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Nano-materials for Energy Production & Storage

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Abstract: The world population is increasing and burst of portable electronic devices, automobile and other industries, the consumption of energy in many forms has been intensively escalated. The world energy sources are being consumed fast and this has put the world in a ditch of energy crisis. On the other side, the availability of sustainable energy is crucial for the economic growth and industrialization, at the end of day sufficient and inexpensive energy is the most important demand of today. So this is the time to conserve the nonrenewable energy sources as well as to find the alternative sources of energy production and storage. It needs to response of modern society and emerging ecological concerns, the new, minimum-cost, and environmentally friendly energy conversion and storage systems should be investigated, and research and development of this field should be rapidly accelerated. Tailored characteristics of nano materials and compound at the nanometer scale, offer unique properties and will play a vital role in the development of new energy technologies for energy production and storage. The objectives of the research have to introduce the nanomaterial for energy production & storage. At the last there have a great potentiality to produce energy & storage by nanomaterials.

Keywords: Nanomaterials, Enegy, Production, Storage, Sustainable

1. Introduction

The world's hunger for energy is increasing rapidly while we at the same time face critical environmental issues as well as dwindling resources. To manage this situation we need to produce, store and consume energy in new and more efficient ways. Nanotechnology is the understanding and control of matter and processes at the nanoscale, typically, but not exclusively, below 100 nanometers in one or more dimensions where the onset of size-dependent phenomena usually enables novel applications. Nanotechnology has played an extremely important role in the design, characterization of various new and novel energy materials and catalysts for processing fuels from fossil fuel resources such as coal, petroleum, and natural gas. Today fossil fuels still account for 90% of the world's energy consumption, and their use is expected to peak around the year 2050. The widespread use of fossil fuels is plagued with problems such as the generation of increasingly serious environmental problems, the related climate changes we are witnessing [1]. Therefore, it is necessary to develop a suite of sustainable energy sources and energy-storage materials. The nanostructured materials include iron-based ultra-soft nanocrystalline magnetic materials, fall under the trade name FINEMET and have potential applications as various kinds of inductor materials having ultra-high permeability and high relative quality factors [2]. These materials have many applications in electrical and electronic devices.

2. Energy Production

2.1. Nanotechnology for Solar Cells and Solar Fuels

A significant and great challenge in the research and development of solar cells and solar fuels is the characterization of various novel materials that must both be inexpensive and have high energy-conversion efficiency. Titanium dioxide (TiO_2) is still by far the most investigated material for solar cell and solar fuel applications. It possesses a band gap of 3 eV and therefore can absorb ultraviolet (UV) light (400 nm or shorter). However, this current TiO_2 based cells are very inefficient with incident photon-to-current efficiencies of 10% or less and peak energy conversion efficiencies of 0.6% or less over the whole solar spectrum [3]. A primary factor limiting the efficiency of these cells is competition between the optical path length required for light absorption and charge diffusion length. It is thus important to engineer systems with both high optical density and high surface area -to- volume ratio [3, 4]. According to Dr. Mingzhao Liu in Prof. Hongkun Park's group at Harvard

University the visible light photocurrent can be enhanced by coating TiO_2 nanowires with gold or silver nanoparticles. The enhancement has been achieved due to optical scattering from the plasmonic nanoparticles, which increased the effective optical path of the thin film. They prepared the TiO_2 nanowires with mixed anatase and rutile phases by a solution-phase method [5]. The nanowires were deposited to form a uniform. TiO_2 nanotubes (TNTs) also have the potential to play crucial roles in solar cells and solar fuels as well as other areas due to their distinctive structural and chemical properties [6]. As a semiconductor material, TiO_2 helps to achieve superior photovoltaic performance in dye-sensitized solar cells (DSSCs). Introducing an organic dye or combining TNTs with a semiconductor that has a narrow band gap and energetically high-lying conduction band are two successful techniques in harvesting light. The application of TNTs to dye-sensitized solar cells would benefit a thin-film configuration having smaller diameter nanotubes. The highest solar cell efficiencies today for pure TNT systems are approximately 4%, whereas for some mixed systems around 7% has been reported [7]. For both types of system there is significant room for improvement. Moreover, TiO_2 nanocrystal thin films with large surface areas covered by monolayers of dye molecules to harvest sunlight can lead to highly efficient DSSCs. To take advantage of the enhanced electron transport and the surface area offered by these devices [8]. Such a structure is effective for enhancing efficiency because it allows light to have multiple interactions with the dye molecules adsorbed on the nanowire surface without increasing the electron-transport distance. In comparison with light illumination from the outside of the device that is normal to the fiber axis, internal axial illumination enhances the energy conversion efficiency by a factor of up to six for the same device. Most recently a new approach for the fabrication of 3D DSSC by integrating planar optical waveguides and nanowires [9]. The ZnO nanowires are grown normal to the quartz slide. The slide serves as a planar waveguide for light propagation. This structure effectively increases the light absorbing surface area without increasing the electron path length to the collecting electrode due to internal multiple reflections. The design allows the solar cell to be concealed, smaller, and more efficient.

2.2. Nanomaterials for Clean Fuel and CO2 Capture

Prof. Reshef Tenne of the Weizmann Institute of Science, Israel, discovered inorganic fullerene-like nanospheres and nanotubes, a new class of nanomaterial [10]. Since this discovery, other inorganic nanotubes (INTs) have been presented [11, 12] Many applications of INTs have been exploited, including uses in solar cells, photocatalytic hydrogen production, [13] piezoelectric nanogenerators, [14] and hydrogen storage [15]. At the ACS symposium recent progress in the synthesis of core shell INTs (CSNTs) via the use of another INT. Three different schemes for the production of CSNTs. The first is the capillary-filling technique that uses INT-WS2 as filling vessels for a molten salt. The second method involves a conformal coating of the INTWS2 from the gas phase. In this case, the MoS2 layers (resulting from reacting MoCl5 and S) most often cover the INTWS2, resulting in CSNT-WS2@MoS2 [16]. The third scheme employs an in situ wetting process within the transmission electron microscopy (TEM) chamber. By carefully selecting the molecular ligands and the cosolvent, the detailed micro- and mesoscale porosity can be tuned in MOFs. The shape selective synthesis of MOF nanocrystals can also be achieved by controlling crystallization behavior. These materials have shown good shape selective catalytic properties and good selectivity and kinetics for CO2 absorption [17]. High surface- area stable crystalline mesoporous materials of different transition metal oxides, which have greatly enhanced thermal stability for catalytic applications in CO oxidation and water gas shift reaction, have been obtained [18]. Though novel preparations of core shell and bimodal Fischer Tropsch (FT) catalysts based on self-assembly of nanomaterial. The core, the FT-active site, converts syngas into linear hydrocarbons, which then migrate to the acidic sites of zeolite where they undergo further hydrocracking and isomerization to form branched hydrocarbons, realizing a one-step production of is paraffin from syngas. To deal with the tradeoff between the dispersion of active sites and the diffusion efficiency of the reactants and products, which made a bimodal catalyst structure with both large and small pores. The large pores lead to high diffusion rates of the reactants and products whereas the small pores provide large surface areas and high metal dispersions. They employed oxides as building blocks to produce small pores inside the large pores of the homo- or heteroatom support. The idea can be used for the combination of two or more sequential reactions with many synergistic effects [19].

2.3. Nanotechnology for Fuel Cells

Fuel cells are attractive power sources but several challenges still exist for practical applications. A major limitation of current proton-exchange membrane fuel cells is related to the catalyst at the cathode. Instead of platinum catalysts, better and less-expensive catalysts are needed to make the widespread use of low temperature fuel cells viable [20]. Bimetallic or trimetallic alloys with controllable size, shape, composition and morphology (alloy, core shell structures, nanocubes) [21]. Provide a particularly exciting possibility for tuning the reactivity of catalysts. According to Chun-Yaung Lu, Dr. Graeme Henkelman the University of Texas at Austin, the effect of bimetallic nanoparticles on the oxygen reduction reaction (ORR) showed that the structural deformation induced by atomic oxygen binding can energetically stabilize the oxidized states and thus reduce the catalytic activity. They indicated that when the metal particle is small (fewer than 100 atoms), the geometric relaxation by oxygen binding becomes significant for soft metals such as Pt. and Au. The overall oxygen binding energy is thus the balance between the intrinsic oxygen affinity and the geometric relaxation. Because geometric relaxation will stabilize the particle energetically, the ORR activity may be reduced accordingly. One possible way to fine-tune the binding energy is to employ an alloy. Introducing hard metals that have mild oxygen affinity, such as Pb or Cu, will not dramatically change the overall oxygen affinity. Instead, the binding energy can be adjusted by suppressing the structural relaxation. This study suggests an effective method for the rational design of nanometallic ORR catalysts, in addition to manipulating the electronic structure.

2.4. Nanogenerators for Converting Mechanical Energy into Electricity

To develop wireless nanodevices and nanosystems is of critical importance for sensing, medical science, environmental monitoring, defense technology, and even personal electronics. It is highly desirable for wireless devices to be self-powered without requiring a battery. Search for sustainable self-sufficient power sources for micro/nanosystems is a new initiative in today's energy research [22]. It is essential to explore innovative nanotechnologies for converting mechanical energy, vibrational energy, and hydraulic energy into electrical energy that will be used to power nanodevices. An approach has been developed for converting nanoscale mechanical energy into electrical energy by piezoelectric zinc oxide nanowire arrays [23]. This operation mechanism of the nanogenerator relies on the piezoelectric potential created by an external strain. The dynamic straining of the nanowire results in a transient flow of the electrons in the external load which due to the driving force of the piezopotential. This approach is the development of the nanogenerator from the initial design from fundamental science to engineering integration and now to technological scale-up [24-26]. Currently, a mild strain can output 1.2 V from an integrated nanogenerator, from which a self-powered nanosensor has been demonstrated [26]. A commercial LED has been lit up to using this power source [27]. It is a key step for developing a complete nanowire-based nanosystem.

2.5. Nanomaterials for Sustainable Energy Production

Nanomaterials have large surface areas, and we are approaching an era in which nanomaterials can be synthesized with unique, functional properties for applications in the areas of energy conversion and storage. No matter what form of energy is used, low-cost nanomaterials will be required for highly efficient energy production and conversion and for the development of efficient & inexpensive energy storage systems. Nanomaterials serve as energy carriers, absorbents, and media for energy transfer, catalysts, converters, and energy pools or vessels for reactions. Conventional methods, such as doping, impregnation, and ion exchange, will continue to be used, but there is great opportunity to learn from and try to mimic the nanomaterials and nanomachinery in nature [28, 29]. The visionary biomineralization pathways developed to group is a promising route for the manufacture of nanomaterials with the desired properties in an environmentally friendly and sustainable way. Many properties of living systems could potentially be harnessed, and methods based on non-equilibrium characteristics will have interesting applications in the future. As example non-equilibrium cold plasma preparations with high electron temperatures (as high as 104 K) and very low gas temperatures can generate materials similar to the virus template [30]. In particular techniques that can be used for in situ analyses under high pressure and high temperature conditions will be of utmost importance for the future developments. A density functional theory study revealed that Ga_2O_3 is excellent for activating synthesis of a Ga-doped Ni/SiO_2 catalyst that showed excellent properties for CO_2 reforming [31]. The results of molecular modeling are also important for interpreting STM data. Nanotechnology for sustainable energy production is now one of the fastest growing research fields in the world and will hopefully head to the development of a renewable energy economy in which fossil fuel resources will only be used to produce more valuable chemicals [32]. This vision is that energy, environmental, and security problems created by the consumption of fossil fuels will be solved once and for all.

3. Energy-Storage Systems

To challenges in creating highly efficient energy-production systems, another hurdle facing the scientific community is energy storage. It is a significant challenge to prepare materials with hierarchical structural control and multifunctionality for Li-ion batteries and other materials. In this regard, exploring a new approach involving a combination of self-assembly and controlled crystallization, in order to produce a new class of nanocomposite materials with well-controlled architectures on the Nano and microscales and with high capacity and stability for energy storage and electrocatalysis [33]. Dr. Liu reported that they have employed extended graphene sheets solubilized in the hydrophobic domains as the fundamental building blocks for the self-assembly of three dimensionally ordered architectures. The graphene sheets and metal oxide precursors self-assemble into ordered 3D composite structures. Prof. Guozhong Cao from the University of Washington has developed nanostructured materials for Li-ion batteries [34]. He reported their recent achievement in intentionally introducing defects in the nanostructured electrodes for enhanced Li-ion intercalation capacity. The first compared acid-anodized TiO_2 nanotube arrays annealed in nitrogen and carbon monoxide. TiO_2 nanotubes annealed in carbon monoxide with detectable trivalent titanium ions and carbon species possessed Li-ion intercalation capacity exceeding the theoretical limit of bulk TiO_2. The second described sol-gel derived nanostructured V_2O_5 film electrodes annealed in nitrogen and then air that demonstrated significantly different intercalation capacity and cyclic stability. Dr. Seung M. Oh from Seoul National University, Republic of Korea, discussed the effects of defects on amorphous MoO_2 electrodes. Amorphous MoO_2 was obtained by the reduction of a molybdate solution with borohydride. The electrochemical performance of the amorphous MoO_2 was compared with crystalline MoO_2 when used as the anode material in Li-ion batteries. The crystallinity of MoO_2 is closely related to its electrochemical performance. Amorphous MoO_2 features a high energy density with a four-electron reduction, whereas crystalline MoO_2 is restricted to only a one-electron reduction. Amorphous MoO_2 shows high reversibility that is close to the theoretical fourelectron capacity. These amorphous materials can have additional Li-ion storage sites and higher lithiation kinetics. That is, the defect sites and disorders in these less crystalline materials are the storage sites for additional Li-ion. Prof. Kwang-Bum Kim from Yonsei University, Republic of Korea, reported on metal oxide/carbon nanotube (CNT) nanohybrid materials ($LiMn_2O_4$/CNT and $Li_4Ti_5O_{12}$/CNT nanocomposites) with excellent high-rate capability and good structural reversibility for energy-storage applications. These hybrid materials were synthesized through selective heterogeneous nucleation and growth of the oxides on a CNT surface using microwavehydrothermal processes [35]. Carbon nanotubes serve here as substrates to support nanosized metal oxide and to connect the nanoparticles along the one dimensional conduction path [36].

4. Conclusion

Nanotechnology promises to be the tool we need. Designing and developing new material properties on the nanoscale enables new applications and solutions. Nano materials with well controlled structures are of the utmost importance for breakthroughs in several sustainable energy technologies. However, fossil fuels will most likely remain the primary source of energy in the world. In this respect, new catalysts are required to deal with changes in the fossil fuel supply and to solve the related environmental problems. These changes include utilizing heavy and low quality crude oil, coal, natural gas, and potentially biogas and methane hydrate. Hydrogen production, desulfurization, isomerization, alkylation, gas-to-liquid conversions, carbon dioxide conversion.

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