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Some Advanced Materials for Solar Energy and Energy Storing Devices

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Abstract: ***More clever designs in the overall energy storage circuit will certainly continue, but in order to have a major improvement in energy storage, we must have a major breakthrough in the materials used to fabricate the storage device itself beyond present Lithium-ion and standard supercapacitor materials and structures. Progress is expected toward this goal in 2014 and maybe even some new ideas about a different storage mechanism altogether. It will be an interesting progression toward that ideal energy storage device for sure.***

Keywords: Single Crystals, Solar cells, Photothermal devices.

1. Introduction

The energy crisis and environmental issues require urgent development of renewable energies. Considerable attention has been paid to solar energy, which is abundant, inexhaustible, and clean. To make solar energy more affordable and accessible to everyone, great efforts have been made on photovoltaic cells with low cost per Watt, which depends on the solar cell power conversion efficiency.

Solar Cells, covering single crystal, polycrystalline and amorphous materials utilizing homojunctions and heterojunctions, Schottky barriers, liquid junctions and their applications. Also of interest is analysis of component materials, individual cells and complete systems, including their economic aspects.

Photothermal Devices, in the broadest sense, including solar absorber devices, heat storage materials, radiative cooling systems and their applications. Photoelectrochemical and Photochemical Devices, covering photoelectrodes, photocatalysis, photo conversion and solar desalination systems and their applications.

Multijunction solar cells are promising in realizing the third generation solar cells with ultrahigh efficieny . However, the lattice and current mismatch between subcells poses a major challenge to further improve the device efficiency. Lattice-matched subcells consisting of quantum structures have been proposed to obtain the optimal energy bandgap and current matching for multijunction solar cells. The quantized energy levels in the semiconductor nanostructures, such as quantum wells (QWs) and quantum dots (QDs) can introduce additional absorption in the cell and provide a better way to manage the current matching, or to implement intermediate band solar cells.

2. Quantum Well Solar Cells

Quantum well solar cells made from III–V nanomaterials, such as InGaAs/GaAs QWs, have demonstrated improved short-circuit current density due to extended photon absorption compared with their bulk counterpart. However, the lattice mismatch between the InGaAs QW structures and the GaAs matrix materials places an upper limit on the number of InGaAs QWs that can be incorporated into the devices, and hence the contribution of sub-bandgap photon absorption to photocurrent remains marginal. As a result, strain-balanced InGaAs/GaAsP QWSCs have been developed as a means of overcoming the limits inherent to the strained approach. Although it is possible to grow locally strained InGaAs/GaAsP layers which are unstrained with GaAs substrates, the strain at the InGaAs and GaAsP interface will limit the indium content and thickness of InGaAs QWs that is directly related to the absorption wavelength. Moreover, GaAsP strain-compensation layers will increase the barrier potential for the photo-generated carriers in InGaAs QWs, and hence reduce the escape rate of these carriers out of InGaAs QWs into base region. This is the key challenge for the further development of strain-balanced InGaAs/GaAsP QWSCs.

3. Submonolayer (SML) QDs

Submonolayer (SML) QDs are grown by depositing strained InAs with less than one monolayer coverage on the GaAs matrix. They have emerged as an alternative low-dimensional nanostructure to the conventional Stranski–Krastanov QDs and QWs. SML QDs possess several advantages, such as high areal density, high uniformity, absence of the wetting layer, and adjustable aspect ratio. The dense and uniform SML QDs are promising in improving the sub-bandgap photon absorption.. The SML QDSCs are investigated in terms of the structural quality, optical properties, current–voltage characteristics, and quantum efficiency. A direct comparison is performed between SML QDSCs and InGaAs/GaAs QWSCs that have the same quantity of indium as the SML QDSCs. Compared with QWSCs; SML QDSCs have been demonstrated with better structural quality as well as optical property, because of the strain relaxation through formation of SML QDs.

4. Polymer Solar Cells

Polymer solar cells are reviewed in the context of the processing techniques leading to complete devices. A distinction is made between the film-forming techniques that are used currently such as spincoating, doctor blading and casting and the, from a processing point of view, more desirable film-forming techniques such as slot-die coating, gravure coating, knife-over-edge coating, off-set coating, spray coating and printing techniques such as ink jet printing, pad printing and screen printing. The former are used almost exclusively and are not suited for high-volume production whereas the latter are highly suited, but little explored in the context of polymer solar cells. A further distinction is made between printing and coating when a film is formed. The entire process leading to polymer solar cells is broken down into the individual steps and the available techniques and materials for each step are described with focus on the particular advantages and disadvantages associated with each case.

5. Polymer and Organic Solar Cells

Polymer and organic solar cells degrade during illumination and in the dark. This is in contrast to photovoltaics based on inorganic semiconductors such as silicon. Long operational lifetimes of solar cell devices are required in real-life application and the understanding and alleviation of the degradation phenomena are a prerequisite for successful application of this new and promising technology. In this review, the current understanding of stability/degradation in organic and polymer solar cell devices is presented and the methods for studying and elucidating degradation are discussed. Methods for enhancing the stability through the choice of better active materials, encapsulation, application of getter materials and UV-filters are also discussed.

6. Polymer Solar Cell Modules

A life cycle analysis was performed on a full roll-to-roll coating procedure used for the manufacture of flexible polymer solar cell modules. The process known as ProcessOne employs a polyester substrate with a sputtered layer of the transparent conductor indium-tin-oxide (ITO). The ITO film was processed into the required pattern using a full roll-to-roll process, employing screen printing of an etch resist and then applying etching, stripping, washing and drying procedures. The three subsequent layers; ZnO, P3HT: PCBM and PEDOT: PSS were slot-die coated and the silver back electrode was screen printed. Finally the polymer solar modules were encapsulated, using a polyester barrier material. All operations except the application of ITO were carried out under ambient conditions. The life cycle analysis delivered a material inventory of the full process for a module production, and an accountability of the energy embedded both in the input materials and in the production processes. Finally, upon assumption of power conversion efficiencies and lifetime for the modules, a calculation of energy pay-back time allowed us to compare this roll-to-roll manufacturing with other organic and hybrid photovoltaic technologies. The results showed that an Energy Pay-Back Time (EPBT) of 2.02 years can be achieved for an organic solar module of 2% efficiency, which could be reduced to 1.35 years, if the efficiency was 3%.

7. Energy Storing Devices

Energy is the single most valuable resource for human activity and the basis for all human progress. Materials play a key role in enabling technologies that can offer promising solutions to achieve renewable and sustainable energy pathways for the future.

Increased demand for energy and the rising carbon dioxide levels in the atmosphere are among the main challenges the world is currently facing. Population growth and developing economies are putting an increased pressure on energy resources, while the traditional sources of energy, especially fossil fuels have been shown to be the main cause of increased carbon dioxide emissions which are thought to be the main contributor to global climate change. Technologies which successfully harvest renewable and environmentally friendly energy such as solar power, wind power and tidal power, to mention only a few are available already for quite some time. Unfortunately, they still cannot meet the demand for energy also due to inefficiency of the available technologies for intermittent energy storage.

7.1 Available Energy Storage Technologies

Many types of energy storage technologies are available for most forms of e which store the energy in the form of heat. They use mediums energy. Solar energy for instance can be stored in many different ways. One option is to use thermal mass systems such as soil, water and stone to retain the heat and use it for space heating. Another option are phase change materials such as paraffin wax and Glauber's salt, while buildings that use off-grid solar photovoltaic systems can store excess electricity in rechargeable batteries. The latter option, however, is not practical nor economically feasible. Most homes that cover their needs for electricity with solar panels therefore usually sent the excess electricity to the transmission grid to compensate for the electricity that is taken from the grid during the winter months.

7.2 New Energy Storage Technologies

With an aim to improve efficiency of the existing energy storage technologies, new ones are being developed at a rapid pace. It is hard to say what the future will bring but according to the latest news, the developers are mostly focused on improving the existing technologies. In the near future, we can therefore probably expect advanced compressed air energy storage (CAES), and sodium sulfur and lithium ion batteries.

Energy storage remains a tough nut to crack. A number of energy storage technologies are available but the problem of efficiency, cost and reliability remains. As a result, many people who decide to install photovoltaic solar panels or wind turbines are disappointed when they discover that they do not provide them with energy independence. When the conditions are right, they generate more energy than they need but during windless or cloudy days, they need to use the conventional sources of energy.

Unfortunately, solar and wind power cannot be stored as efficiently as non-renewable sources of energy. During windless days, the turbines will not rotate and during cloudy days and nights, solar panels will not generate electricity. There are, however, ways to convert the excess energy into a different form of energy and use it during those windless or cloudy days. The options are:

- Rechargeable batteries. They are a simple and effective way to capture excess electricity. However, they are neither a particularly environmentally friendly option nor cost efficient due to their relatively high price and low life span. In fact, the cost per kilowatt hour is higher than what you are paying to your electricity supplier. At the same time, you would need huge amount of batteries to capture enough energy to be able to use it when you need it the most.
- Thermal mass systems. These are a much better idea to store energy, especially solar energy that is used for heating. Several types of thermal mass systems are available and they either use soil, water or rock to store the excess heat. Their efficiency, however, depends greatly on insulation of the building.
- Phase change materials. These are effective and relatively inexpensive way to capture thermal energy, especially for residential buildings. Examples include Glauber's salt and paraffin wax. Again, the efficiency will depend on your home's insulation.
- Connect on the grid. If you generate electricity, the easiest way to prevent the excess electricity from going to waste is to simply send it to the transmission grid and "takes" it back when you need it. If your annual electricity generation covers your household needs, you will have net electricity use near zero which means that you probably will not be charged for the electricity taken from the grid.

Energy storage methods are not necessarily limited to renewable energy. The mentioned methods to capture excess energy are of course most effective for intermittent sources of energy but you can also store energy even if you do not utilise wind or solar energy. For example, a hot water storage tank is a great idea if you use wood furnace to heat your home, while storage heater is a great way to reduce your electricity bills. It works by storing thermal energy during the night when the electricity is cheaper and releasing heat during the day when electricity is more expensive.

Energy storage devices are key components for a successful and sustainable energy system. Some of the best materials and types right now are Lithium-ion/lithium-sulfur/lithium air cells, supercapacitors, and beyond. Research in this area has greatly improved electrode materials, enhanced electrolytes, and conceived clever designs for cell assemblies with the goal of increasing specific energy (Wh/kg) and pushing the power envelope (W/kg).

But moving forward, new developments must lower cost, shrink size, and increase reliability and life, while also improving upon safety under temperature, vibration, overloading, and other harsh conditions. A major breakthrough is needed in higher capacity electrode materials and new cell technologies in order to keep pace with the needs of hand-held devices, electric vehicles (EV), alternative energy, energy harvesting and more.

8. Batteries / Cells

8.1 Lithium-ion

Techniques have been developed and are being refined for stretchable Lithium-ion batteries, replacing the graphite negative electrode with a silicon one in a Lithium-ion cell, new Lithium-Sulfur batteries with sulfur-carbon nanotubes as the cathode for fast charge-discharge, any many more efforts. The fact is these are all relatively small steps of progress in the right direction, but we still need that earth-shaking discovery to leap to the next storage platform. When that next technology will appear is unclear, but 2014 will certainly make good progress toward it.

8.2 Supercapacitors

Low-cost battery solutions tend to have high ESR and subsequently large amounts of stored energy can't be used when supplying pulse currents. Supercapacitors, in parallel with batteries, reduce the overall ESR and can increase battery life by as much as 300%. That's really good, but still not good enough.

8.3 New materials in supercapacitor electrodes

Graphene

EVs are perfect examples of a system in need of new energy storage technology. One promising new technology is graphene supercapacitors that can enhance the efficiency of regenerative braking in an EV. These devices charge quicker than Lithium-ion cells and discharge the stored energy fast, as well. The traditional supercapacitor charges and discharges too quickly and, hence, do not store much energy. The graphene supercapacitor, however, can store as much energy as a Lithium-ion battery. The graphene version has a specific capacitance of more than 150 Farads per gram and can store energy at a density of more than 64 watt-hours per kg at a current density of 100 to 200 watt-hours per kg. They can also be fully charged in 16 seconds, with repeated charging as many as 10,000 times without much reduction in capacitance.

8.4 Manganese dioxide

An even more astounding new electrode material in supercapacitors is being developed by researchers at the Leibnitz Institute for Solid State and Materials Research in Dresden, Germany. Manganese dioxide is not really good in conducting electrical current, but when it is vaporized and reformed into thin, flexible strips, and thin layers of gold is connected to those strips, the supercapacitor stored more energy and provided more power per unit volume than the standard supercapacitor. More work will be done to reduce cost, as gold is expensive, but we can expect to see more ingenuity out of this effort in 2014.

Sometimes an added or improved component in the overall system design for storage will further improve the process. One example is ALD's Supercapacitor Auto Balancing (SAB) MOSFETs that provide automatic active leakage current regulation and self-balancing of supercapacitors connected in a series stack. The addition of a simple, but uniquely designed, MOSFET can eliminate both overcharging and excessive power dissipation to preserve lifespan of the supercapacitor and battery components.

Scientists are also exploring hybrid technologies that can bridge the gap between traditional batteries and the supercapacitor. This would create a device that could simultaneously store and deliver energy efficiently -- a perfect EV power source.

9. Conclusion

More clever designs in the overall energy storage circuit will certainly continue, but in order to have a major improvement in energy storage, we must have a major breakthrough in the materials used to fabricate the storage device itself beyond present Lithium-ion and standard supercapacitor materials and structures. Progress is expected toward this goal in 2014 and maybe even some new ideas about a different storage mechanism altogether. It will be an interesting progression toward that ideal energy storage device for sure.