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能源材料新时代

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人类发展的历史，也是能源变革的历史，人类社会的每一次技术革命无不伴随着对能源认识、开发和利用的创新与进步。当下，我国已经成为全球排名第一的能源生产和消费大国，并且两个总量还在不断攀升。能源技术是解决对传统化石能源过度依赖及环境污染等问题，构建合理的社会能源结构，推进可持续发展，实现“双碳”减排的关键手段。2020 年，我国以太阳能、风能为代表的可再生能源增长达到全世界的三分之一，发展迅速。这其中，能源材料是能源工业和能源技术体系中涉及的特殊材料，在实现清洁能源的转化和利用，发展新能源技术，以及支撑整个能源系统中扮演着核心角色。

近年来，能源材料在诸多领域取得了广泛而持续的发展，包括二次电池、燃料电池、太阳能电池、超级电容器、光电催化、含能材料等。比如，以高镍三元材料(NCM)为代表的新型锂离子电池正极材料，正引领着新一代汽车动力电池技术的发展，以支持更快的充电速度、更久的服役寿命和更长的行驶里程[1-4]。不断提升的储能需求也催生了一系列新型电池技术，如锂硫[5]、锂空气[6]电池体系，以及固态电池[7]技术等，多种技术并行发展。它们在能量密度、经济性、安全性等方面各具优势，但也存在如锂硫电池中多硫化锂造成的穿梭效应，锂空气电池中放电产物易堵塞基底的孔道以及固态电池中电解质的电导率不佳等诸多问题，其技术完善和产业化推动强烈依赖于电极和电解质材料的创新设计和结构优化。同时，为了提高非化石能源占一次能源的消费比，太阳能电池作为新能源技术的翘楚，被寄予厚望。其中，以钙钛矿为代表的第三代太阳能电池技术已获得与单晶硅相媲美的光电转换效率[8]，让人们对光伏产业的未来充满了期待，然而其对温、湿、光、氧的敏感性和不稳定性[9]，以及在材料制备过程中难以回避污染环境的含 Pb 原料，种种问题仍需从材料的底层设计中寻求解决之道。此外，以 Pt、Pd 等贵金属为代表的传统催化剂材料不断优化，以及开发的新型非贵金属、非金属催化剂，正逐步提高燃料电池的能量转换效率，降低其技术成本，并已取得了一定程度的商业化应用[10-11]。同时，涉及如 CO_2 还原、固氮等过程的光、电催化新材料与新技术，也为可再生能源的存储及利用形式提供新的出口，为 2030 年完成碳达峰、2060 年实现碳中和提供技术支撑[12-13]。

在可持续发展的时代大背景以及竞争激烈的国际前沿科技大环境下，我国在能源材料的理化机理探索、功能发现、精准设计制备以及先进器件组装等方面做出了许多开创性的工作。为集中展示我国学者在相关领域的研究成果，推动学术交流，激发社会各界对能源材料的兴趣，南京理工大学联合中国科学院上海硅酸盐研究所、华中科技大学等单位组织出版“能源材料专辑”，专辑收录了能源材料相关的最新研究论文和综述文章，涉及钙钛矿太阳能电池、半透明太阳能电池、锂离子电池、镁电池、锂硫电池、热电、二氧化碳裂解等。期望该专辑能够抛砖引玉，为促进我国能源材料的科学研究和学科发展提供有益参考。

Energy Materials in New Era

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In the long river of human history, every technological revolution is accompanied by transition of cognition, development and utilization of energy. At present, China has become the No. 1 in the world in both production and consumption of energy, which continue rising in the expected future. Developing energy technology is still a key way to solve the problems of excessive dependence on traditional fossil energy and environmental pollution, construct a reasonable social structure, promote the sustainable development of human society, and achieve the goals of carbon emission peaking and carbon neutrality. In 2020, renewable energy in China such as photovoltaics and wind power evolved marvelously which occupied 1/3 of global total volume. In this regard, energy materials are indispensable components, which play the core role in realizing conversion and utilization of clean energy, developing new energy technologies, and supporting the entire energy system.

In recent years, energy materials have achieved extensive and sustainable development in many fields, including secondary batteries, fuel cells, solar cells, supercapacitors, photoelectric catalysis, and energy-containing materials. For example, high nickel ternary materials as cathode material in the lithium-ion battery are leading the future of a new generation of automotive power battery technology towards faster charging speed, longer service life and longer mileage[1-4]. The ever increasing demand for energy storage has also spawned simultaneously a series of new battery technologies, such as lithium-sulfur[5], lithium-air[6] and solid-state batteries[7]. They have advantages in energy density, economy and safety, but technical defects (*e.g.*, shuttle effect in Li-S battery attributed to polysulfides, blockage of matrix pores in Li-air battery attributed to discharging product, unsatisfactory electrical conductivity of electrolyte in solid-state battery) are frustrating. Technological improvement and industrialization are strongly dependent on the innovative design and structural optimization of electrode and electrolyte materials. To promote the share of renewable energy in primary source, photovoltaics, the representative of new energy, has received great expectation. In addition, halogen perovskite-based third-generation solar cell technology has achieved a solar energy conversion efficiency comparable to that of silicon single crystal, showing a prosperous photovoltaic industry in the future[8]. However, its sensitivity to temperature, humidity, light, and oxygen[9], and inevitable Pb-containing raw material in preparation still need to find a solution in the underlying materials design. Moreover, as continuously optimizing the traditional catalyst materials, like Pt and Pd, as well as the non-precious and non-metallic catalysts, the energy conversion efficiency of fuel cells has been gradually improved with reduction of their technical costs, meeting a certain degree of commercial application[10-11]. Besides, photocatalytic and electrocatalytic technologies for CO_2 reduction and nitrogen fixation also provide a new way for the storage and utilization of renewable energy, technically supporting the carbon emission peak in 2030 and carbon neutrality in 2060[12-13].

In the context of the era of sustainable development and the fiercely competitive international scientific and technological frontier research environment, in the energy materials research, including the exploration of physical and chemical properties, function discovery, precise design and preparation of nanomaterials, and advanced device assembly, China has made many important breakthroughs. In order to focus on displaying the research results of Chinese scholars in this field, to promote academic exchanges among peers, and to stimulate interest in energy materials from all walks of life, Nanjing University of Science and Technology, Shanghai Institute of Ceramics, Huazhong University of Science and Technology, *etc.* hereby organize the “Special Issue on Energy Materials”, containing the latest research articles and reviews related to energy materials involving perovskite photovoltaics, semitransparent solar cell, Li-ion battery, Mg battery, Li-S battery, thermoelectrics, CO_2 splitting, *etc*. It is hoped that this special issue can offer useful references for the scientific research and disciplinary development of energy materials in China.

参考文献：

[1] SUN Y K, CHEN Z H, NOH Y J, *et al*. Nanostructured high-energy cathode materials for advanced lithium batteries. *Nat. Mater.*, 2012, **11:** 942–947.

[2] BAI X, BAN L, ZHUANG W. Research progress on coating and doping modification of nickel rich ternary cathode materials. *J. Inorg. Mater.*, 2020, **35(9):** 972–986.

[3] LIU Y, BAI H, ZHAO Q, *et al*. Storage aging mechanism of $LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$/graphite Li-ion batteries at high state of charge. *J. Inorg. Mater*., 2021, **36(2):** 175–180.

[4] SCHIPPER F, DIXIT M, KOVACHEVA D, *et al*. Stabilizing nickel-rich layered cathode materials by a high-charge cation doping strategy: zirconium-doped $LiNi_{0.6}Co_{0.2}Mn_{0.2}O_2$. *J. Mater. Chem. A*, 2016, **4:** 16073–16084.

[5] YUAN K, YUAN L X, CHEN J, *et al*. Methods and cost estimation for the synthesis of nanosized lithium sulfide. *Small Struct.*, 2021, **2:** 2000059.

[6] JUNG H G, HASSOUN J, PARK J B, *et al*. An improved high-performance lithium-air battery. *Nat. Chem.*, 2012, **4:** 579–585.

[7] KATO Y, HORI S, SAITO T, *et al*. High-power all-solid-state batteries using sulfide superionic conductors. *Nat. Energy*, 2016, **1:** 16030.

[8] Best Research-Cell Efficiency Chart. [2021-10-20] https://www.nrel.gov/pv/cell- efficiency.html, 2021.

[9] YANG D D, LI X M, MENG C F, *et al*. Research progress on the stability of $CsPbX_3$ nanocrystals. *J. Inorg. Mater.*, 2020, **35(10):** 1088–1098.

[10] LIN G X, JU Q J, JIN Y, *et al*. Suppressing dissolution of Pt-based electrocatalysts through the electronic metal-support interaction. *Adv. Energy Mater.*, 2021, **11:** 2101050.

[11] FAN C, JIANG X, CHEN J, *et al*. Low-load Pt nanoclusters anchored on graphene hollow spheres for efficient hydrogen evolution. *Small Struct.*, 2021, **2:** 2000017.

[12] WANG Z H, HU X, LIU Z Z, *et al*. Recent developments in polymeric carbon nitride-derived photocatalysts and electrocatalysts for nitrogen fixation. *ACS Catal.*, 2019, **9:** 10260–10278.

[13] VOIRY D, CHHOWALLA M, GOGOTSI Y, *et al*. Best practices for reporting electrocatalytic performance of nanomaterials. *ACS Nano*, 2018, **12(10):** 9635–9638.

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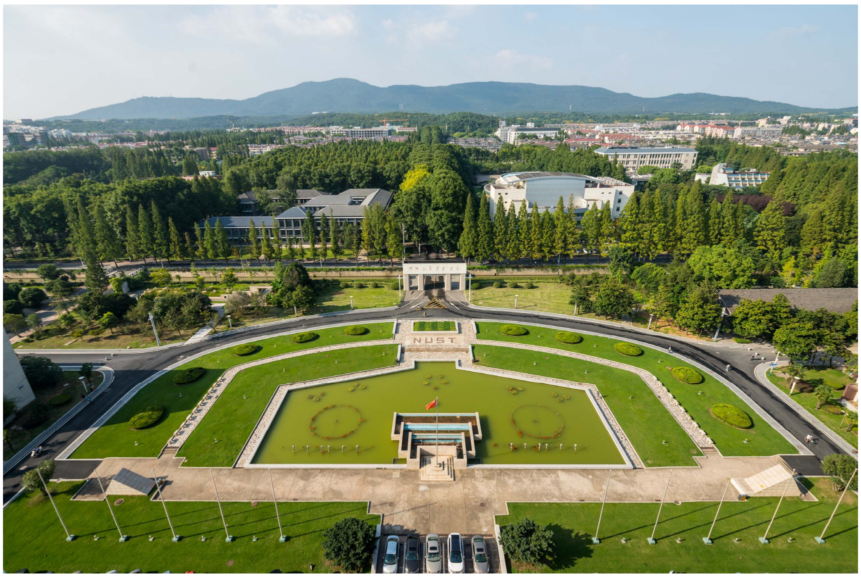

南京理工大学是隶属于工业和信息化部的全国重点大学，坐落在钟灵毓秀、虎踞龙蟠的古都南京，办学环境宜人，基础设施一流。学校由创建于 1953 年的新中国军工科技最高学府——中国人民解放军军事工程学院（简称“哈军工”）分建而成。近年来，学校立足南京、面向江苏，不断延伸和扩展办学面，形成了“一校三区”的发展布局，是国家首批“211 工程”重点建设院校和“985 工程优势学科创新平台”项目重点建设高校, 2017 年入选国家“双一流”建设高校。

南京理工大学被誉为“兵器科学与技术的摇篮”，科技优势突出，标志性成果不断涌现。始终坚持面向国家重大战略，瞄准科技前沿，在先进发射、光电信息、导航制导、先进材料等科技领域处于国内领先水平。2019 年 10 月，由我校担任总师单位研制的武器装备亮相中华人民共和国成立 70 周年阅兵式，接受了党和全国人民的检阅。学校大力推进产学研合作，发挥国家级技术转移中心和校外研究院的作用，推动重大科技成果的转化应用，服务国家和地方经济社会发展，民用爆破、特种超细粉体制备、智能熔敷焊、滚动功能部件测试等技术，填补了相关领域的空白，创造了显著的经济效益和社会效益。

近年，为响应国家能源结构调整战略，推进可持续发展，保障能源安全，南京理工大学在国际上也逐渐发展成既有鲜明特色的研究领域，如含能材料、航天燃料和生物质燃料，也有民用的高能量密度、高安全性的储能材料和器件，热电、光电、光热等重要的新型能源转化系统的科研院校。在含能材料领域, 2017 年研制出世界上首个全氮阴离子盐，为我国占领全氮类超高能量密度材料的制高点打下了关键基础，现代含能材料也正朝着高能量密度、高可靠性和安全性的方向快速发展。在光电器件领域率先开发了全无机钙钛矿量子点室温合成方法及其 QLED 发光器件，被同行在 *Nature* 等期刊数十次评价为“首次(first)”、“发起了(initiated)”、“开启了(opened)”。在能源存储领域设计了一种具有层状和尖晶石共生异质结构的 $LiMnO_2$ 阴极，为抑制锰基正极材料中的姜–泰勒畸变提供了崭新途径，推动了可持续性、规模化储能器件的商业化发展。