来自于水和石墨烯间的能量

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摘要 石墨烯材料在能量存储和能量转换方面显示出巨大的潜力, 如电池、超级电容器、驱动器、产电器件等。其中, 石墨烯基材料水力生电这一新能源的发现与开发成为近两年来的研究热点之一。本文总结了本课题组和国内外相关研究组在石墨烯组装和水力生电相关应用方面的重大进展, 包括不同结构的石墨烯的组装和加工及其在水力生电、产能领域的应用, 如湿气产电、水蒸发诱导产电、湿气响应驱动器等。本文旨在增强对水伏纳米器件的认识, 希望对将来石墨烯基材料水力生电的研究有指导意义。

关键词 石墨烯, 组装与加工, 水, 机械性响应, 产电

石墨烯自2004年诞生以来就引发了科学工作者巨大的研究兴趣^[1]。作为第一个真正的二维(2D)材料, 石墨烯拥有很多优点, 如具有大比表面积、高载流子迁移率^[2~4]、较高的机械强度^[5]和优异的柔韧性^[6], 已经展示出广阔的应用前景^[1,7~13]。作为石墨烯重要的官能化材料之一, 氧化石墨烯(GO)是一种具有丰富含氧官能团的二维大分子, 它有良好的亲水性, 在众多相关领域被广泛地用作化学官能化材料, 并应用于能量的转换和存储装置^[14,15]。然而, 将石墨烯及其衍生物的理想性能转化为宏观结构或器件仍是科学家面临的一项挑战。

如今, 由于自然资源的短缺, 新能源的开发变得十分迫切。在这方面, 科学工作者已经成功开发了一些能源转换器, 如将太阳能转化为电能的太阳能电池^[16], 将水光解出氢气的光电化学电池^[17], 将化学能转化为电能的电池(锂离子电池^[18]和钠离子电池^[19])等。水资源作为自然界珍贵的宝库, 人类除了水电应用之外还没有大规模开发出其他与水有关的能源应用, 为此科学家也做了大量的努力。最近有研

究表明, 研究人员发掘出一种潜藏在水和石墨烯之间的能量, 水分子与特殊结构的石墨烯相互作用能够产生电能或者机械能等能量。随后, 在此基础上研究人员开发出了一系列基于石墨烯等碳基材料的水力生电材料与器件, 如湿气发电机^[20]、水蒸发产电碳材料^[21]和湿气机械响应器件^[22]等。随着研究的深入, 研究人员还发现石墨烯的特殊微观结构的调控对石墨烯和水的相互作用有着重大影响。因此, 对石墨烯基材料进行合适的组装和加工有利于石墨烯在材料、水力产能器件方面发挥更大的作用。

本文主要介绍和总结了各种基于石墨烯、官能化石墨烯以及其他碳材料的水力产能, 尤其是水力生电器件的最新进展。除了介绍具有相关特定结构的石墨烯的设计与制备外, 还详细介绍了这些石墨烯基水力生电器件的产能工作原理, 对未来各种碳基材料在水力生电领域的研究具有重要的指导意义。

1 石墨烯的组装和加工

在石墨烯基材料与器件的加工过程中, 由于受

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石墨烯的鳞片状结构影响,片层与片层之间的强相互作用很容易导致其堆叠,大大降低了它们的比表面积并严重限制了它们的表面利用效率.因此,石墨烯在电子器件、催化、储能等领域的应用都会受到很大的限制.因此,提高石墨烯使用性能的关键之一是如何有效防止石墨烯片层堆叠.具有特定微/纳米形态的石墨烯的组装和加工有利于更好地发挥石墨烯的优势,从而有效地提高石墨烯器件的性能.研究人员在石墨烯基材料的结构和形态设计方向已经做了很多研究.在石墨烯基水力发电领域的应用中,石墨烯的形态和微观结构变化对水分子与石墨烯的相互作用有更大的影响.因此,石墨烯基材料的微观与宏观的前期组装也显得尤为重要.

1.1 石墨烯宏观组装纤维

石墨烯纤维(GF)是一种宏观的一维(1D)材料,具有较轻的质量、高机械强度和环境稳定性等优点.

然而,由于石墨烯衍生物的不规则尺寸和形状,将2D石墨烯片直接组装到宏观纤维中是一项非常具有挑战的工作,科学家为此做了很多努力. Xu和Gao^[23]在2011年首次报道了石墨烯的1D组装.他们通过湿法纺丝制备GO纤维,使用NaOH(质量分数为5%)的甲醇溶液作为凝固浴,然后通过高温退火得到GFs.此后, Dong等人^[6]采用一步法制备GFs(图1(a)~(c)).他们使用直径为0.4 mm的毛细管作为反应装置,通过水热反应得到GFs,拉伸强度为180 MPa.之后,他们使用含有3 mol/L KCl的甲醇溶液作为凝固浴^[24],采用同轴双毛细管纺丝策略来制造中空 of 的石墨烯基纤维(GO-HF)(图1(d)~(f)).这种同轴双毛细管喷丝技术大大便利了GO-HF的生产,直接纺丝出的GO-HF具有高达140 MPa的拉伸强度.

1.2 石墨烯宏观组装薄膜

2D层状结构的石墨烯由于层间的范德华力和

图1 (网络版彩色)石墨烯纤维的制备. (a) 干燥石墨烯纤维的照片. 打结(b)和双层(c)石墨烯纤维的扫描电子显微镜(SEM)图像, 标尺为 100 μm . (d) 旋转GO-HF示意图. (e) 纺出的GO-HF照片. (f) 空气流速为 1.0 mL/min时产生的项链状、中空的石墨烯纤维(nGO-HF)照片^[6]

Figure 1 (Color online) Preparation of graphene fibers. (a) A photograph of dry graphene fibers. SEM images of the knotted (b) and two-ply (c) graphene fibers, scale bars=100 μm . (d) Schematic illustration of the spin GO-HFs. (e) Photos of the spun GO-HFs. (f) A photo of nGO-HF produced at an air flow rate of 1.0 mL/min^[6]

π - π 堆叠作用, 很容易被组装成宏观2D结构. 这种结构便于与水分子的接触, 从而在某一特定方向构建出功能性梯度. Li等人^[25]采用Langmuir-Blodgett组装技术制备石墨烯薄膜, 并应用于透明电极. 这种制备方法相对比较复杂且耗时, 不适合大规模生产. Ruoffy课题组^[26]发现氧化石墨烯薄膜可以通过真空过滤制备. 随后, 部分还原的氧化石墨烯和聚吡咯(prGO-PPy)复合膜被制造出来^[27]. 将GO溶液烘干得到GO膜, 并将GO膜的一侧暴露于吡咯单体蒸气中以制造GO/prGO-PPy混合膜(图2(a), (b)). 膜的两侧具有不对称性, 对水分子具有不同的亲和力, 进而产生不同的响应.

1.3 石墨烯宏观组装泡沫

具有重量轻、孔隙率高、高电导率等优点的三维(3D)石墨烯泡沫在能量转换领域引起了越来越多的关注^[28]. 具有官能团梯度的GO泡沫已经被用于湿气发电的器件^[29]. 采用冷冻干燥法制备的GO泡沫具有丰富且均匀分布的孔(图3(a)). 丰富的孔的存在极大地促进了水分子的扩散, 导致GO中的含氧官能团发生解离产生带电离子, 可以显著提高在湿气环境下的电压输出值. Zhao等人^[30]也制备了具有高压缩性的聚吡咯掺杂的石墨烯泡沫(图3(d)~(f)). 该泡沫可以被压缩并且快速恢复原状, 而其电学性能不产生明显的变化.

1.4 石墨烯微结构加工制造

石墨烯的组装对于石墨烯材料的应用是必需的, 这些组装后的特征使石墨烯的应用更加广泛和多样化. 除了石墨烯的预组装之外, 石墨烯的加工处理如激光加工、湿气电退火(MeA)等也可以有效地控制石

墨烯的功能化. 还原碳基材料大多数通过化学方法或其他方法. 最近, 研究者报道了一种新的还原方法, 可以成功地将GO进行还原^[31~33]. 激光可以远程诱导GO结构的局部还原. 该方法是一种具有选择性的、无溶剂、无试剂的固态路线, 可以非常简单快速地制备出石墨烯及其多功能复合材料. 该方法已经制备出单边还原的GFs^[11], 并且该方式还可以制造rGO泡沫^[34]. 在水力生电领域, 材料中含氧基团的梯度最为重要. 目前, 构建GO含氧官能团梯度的方法是MeA和极化. 在这方面, Zhao等人^[20]使用MeA的方法将GO膜转换成梯度GO膜, 使用极化的方法将GO泡沫转换成梯度GO泡沫^[29]. 石墨烯的组装和加工都十分重要, 组装使石墨烯形成特殊的形貌, 加工使材料性能进一步优化, 都对水力生电的研究具有重要意义.

2 石墨烯基水力产能器件

近年来, 石墨烯等碳基材料的水力产能尤其是水力发电现象引起了科学家的兴趣. 研究人员发现, 碳基材料与水之间的相互作用可以使内部能量转化为其他能量, 如机械能和电能. 目前, 国内外研究团队在石墨烯等碳基材料的水力产能领域已经获得了较大进展.

2.1 湿气机械响应器件

石墨烯水致机械响应驱动器是基于水嵌入和嵌出过程引起的体积变化原理来设计的. Cheng等人^[11]制造了在湿气环境下具有预定形变的GFs. 通过激光还原新纺GO纤维制成的石墨烯/氧化石墨烯(G/GO)纤维(图4(a), (b))与GO纤维类似, 具有高达100 MPa的高拉伸强度, 并且具有良好的柔韧性, 可任意变形, 能够应用于纤维和纺织设备中. 由于GO层具有丰富的含氧官能团, 因此GO层拥有比G层更强的亲水性, 导致GO层可以更快地可逆膨胀/收缩. 在此, 不对称的G/GO纤维可以被用作湿气敏感性纤维驱动器(图4(c)~(f)).

与此同时, Cheng等人^[35]制备出一种由湿气活化的、可以进行机械性高速旋转的石墨烯纤维电机. 首先通过电机扭曲GO水凝胶纤维, 然后重新构建石墨烯纤维并赋予它新功能(图4(g)). 水分子的嵌入和嵌出作用, 使得已预先加工成螺旋形状的GO纤维会发生水分进出交替下的可逆扭转旋转(图4(k)).

图2 (网络版彩色)GO/prGO-PPy薄膜的制备及形貌. (a) 湿度响应的非对称GO/prGO-PPy薄膜驱动器的制备示意图. (b) GO/prGO-PPy膜截面的SEM图像^[27]

Figure 2 (Color online) Preparation and morphology of GO/prGO-PPy films. (a) Schematic fabrication process of the humidity responsive asymmetric GO/prGO-PPy film actuator. (b) SEM image of the section view of GO/prGO-PPy film^[27]

图3 (网络版彩色)泡沫的制备及性质. (a) g-3D-GO的制备过程. 多孔3D组装的GO(b)和压缩后的3D-GO(c)的SEM图像^[29]. (d)~(f) PPy-G泡沫的压缩恢复过程. (g)~(i) PPy-G泡沫的表面照片, 分别对应于(d)~(f)中未压缩-压缩-未压缩的状态^[30]

Figure 3 (Color online) Preparation and properties of foam. (a) Preparation process of g-3D-GO. SEM images of the porous 3D assembly of GO (b) and the close-grained 3D-GO (c)^[29]. (d)~(f) The compression-recovery processes of PPy-G foam. (g)~(i) The surface views of PPy-G foam corresponding to the unloading-loading-unloading status in (d)~(f), respectively^[30]

研究人员已经开发出了以石墨烯薄膜为基础的机械响应驱动器, 比如在湿气环境下响应驱动的GO膜^[22]. 该膜通过将GO悬浮液直接浇铸在平板上制造而成, 由于重力作用导致了GO膜表面两侧具有不对称的微结构. 这种不对称的表面使薄膜对光线、温度和湿度具有不对称的响应, 从而可以发生可逆的弯曲与变形(图4(m)). 此外, Jiang等人^[27]制备了一种用于水分诱导致动的, 部分还原的氧化石墨烯/聚吡咯复合膜^[27]. Zhao等人^[36]还制备了石墨烯纤维状响应

器来感应热量、湿度和机械变化.

2.2 湿气产电

除了G/GO的微形态与结构的设计改变能够将其用于机械响应性器件, GO的水诱导也可以产生电能. 水分子的进入过程和离子梯度的构建在设计湿气敏感装置中是十分重要的. 在这些方面, 本研究团队已经进行了大量的研究来实现能量转换器. 随着便携式设备的出现, 便携式电源正变得越来越不可或缺.

图4 (网络版彩色)湿气机械响应器件的制备和响应。(a) GO纤维的单侧激光还原。(b) G/GO纤维的显微镜照片,标尺为50 μm 。(c)~(f)暴露于不同相对湿度的G/GO纤维的弯曲状态^[11]。(g) TGF制备示意图。干燥的GO纤维(h)和TGF(i)的SEM图像。(j) TGF的旋转示意图。(k)不同湿度下的纤维SEM图像,标尺为100 μm ^[35]。(l) rGO电路的原理图。(m)不同相对湿度下GO薄膜变形的照片^[22]

Figure 4 (Color online) Preparation and response of moisture mechanical response devices. (a) Positioned laser reduction on one side of a GO fiber. (b) Photomicrograph of the asymmetric G/GO fiber, scale bar=50 μm . (c)~(f) The bending of a G/GO fiber exposed to different relative humidity. (g) Scheme of the TGF fabrication. SEM images of directly dried GO fiber (h) and TGF (i), respectively. (j) Schematic rotation of a TGF. (k) SEM images of different humidity, scale bar=100 μm ^[35]. (l) Schematic of the rGO circuit. (m) Photo of the film deformation under different relative humidity^[22]

为了满足这一要求,许多研究人员致力于实现这个目标,包括可穿戴电容器^[37]和柔性电池^[38]。近几年,

自产电的GO纤维已经被制造出来^[39]。GO纤维可以从环境湿气中获得能量进而转化为电能。它由湿法纺

丝法^[40]制成, 通过沿着纤维的拉力使GO纳米片对齐排列. 他们通过选择性激光照射将GO部分地转变为rGO电极, 并通过电化学处理过程(ECT)构建含氧官能团梯度, 合成过程如图5(a)所示. 在湿气环境下, GO吸收水分导致氢离子(H^+)从含氧官能团中电离出来, 由于含氧官能团存在浓度梯度, 产生的氢离子也会产生浓度梯度, 因此, 导致氢离子从高浓度向低浓度区域移动(图5(b)). 他们通过调整干燥的氮气和水的流量来控制湿度(RH). $\Delta RH=35\%$ 的条件下, 电压输出为290 mV, 电流密度为 0.46 mA/cm^2 (图5(c), (d)). 设备单元串联和并联可以提高湿气发电的功率输出. 在 $\Delta RH=65\%$ 的环境下, 4个器件串联可以使电压输出

高达1.32 V(图5(e)), 4个器件并联可以使电流密度增加到 3.6 mA/cm^2 (图5(f)).

Zhao等人^[20]制备了具有含氧官能团梯度的氧化石墨烯薄膜(也称为梯度GOF, g-GOF). 采用真空过滤法制备GOF, 干燥后自支撑的GOF可从滤纸上剥离. g-GOF通过MeA过程处理可以获得含氧基团梯度(图6(a)~(d)). 成功构建含氧基团梯度后, 当水分子进入g-GOF内部后, 由于预设的浓度梯度使之在材料内部会产生 H^+ 的迁移, 从而导致电流的产生. 当器件暴露于湿气 $\Delta RH=30\%$ 环境下, 所产生的电压和电流密度可以达到约20 mV和 $5 \mu\text{A/cm}^2$.

Zhao等人^[29]制备了用于产电的3D GO骨架. 他

图5 (网络版彩色)石墨烯纤维发电机(GF-Pg)的制备和产电信号. (a) GF-Pg的制备示意图. (b) 湿-电转换机制. 在湿气刺激下GF-Pg的电压(c)和电流(d)密度响应. $\Delta RH=65\%$ 的环境下, 分别串联和并联1~4个GF-Pg单元产生的电压(e)和电流密度(f)^[39]

Figure 5 (Color online) Preparation and electricity generation of GF-Pg. (a) Schematic illustration of the GF-Pg fabrication. (b) Mechanism of moisture-electric transformation. The voltage (c) and current density (d) responses of GF-Pg unit under the stimulation of moisture. Voltage (e) and current densities (f) generated by 1~4 GF-Pg units connected in serial and parallel under $\Delta RH=65\%$, respectively^[39]

图6 (网络版彩色)GOF的表征及产电信号. (a) 在潮湿环境下GOF的MeA过程. (b) g-GOF横截面的SEM图像和相应的碳(c)、氧(d)元素分析. (e) 对周期性相对湿度变化响应的电压和电流输出^[20]

Figure 6 (Color online) Characterization and electricity generation of GOF. (a) MeA process of GOF with applied voltage under humid environment. (b) Cross-section SEM image and the corresponding carbon (c) and oxygen (d) mapping. (e) Voltage and current output cycle in response to the intermittent and periodic RH variation^[20]

们采用冷冻干燥法得到具有丰富且分布良好的孔的GO组装体, 并采用极化法得到含氧基团梯度. 不对称含氧基团的存在, 将会显著提高功率密度. 当其暴

露在湿气中, 含氧基团会电离出 H^+ 离子, H^+ 离子的定向移动可以产生电流. 在相对湿度变化(ΔRH)为75%的情况下, 该器件可以产生约0.26 V的输出电压和约

3.2 mA/cm²的电流密度(图6(e)).

Zhao等人^[41]还通过尺寸限制的冷冻自组合法将氧化石墨烯纳米带(GOR)网络(GOR-Ns)堆叠成层状GOR-N膜(GOR-NM). 他们之所以选择特定的GOR是因为GOR具有含氧的亲水官能团, 可以形成具有广泛分布的纳米孔的GOR-NM, 不仅加快了湿气捕获, 而且促进了离子传输. 图7(a)显示了一种人造湿气开关的合成方案. 使用氧化方法纵向切割多壁碳纳米管制备了GOR, 随后使用定向冷冻方法使GOR形成GOR-N的多孔薄片叠层(图7(b), (c)), 从而通过结构极化得到GOR-NM的含氧基梯度. 在湿气环境下, GOR-NM内将发生离子移动. 水分 ΔRH 为35%下, 输出电压约40 mV. 最近, Xu等人^[42]也发现, 没有任何添加物、未进行任何预处理的石墨烯薄膜在湿气条件下能够产生0.7 V电压输出. Nie等人^[43]通过电沉积方法在聚吡咯纳米线中构建官能团梯度, 从而实现湿气产电.

湿气产电的产生源于GO中预先建立的含氧官能团梯度, 当处于湿气环境时, 在水分子的作用下, 含氧官能团会电离出氢离子. 含氧官能团梯度的存在, 导致电离出的氢离子浓度存在明显梯度, 进而引发氢离子的定向移动, 产生电流.

3 水蒸发产电

值得注意的是, 除石墨烯外, 还有一些碳材料也

可以用于水力发电. 最近, Zhou等人^[21]研究发现, 在碳纳米材料中的水分蒸发也能产生电能. 产电材料用炭黑(CB)制备, 将基板放在乙醇火焰上使得CB在表面聚集, 2个电极多壁碳纳米管薄膜; 随后, 器件在370℃下退火2.5 h, 氧气等离子体处理1 min, 功率为130 W. 该材料可以发电是由于水分子与碳基材料纳米层之间的相互作用; 换句话说, 与传统的流动电势有关(图8(b)). 在实验室环境下, 感应电压可保持在1.0 V左右, 并且可持续8 d.

已有研究者制造出水蒸发驱动水流动产电的全印刷多孔碳膜^[44], 该装置利用印刷方式制造(图8(c)), 电压可升至1.0 V(图8(e)). 随后, Zhou课题组^[45]利用热电效应使多孔碳膜能够在封闭的环境下持续输出电压, 使纳米材料的水致能量转换器研究更进一步.

在水致发电领域, 除了湿气产电和水蒸发产电的研究, Guo课题组^[46,47]还做了许多其他工作. 例如, 在石墨烯中的波动电位^[46], 和将1滴离子液体沿石墨烯移动导致发电^[47]等.

4 总结和展望

石墨烯作为一种新型纳米材料, 它的组装能够进一步扩大其应用范围. 由于便携式、灵活性和可穿戴电子设备的流行, 石墨烯材料已经引起了能源转换器领域研究者的巨大兴趣. 石墨烯纤维和薄膜都可以很好地解决便携式的需求, 具有压缩性的石墨

图7 GOR-NM的制备和形貌. (a) 人造湿气开关的制备过程. GOR-NM截面(b)和表面(c)的SEM图像^[41]

Figure 7 Preparation and morphology of GOR-NM. (a) Synthetic strategy for an artificial moisture-enabled potential switching. Typical cross-section (b) and top-view (c) SEM images of GOR-NM^[41]

图 8 (网络版彩色)用于水蒸发发电的纳米碳材料。(a) 器件和实验装置示意图。(b) 水在CB材料中蒸发产生的开路电压(V_{oc})。 (c) 器件制备过程示意图。(d) 多孔碳膜的SEM图像。(e) 当烧杯周期性密封和打开时装置的 V_{oc} 。(f) 气流流速增强时的 V_{oc}

Figure 8 (Color online) Water-evaporation-induced electricity with nanostructured carbon materials. (a) Schematic of device and experimental set-up. (b) Open-circuit voltage (V_{oc}) generated by water evaporation from the CB. (c) Schematic diagram of device fabrication process. (d) SEM image of the porous carbon film. (e) Measured V_{oc} of the device when the beaker was periodically sealed and unsealed. (f) V_{oc} enhancement by increasing the velocity of air flow in the laboratory environment

烯泡沫也有重要的应用价值。

在水力发电领域,氧化石墨烯的湿气产电最重要的是含氧基团梯度的构建和水分子的进入。在湿气环境中,水分子能够引起正负电荷分离,使材料两侧呈现相应的电位差,导致化学势能转化为电能。湿气响应驱动器取决于水和石墨烯层之间的亲和力。水蒸发产电取决于水分子和碳纳米层之间的相互作用。

本文总结了目前国内外主要研究团队在石墨烯的组装和加工,以及石墨烯基等碳材料在水致能量

转换等领域的相关工作,包括石墨烯微结构的组装和加工以及湿气发电、湿气响应驱动器和水蒸发产电。这将对水力发电中其他各类材料的研究具有指导意义,未来我们仍需在构建材料官能团浓度和梯度方面努力,尽力挖掘实际可应用的电能。另外,目前很多碳材料产电的电流都相对较低,针对电流提高的研究仍在继续,以便能够应用于实际生活中。但是,碳材料与水之间相互作用产电的机理仍需进一步探索,将为未来更多其他材料产电的研究奠定基础。

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Summary for “来自于水和石墨烯间的能量”

Power from water and graphene

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Since the birth of graphene in 2004, it has attracted great research interests of scientists. As the first true two-dimensional (2D) material, graphene has many advantages, such as large specific surface area, high intrinsic carrier mobility, strong mechanical strength, and superior flexibility. Graphene shows broad application prospects. As an important functionalized material, graphene oxide (GO) is 2D macromolecule rich in oxygen-containing functional groups. It has good hydrophilicity and is widely used as a chemical functionalized material in many related fields and applied to energy conversion and storage devices. However, converting the ideal properties of graphene and its derivatives into macrostructures or devices remains a challenge for scientists.

The strong interaction between graphene sheets leads to their easy stacking, which greatly reduces their specific surface area and severely limits their efficient use of interfaces. Therefore, the applications of graphene in electronic devices, catalysis, energy storage and other fields have been greatly limited. The key to improve the performance of graphene is how to effectively prevent the stacking of graphene sheets. The assembly and processing of graphene with specific micro-/nano-morphology is conducive to better play the expertise of graphene, thus effectively enhancing the performance of graphene based devices. In this regard, there are lots of efforts have been devoted to the design of structure and morphology for graphene based materials. In the field of water-induced graphene energy converters, the interaction between water molecule and graphene is affected more by the morphology and microstructure change of graphene.

As a new type of nano-material, graphene assembly can further expand its application scope. Due to the popularity of portable, flexible and wearable electronic devices, graphene materials have attracted a great deal of research interest from researchers in the field of energy converters. Graphene fibers and films are good solutions for portable needs. Graphene foam with compressibility also has important application value.

In the field of hydropower, the moisture induced power generation of graphene oxide, most importantly, the construction of oxygen-containing radical gradients and the entry of water molecules. In a wet environment, water molecules can cause positive and negative charge separation, so that the potential difference appears on both sides of the material, resulting in the conversion of chemical potential energy into electrical energy. Moisture responds to the driver, depending on the affinity between the water and the GO layer. Water evaporation depends on the interaction between water molecules and carbon nanolayers.

In this review, we summarized the current work of the major research teams at home and abroad on the assembly and processing of graphene, and the related work of graphene-based carbon materials in water-induced energy conversion, including the assembly and processing of graphene microstructures. As well as moisture power generation, moisture response drivers and water evaporation power generation, this will have guiding significance for the research of other types of materials in hydroelectric power generation. In the future, we still need to work hard in constructing the concentration and gradient of material functional groups to try to find out the actual applied electrical energy. In addition, many current carbon-based materials generate relatively low currents, and current researches on current increase are still continuing so that they can be applied in real life. Moreover, the interaction between carbon materials and water produces electricity. The mechanism still needs to be further explored, which will lay the foundation for future research on the production of electricity from other materials.

graphene, assembly and processing, water, mechanical response, power generation

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