

# Applications of Nanotechnology in next generation Solar PV Cell

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## ABSTRACT

The solar cell industry has grown quickly in recent years due to strong interest in renewable energy and the problem of global climate change. Cost is an important factor in the success of any solar technology. Today's solar cells are simply not enough efficient and are too expensive to manufacture for large-scale electricity generation. However, potential advancements in nanotechnology may open the door to the production of cheaper and slightly more efficient solar cells. Nanotechnology has already shown huge breakthroughs in the solar field. Quantum dots have the potential to change the world. They are a form of solar cell that is completely beyond anything you might imagine. Nanotechnology might be able to increase the efficiency of solar cells, but the most promising application of nanotechnology is the reduction of manufacturing cost. PVs based on CdTe, CuInGaSe (CIGS), CuInSe (CIS), and organic materials are being developed with the aim of reducing the price per watt even if that means sacrificing conversion efficiency and reliability. Utilizing nanotechnology in inexpensive solar cell would help to preserve the environment.

**Keywords:** Nanotechnology, Quantum dots, Breakthroughs.

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## 1. INTRODUCTION

Renewable energy is increasingly viewed as critically important globally. Solar cells, or photovoltaics, convert the energy of the sun into electricity. In theory all parts of the visible spectrum from near-infrared to ultraviolet can be harnessed. The mainstay at present is the silicon solar cell which accounted for 90% of the market in 2004. However these are costly to manufacture and have limited efficiency (around 14% in most production modules, and up to 25% in the lab). The cost per unit of power is at least several fold higher using silicon solar cells than that derived from fossil fuel combustion (The Institute of Nanotechnology, 2006). Thin film is a more cost-effective solution and uses a cheap support onto which the active component is applied as a thin coating. As a result much less material is required (as low as 1% compared with wafers) and costs are decreased.

Most such cells utilize amorphous silicon, which, as its name suggests, does not have a crystalline structure and consequently has a much lower efficiency (8%), however it is much cheaper to manufacture (Chopra I K et al. 2004; Konenkamp R et al. 2002). Nanotechnology ("nano") incorporation into the films shows special promise to both enhance efficiency and lower total cost (Escolano C et al. 2005). Many nano-structured materials are now being investigated for their potential applications in photovoltaics. Nano-structured layers in thin film solar cells offer three important advantages. First, due to multiple reflections, the effective optical path for absorption is much larger than the actual film thickness. Second, light generated electrons and holes need to travel over a much shorter path and thus recombination losses are greatly reduced. As a result, the absorber layer thickness in nano-structured solar cells can be as thin as 150 nm instead of several micrometers in the traditional thin film solar cells. Third, the energy band gap of various layers can be tailored to the desired design value by varying the size of nano-particles.

This allows for more design flexibility in the absorber and window layers in the solar cells (Singha R et al. 2004). Forecasting the extent of nanotechnology incorporation into photovoltaics would be valuable intelligence to facilitate technology management (Porter, et al., 1991). One solution to forecast technology is to find the recent position of leading countries/institutes. Such information can help optimize photovoltaic R&D investments and speed operational applications. There has been much interest in the positioning of countries relative to one another in scientific performance, particularly in emergent fields such as nanotechnology. Much of this analysis emphasizes publication counts and impacts as measures of research strength (Glanzel, et al., 2003; Kostoff, et al., 2007; Miyazaki, et al., 2007; Youtie, et al., 2008). Given the dynamic development and expansion of nanotechnology-enhanced thin-film solar cells research, it is useful to assess international scientific performance. Drawing on a newly constructed and comprehensive dataset of global nanotechnology thin-film solar cells publications, this article examines both quality and quantity patterns by leading large countries in this research area.

## 2. MOTIVATIONS FOR SOLAR ENERGY

Solar energy production is rapidly becoming a vital source of renewable energy being developed as an alternative to traditional fossil fuel-based sources of power. One of the primary challenges to the fullscale implementation of solar energy remains expensive associated with the construction of photovoltaic modules and also certain toxic elements presents in some of the thin film solar cells. For many decades, solar energy has been considered as a huge source of energy and also an economical source of energy because it is freely available. However, recently after years of research that technology has made it possible to harness solar energy. Some of the modern solar energy systems consist of magnifying glasses along with pipes filled with fluid. These systems consist of pipes. The fluid present in the pipes heats up instantly. In addition, the pipes are painted black outside so as to absorb maximum amount of heat. The pipes have reflective silver surface on the backside that reflects the sunlight back, thus heating the pipes further and also helps in protecting everything present on the back of the solar panel. The heat thus produced can be used for heating up water in a tank, thus saving the large amount of gas or electricity required to heat the water.

### 2.1 IMPORTANCE OF SOLAR ENERGY

Solar energy is already being successfully used in residential and industrial settings for cooking, heating, cooling, lighting, space technology and for communications among other uses. In fact, fossil fuels are also one form of solar energy stored in organic matter. With the fossil fuels making major impact on the environment and raising issues of pollution and global warming, solar energy has increased in its importance to industries and homes. While the reserves of fossil fuels are restricted, there is no limitation to the availability of solar energy.

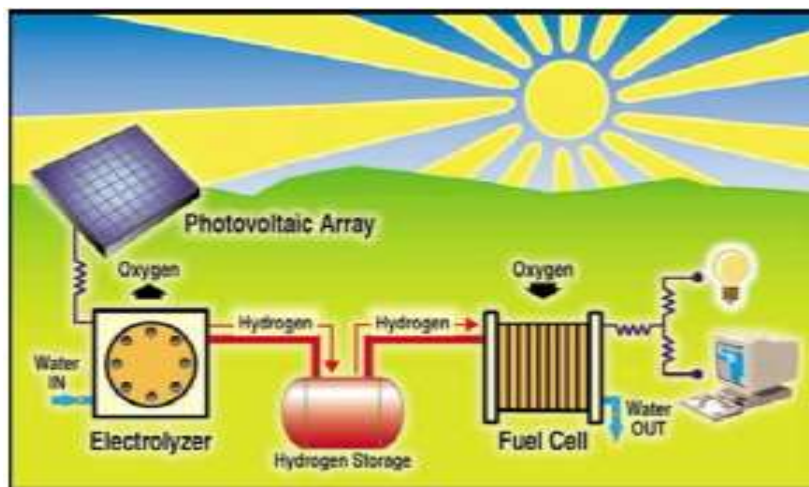


Fig. 1. Fossil fuels applications of solar energy.

With the improvement in solar energy technology and the increase in prices of fossil fuel, solar energy is gradually becoming more and more affordable. Hence, there is an additional cost in the form of importation and transportation required for oil, coal and gas. Fig.1. depicts the application of the fossil fuels as a form of solar energy sun, solar radiation hits at the rate of 1,366 watt per meter square. This is known as solar constant. While 19% of this energy gets absorbed in the atmosphere, 35% are reflected from the clouds. In the last few years, the costs of manufacturing the PV cells have gone down by a more than 5% in a year and thereby the percentages of government subsidies have gone up. This implies that every year, it is becoming more and more affordable to use Solar Energy. In 2004, the global solar cell production increased by 60%. The amount of energy released from a single kilo watt of solar energy unit is equivalent to burn as much as 76 kg of coal that releases over 135 kg of carbon dioxide. In recent years, the number of photovoltaic installations on homes connected to utility grid has been growing significantly. The demand is also extending due to the interest of households to get electricity from renewable, nonpolluting and clean source. However, most of the users are interested in solar energy but they can pay only a limited premium for it. The returns on the initial high costs of installation are in the form of selling solar energy to the grid at premium rates and also in the form of long-term savings that can be maintained without paying any utility bills. The solar system that is connected to the utility grid supplies the regular generation of electricity to be used at home and the excess electricity is exported to the utility. Vacation homes or holiday homes that do not have an access to the grid can utilize the solar energy in a more cost-effective manner as compared to rely upon the grid for running wires to reach the remote location. The basic components required in the solar power system are solar panel, battery for storing all the energy gathered during daytime, a regulator and essential switches with wiring. These types of systems are commonly known as Solar Home Systems (SHS).

## 2.2. SOLAR ENERGY AND ITS ECONOMY

Solar energy is available free of cost and rather found in many parts around the world. This kind of energy source can be utilized in different ways: PV technology which directly converts light into electrical current, solar thermal systems used in solar collectors, artificial photo synthesis which produces either carbohydrates or hydrogen via water where the building design maximizes solar lighting and heating, and even biomass technology where

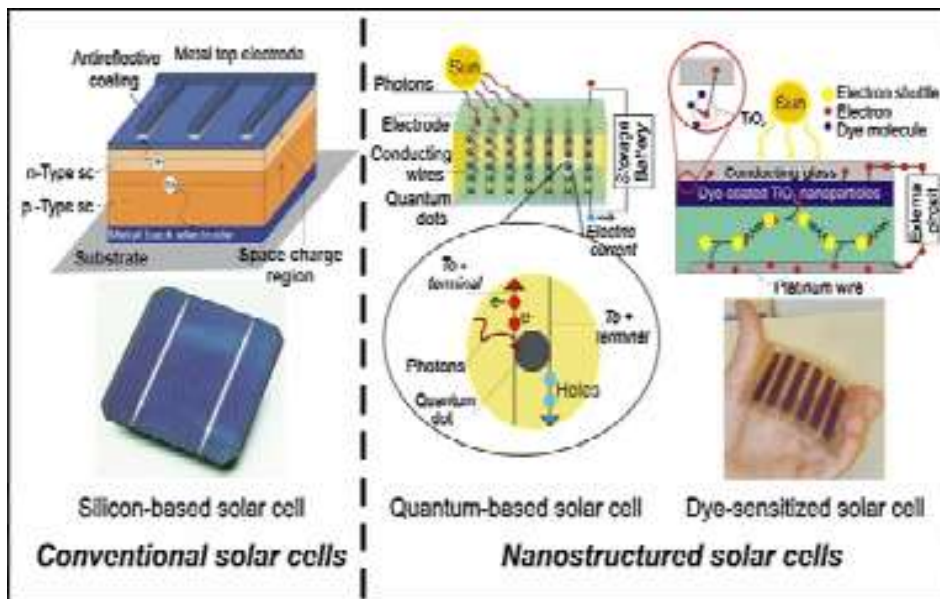


Fig. 2. Evolution of photovoltaic technology from conventional to nanostructured solar cells.

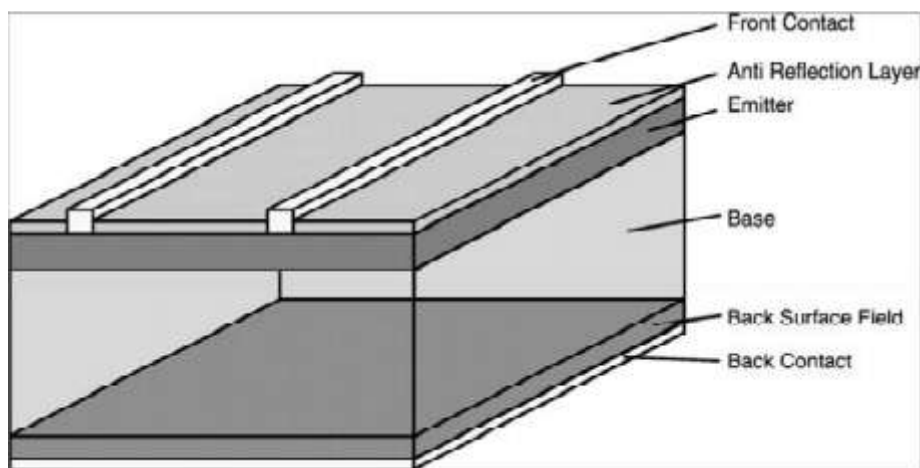


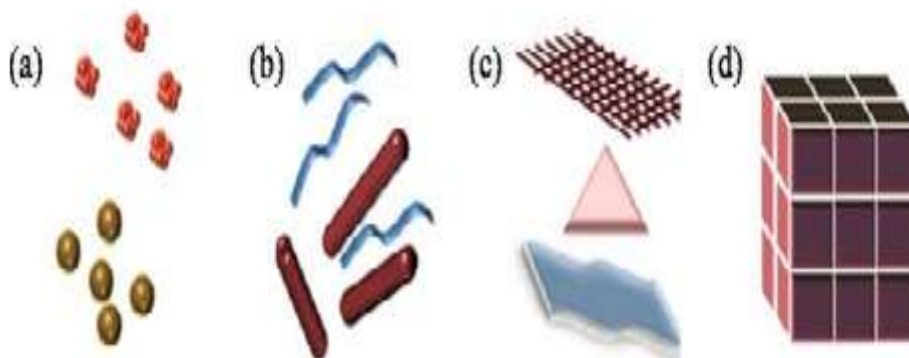
Fig. 3. Typical solar cell structure a cross-section.

plants use the solar radiation to drive chemical transformations and create complex carbohydrates which are used to produce electricity, steam or biofuels. All these energy-related processes and their applications are enclosed in the so-called solar economy (Fig. 2). Biomass technologies are mostly based on the production of biofuels from agricultural and forest feed stocks specifically grown crops or organic wastes. These biofuels can be further used in fuel cells to obtain electricity. In comparison with solar PV, biomass shares a low energy density and relatively low conversion efficiency, but in contrast biomass has the advantage of being able to store solar energy for use on demand. Current research is much focused on the development of new photoactive materials that can be used to directly convert sunlight (or artificial light) into electricity. Also, solar thermal systems find interesting applications in self-cleaning devices like using the heat from solar radiation and storing it in a thermal store that is ready for use in heating and hot water applications. The evolution of nanostructured solar cells is given in Fig. 2.

## 2.3. PHOTOVOLTAIC SYSTEMS

PV systems use solar panels to convert sunlight into electricity. A PV system is made up of one or more solar panels, usually a controller or power converter, and the interconnections and mounting for the other components. A small PV

system may provide energy to a single consumer, or to an isolated device like a lamp or a weather instrument. Large grid-connected PV systems can provide the energy required for many customers. Due to the low voltage of an individual solar cell (typically ca. 0.5 V), several cells are wired in series in the manu- into a protective weather proof enclosure, thus making a photovoltaic module or solar panel. The electricity generated thereby can be either stored or



**Fig. 4. Classification of Nanomaterials (a) 0D spheres and clusters, (b) 1D nanofibers, wires, and rods, (c) 2D films, plates, and networks, (d) 3D nanomaterials.**

used directly (island/standalone plant), or fed into a large electricity grid powered by central generation plants (grid-connected/grid-tied plant) or combined with one or many domestic electricity generators to feed into a small grid (hybrid plant). Practically all PV devices incorporate a p-n-junction in a semiconductor across which the photovoltage is devel. A cross-section of a typical solar cell is shown in Fig. 3. The semiconductor material must be able to absorb a large part of the solar spectrum. Dependent on the absorption properties of the material the light is absorbed in a region more or less close to the surface. When a light quantum is absorbed, electron hole pairs are generated and if their recombination is prevented they can reach the junction where they are separated by an electric field. Even for weakly absorbing semiconductors like silicon most carriers are generated near the surface. The thin emitter layer above the junction has a relatively high resistance, which requires a well-designed contact grid as shown in the Fig. 3.

### 3. RESULTS AND APPROACH IN PARTICIPATING RESEARCH FIELDS

To gain a sense of which research fields are engaged in this work, Figure 1 overlays the concentrations of the 1659 articles on a base map of science. This mapping process categorizes articles indexed in Web of Science according to the journals in which they appear (Rafols and Meyer, forthcoming; Leydesdorff and Rafols, forthcoming). Those journals are associated with Web of Science “Subject Categories.” In Figure 1, these constitute 175 nodes reflected by the background intersecting arcs among them. The Subject Categories are then grouped into “macro-disciplines” using a form of factor analysis (Principal Components Analysis) based on degree of association. Those macro-disciplines become the labels in the figure. The nano thin-film solar cell research concentrations appear as nodes on this map. What we see is that nano thin-film solar cell research is concentrated in the Materials Science and Chemistry macro-disciplines. It engages many specific Subject Categories (research fields). So, this is highly multidisciplinary research. This paper is particularly interested in cross-national differences in research and development on this technology. With that in mind, we have compared the relative emphases of the leading countries (discussed shortly). We generate such science overlay maps for each country (not reproduced here). What stands out among those is that all of them show very similar involvement of the key component research fields:

- ( i ) Materials Science, Multidisciplinary
- ( ii ) Physics, Condensed Matter
- ( iii ) Physics, Applied
- ( iv ) Chemistry, Physical
- ( v ) Materials Science,

Coatings & Films But one of the countries, India, shows by far the most research in “energy & fuels.” Such concentration differences could be important in distinguishing national (or institutional) emphases. They can also help technology managers identify appealing collaboration opportunities to take advantage of complementary strengths.



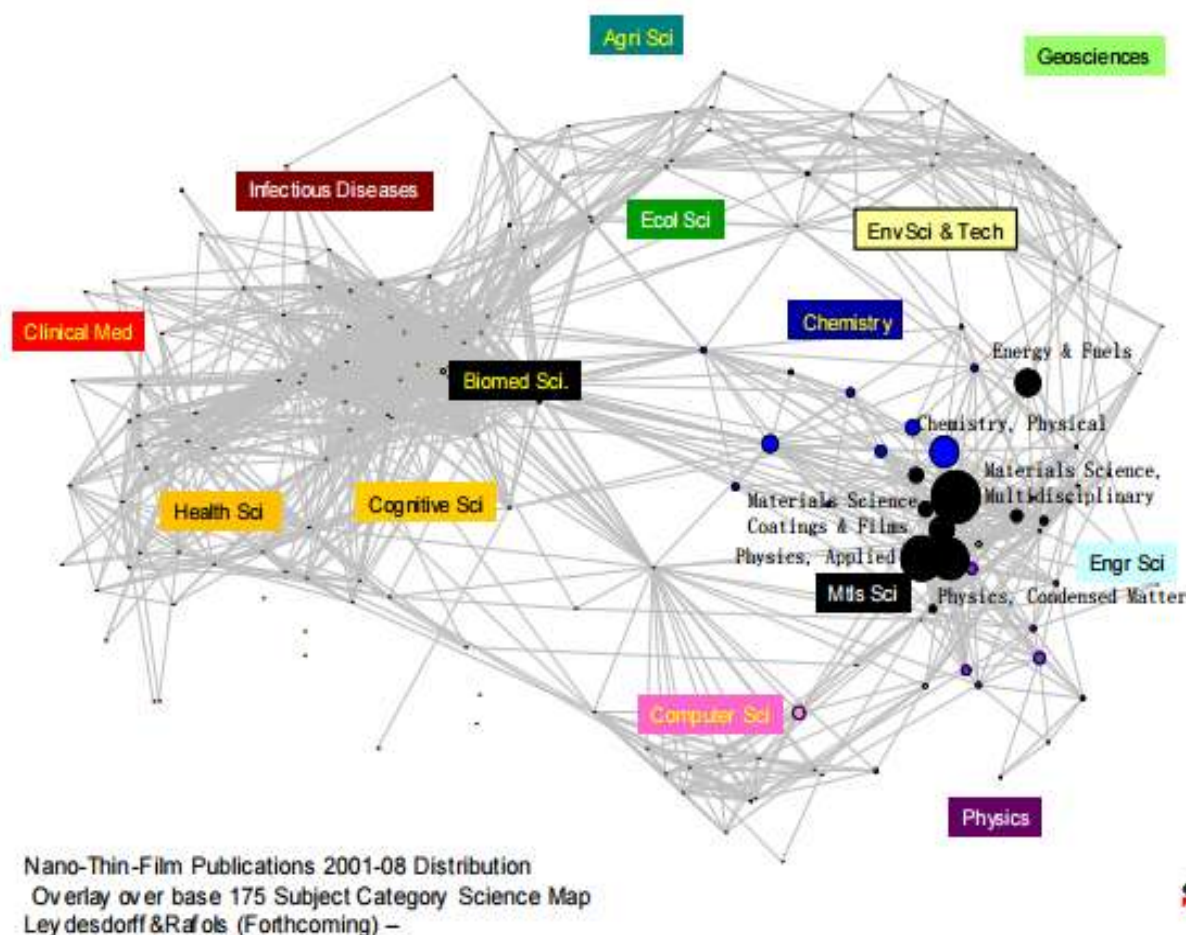


Fig. 5: Nanotechnology Thin-film Solar Cells Publications by Research Field

#### 4. RESEARCH ACTIVITY AND IMPACT CHARACTERISTICS

However, quantity (activity) and diversity are not sufficient to describe country position in the nanotechnology thin-film solar cells research arena. Quality and influence in the field is important to consider in depicting inter-country standing in nanotechnology (Glanzel W et al. 2003). Citations, as measured by the number of times a paper has been cited, are used here to gauge the level of quality of the publications of a country. We, of course, recognize that this is an imperfect measure as citations reflect many purposes. However, citations reflect attention to the work, and the Scientometrics community has found them to be a valid indicator of the impact of the research outputs (publications) (c.f., van Raan, 1988). Citation counts are related to publication counts, in that the greater the number of publications, the higher the probability of larger citation counts.

Thus, we make a scattergram plot to see both publication and citation counts. The X-axis represents the number of publications, while the Y-axis shows the number of citations. This kind of figure helps assess research quality relative to activity. The particular method used in this part of the analysis focuses on the country location of the affiliation of the first author of the publication. This focus is designed to preclude duplicating citation counts. The first author's country is used to assign citation numbers to that country. Turning to the results of the citation counts, Figure 5 compares the activity and quality of the top 10 countries. Nodes above the diagonal suggest relatively higher quality, represented by the US and UK. Comparing these two countries, we see that both the number of citations and publications is quite high for the US; the UK, in contrast, has a relatively small number of publications, but notable quality. The quality analysis places the US in an even stronger position, combining with the counts of nanotechnology thin-film solar cells. The other top 5 countries—India, Germany, China and Japan—are all below the diagonal. In that case, the closer to the diagonal, the higher the quality of that country's research. We see that Japan and Germany are closer to the diagonal than India and China, that is to say, taking the time period from 2001 to 2008 as a whole, both Japan and Germany have much higher number of nanotechnology thin-film solar cells citations relative to their number of publications than do India and China. China and India's citation levels do not approach those of Japan and Germany the way that their publication counts do.

## CONCLUSION

The growing interest in applying nanoscale materials for solving the problems in solar energy conversion technology can be enhanced by the introduction of new materials such as quantum dots, multilayer of ultrathin nanocrystalline materials and the availability of sufficient quantities of raw materials. The inexpensive purification or synthesis of nanomaterials, deposition methods for the fabrication of thin film structures and easy process control in order to achieve a large-area production within acceptable performance tolerances and high life time expectancy are still the main challenges for the realization (fabrication) of solar cells. Therefore in attaining the main objectives of photovoltaics, the efficiency of solar cells should be improved without any compromise on the processing cost of these devices. Nanotechnology incorporation into the films shows special promise in enhancing the efficiency of solar energy conservation and also reducing the manufacturing cost. Its efficiency can be improved by increasing the absorption efficiency of the light as well as the overall radiation-to-electricity. This would help to preserve the environment, decrease soldiers carrying loads, provide electricity for rural areas and have a wide array of commercial applications due to its wireless capabilities. The solar energy, a boon to the mankind has to be properly channelized to meet the energy demand in the developing countries and solar cell industry can reach greater heights by the incorporation of third generation solar cell devices and panels based on nanostructures.

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