of Silicon–Carbon Composite Material for Lithium-Ion Batteries, Angewandte Chemie - International Edition, 56 (2017) 10780-10785.

. Clearly, incorporating Si into a carbon matrix does indeed improve the structural and electrical integrity of the Si–C composites.[11] 【大多数合成硅碳复合材料方法面临的挑战，均匀分散困难，原因】

## 【将硅融入碳基体被认为是一个有效方法提升性能】

[4] B. Chen, L. Zu, Y. Liu, R. Meng, Y. Feng, C. Peng, F. Zhu, T. Hao, J. Ru, Y. Wang, J. Yang, Space-Confined Atomic Clusters Catalyze Superassembly of Silicon Nanodots within Carbon Frameworks for Use in Lithium-Ion Batteries, ANGEWANDTE CHEMIE-INTERNATIONAL EDITION, 59 (2020) 3137-3142.

Incorporating Si into a carbon matrix is recognized as an effective method by which to improve structural and electrical integrity of Si- based electrodes for enhanced LIB performance. [12–14] 【然而，物理混合硅碳复合物的缺点】

## 【碳基体中分散纳米硅的优势】

[9] J.-C. Kim, K.-J. Kim, S.-M. Lee, Preparation and Characterization of Core-Shell Structure Hard Carbon/Si-Carbon Composites with Multiple Shell Structures as Anode Materials for Lithium-Ion Batteries, ENERGIES, 14 (2021).

The dispersion of nanoscale Si in a carbon matrix has been a favorable approach in synthesizing Si-based anode materials for LIBs because it improves the performance of Si through avoiding the direct contact with electrolytes [ 11 , 12 ]. On the one hand, the dispersion of nanosized Si particles in a carbon matrix is known to be challenging since these nanosized particles are prone to forming agglomerations [ 13 , 14 ]. On the other hand, it is anticipated that the problem in dispersion of nanosized Si particles will be overcome by synthesizing a Si-carbon black (CB) carbon composite [15].

【石墨烯有前景，用于硅碳复合物，原因】

# SiO2转化为纳米硅

## 【硅的储量，SiO2是最常见的硅形式。因此，直接将SiO2转化为纳米硅的优势】

[10] X. Zhou, H. Xie, X. He, Z. Zhao, Q. Ma, M. Cai, H. Yin, Annihilating the Formation of Silicon Carbide: Molten Salt Electrolysis of Carbon–Silica Composite to Prepare the Carbon–Silicon Hybrid for Lithium-Ion Battery Anode, Energy and Environmental Materials, 3 (2020) 166-176.

As we know, Si is the second most abundant element in the earth’s crust (26.4% by mass), and silica (SiO 2 ) is the most common natural Si resource. Thus, direct converting silica to nano-Si is of great interests due to the short process, low energy consumption, low cost, and sustainable raw materials.

【除了镁热还原，熔盐中直接电化学还原SiO2的优势。文献举例。问题。针对这一问题，文献报道的解决方案】

## 【硅可通过镁和二氧化硅的反应生产，可制备纳米硅。】

[11] Z. Wu, J. Luo, J. Peng, H. Liu, B. Chang, X. Wang, Rational architecture design of yolk/double-shells Si-based anode material with double buffering carbon layers for high performance lithium-ion battery, GREEN ENERGY & ENVIRONMENT, 6 (2021) 517-527.

Fortunately, Si also can be obtained by making use of magnesium (Mg) to scavenge oxygen from silica (SiO2) at high temperature (500 C–900 C), and the microscale morphologies of the original SiO2 can be maintained, so magnesiothermic reduction have been used to prepare the nanosized Si particles [29–31]. 【镁热反应方程】