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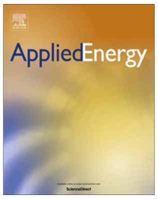

Advances and challenges in lithium-air batteries

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HIGHLIGHTS

- The overall picture about the present lithium-air batteries is reviewed.
- The challenges of battery's electrolyte and electrodes are emphasized.
- Several possible research directions for performance improvements are highlighted.

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ABSTRACT

Rechargeable lithium-air batteries have ultra-high theoretical capacities and energy densities, allowing them to be considered as one of the most promising power sources for next-generation electric vehicles. The technology has been honed in various ways over the years, but it still experiences critical issues that need to be addressed in order to make it commercially viable. For instance, its practical capacity, round-trip efficiency, and cycling life are among the factors that need to be improved. In this review, the developments of this type of battery are presented. In particular, the system levels of design that encompass the optimization of the battery's electrolyte and electrodes are discussed. More importantly, this report provides perspectives on achieving the desired battery performance to meet the demands of commercial viability.

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Abbreviations and acronyms

AAO	anodized aluminum oxide
CNT	carbon nanotube
CPL	composite protective layer
DEGDME	diethylene glycol dimethyl ether
DEMS	differential electrochemical mass spectrometry
DFT	density functional theory
DMA	N,N-dimethylacetamide
DME	dimethoxyethane
DMSO	dimethyl sulfoxide
EC	ethylene carbonate
ETPTA	ethoxylated trimethylolpropane triacrylate
EV	electric vehicles
FePc	iron phthalocyanine
HMPA	hexamethylphosphoramide
LAGP	lithium aluminum germanium phosphate
LATP	lithium aluminum titanium phosphate
LiTFSI	lithium bis(trifluoromethanesulfonyl)imide
OER	oxygen evolution reaction
ORR	oxygen reduction reaction
PC	propylene carbonate
PVDF	polyvinylidene fluoride
PVDF-HFP	poly(vinylidene fluoride-co-hexafluoropropene)
RH	relative humidity
RM	redox mediator
RTIL	room temperature ionic liquid
SEI	solid-electrolyte interface
SEM	scanning electron microscope
SPE	solid polymer electrolyte
TEGDME	tetraethylene glycol dimethyl ether
TEM	transmission electron microscope
TEMPO	2,2,6,6-tetramethylpiperidinyloxyl
TPFPB	tris(pentafluorophenyl) borane
TTF	tetrathiafulvalene
VC	Vulcan carbon
XPS	X-ray photoelectron spectroscopy
XRD	X-ray diffraction

1. Introduction

Global warming and finite oil reserves are two issues that exert tremendous pressure on the traditional vehicle industry. Radically different from the conventional gasoline-fuelled vehicles, electric vehicles (EV), which are powered by rechargeable batteries, not only relieve the pressure on gasoline usage but perhaps more importantly, eradicate pollution generated from exhausts, lending hopes to the vehicle industry. To date, one of the most promising candidates for such power sources is the lithium-ion battery [1–3]. It has demonstrated a reasonable energy density (theoretical value: ~400 $\mathrm{W\,h\,kg^{-1}}$), which is much higher than that of conventional lead-acid batteries (30–40 $\mathrm{W\,h\,kg^{-1}}$) and nickel-cadmium batteries (40–60 $\mathrm{W\,h\,kg^{-1}}$) [4]. As a result, lithium-ion batteries have been used as the power source for electric vehicles with achieving a driving distance of ~400 km per charge [5]. Despite the progress accomplished to date, however, the specific energy densities of lithium-ion batteries are still far inferior to that of the conventional gasoline engines (~13,000 $\mathrm{W\,h\,kg^{-1}}$) [6]. Thus, the exploitation of new energy storage technologies for EVs is still a grand challenge.

In attempts to improve the energy density, much attention has been paid to metal-air batteries, especially lithium-air, aluminum-air, and zinc-air batteries [7]. In this type of batteries, oxygen is straight obtained from air, as opposed to storing an internal oxidizer, and the pure metal is used as the electrode instead of conventional intercalated materials. Theoretically, the energy density of metal-air batteries only relies on the metal electrode so that it can be significantly increased. Among the metal-air batteries, the lithium-air battery has garnered the most attention, predominantly because lithium is the lightest metal. This means that it has the highest theoretical capacity (3862 $\mathrm{A\,h\,kg^{-1}}$), which corresponds to an energy density of 11,680 $\mathrm{W\,h\,kg^{-1}}$ for a potential of about 3.0 V. Even based on the consideration of the entire battery system, the energy density of ~1000 $\mathrm{W\,h\,kg^{-1}}$ is still several times higher than that of lithium-ion batteries [8], showing the remarkable potential to completely replace gasoline in vehicles.

The fundamental chemistry of lithium-air batteries involves lithium dissolution and deposition on the lithium electrode (or anode) and oxygen reduction reaction (ORR) and oxygen evolution reaction (OER) on the air electrode (or cathode) [9]. Since the demonstration of a prototype rechargeable lithium-air battery by