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Notation and abbreviations

AEM	anion exchange membranes
BC	bacterial cellulose
CPEs	composite polymer electrolytes
DC5700	octadecyldimethyl(3-trimethoxysilylpropyl)ammonium chloride
DN	double-network gels
DNA	deoxyribonucleic acid
EDLCs	electrochemical double-layer capacitors
FSSCs	flexible quasisolid-state supercapacitors
GO	graphene oxide
GPE	gel polymer electrolyte
HER	hydrogen evolution reaction
IPNs	interpenetrating polymer networks
LIBs	lithium-ion batteries
MFC	microbial fuel cell
NMAs	noble-metal aerogels
OER	oxygen evolution reaction
ORR	oxygen reduction reaction
PANI	polyaniline
PDDA	poly(diallyldimethylammonium chloride)
PEC	photoelectrochemical
PEDOT	poly(3,4-ethylenedioxythiophene)
PEM	proton-exchange membrane or polymer-electrolyte membrane
PEMFCs	proton-exchange membrane fuel cells
PPy	polypyrrole
PVA	poly(vinyl alcohol)
PVP	polyvinyl pyrrolidone
rGO	reduced graphene oxide

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SC supercapacitor
SPEs solvent-free polymer electrolytes
TEOS tetraethyl orthosilicate
TMOS tetramethyl orthosilicate

1. Introduction

Carbon-based hydrogels can be classified into three main categories: graphene-based, polymer-based, and biomass-derived. Due to their unique relation between structure and application properties, carbon-based hydrogels have been considered for sustainable systems dealing with energy, environmental as well as several biomedical applications [1]. The tailoring of carbon-based hydrogels and their various hybridizations (graphene-based/synthetic/natural polymers) lead to materials presenting mixed ionic and electronic conductivity, stimuli-responsive features, controlled swelling with water, and viscoelasticity. Therefore, these materials are currently being used in advanced applications, namely, for energy storage and conversion and improvement of energy efficiency in many processes. Batteries, fuel cells, supercapacitors, electrocatalysis, wearable electronics, environmental and health sensing, water harvesting, desalination, and purification are important examples of such kinds of areas where carbon-based hydrogels play an important role [2]. Further below, these applications are detailed with the analysis of some recent research works on improving energy storage and conversion systems as well as energy efficiency for sustainability. The subjects herein addressed were recently reviewed, namely, in Refs. [1–4] and others cited along the text.

2. Graphene-based hydrogels

Graphene-based hydrogels are 3D structures obtained from 2D arranged carbon materials, namely, graphene and graphene oxide (see depiction in Fig. 1). The 3D spatial arrangement of these hydrogels is grounded by intermolecular forces like π-π stacking, hydrogen bonding, or van der Waals forces. The hierarchical structure of the 3D graphene-based hydrogels grants them superior porosity and mechanical or electrical properties, as compared with the analogous 2D counterparts [1]. Like the original 2D carbon materials (graphene/graphene oxide), the 3D graphene-based hydrogels encompass a set of particular features as compared with alternative materials, namely, a large specific area, high electrical and thermal conductivities, flexibility and hardness, transparency, and chemical stability.