Carbon-based solar cell: a possible solution for energy and environmental problems

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Abstract

The cost reduction of solar cell and establishment of environmentally friendly production process are very important in order to solve the existing worldwide energy and environmental problems. Solar cells (mostly silicon-based) fabricated to date are very expensive to use on a commercial basis. Low cost and high efficiency solar cells are yet to be realized for their commercialization. In connection to the search for an alternative material, carbon is highly attractive for its possible application in photovoltaic solar cells. Moreover, it is a material of highly stable, cheap and non-toxic, which can be obtained from precursors those are sufficiently available in nature. This paper reports research progress on carbon-based solar cell achieved by our research group over the last one decade. Especially, camphor ($C_{10}H_{16}O$), a natural precursor of carbon was introduced and solar cells of various configurations, such as n-C/p-Si, p-C/n-Si and n-C/p-C/p-Si were fabricated and their photo-response characteristics were studied. The highest efficiency of 2.3% was obtained, so far, for the cell of configuration n-C/p-C/P-Si. In addition to the brief review of our past results, present research activities and future research plan for the construction of carbon-based solar cell are explained.

1. Introduction

With the increase in world population there is an ever-increasing demand of energy. Now the world is suffering from many kinds of energy and environmental problems. Energy is indispensable for human beings. Because of the rapid increase of global population and the advent of modern era, energy consumption rate is increasing and human beings are becoming more dependent on energy. Consequently, traditional fossil fuels, such as coal, oil, natural gas, which are limited and their reserves will run out in the near future [**1**]. Also, people are well aware of the dark side of the use of fossil fuels that has contributed to local or regional air pollution and unpredictable, probably irreversible climate changes through CO_2 emission in many parts of the world. So, there is an increasing need for cheap and clean energy sources for the future. In this situation, solar energy has emerged as the most attractive and reliable source of alternative energy because it is clean and renewable. In other words, the use of sunlight offers a conceivable alternative to worldwide energy related problems.

Solar cells are semiconductor devices that convert sunlight directly into electricity, either directly through the photovoltaic effect, or indirectly by first converting the solar energy to heat or chemical energy.

Over the last few decades, silicon and compound semiconductor materials have been the main subjects of solar cell research [**2**]. However, solar cells (mostly silicon-based) fabricated to date are very expensive compared to cost of electricity obtained by conventional process. Low cost and high efficiency solar cells are yet to be

realized for their commercialization. In connection to the search for an alternative material, carbon is highly attractive for its possible application in photovoltaic (PV) solar cells [**3**]. Carbon can be obtained from precursors that are abundantly available in nature, economically cheap and environmentally friendly.

In our carbon solar cell research, camphor ($C_{10}H_{16}O$), a reproducible tree product has been used as a source material to deposit carbonaceous films on silicon, quartz and flexible plastic substrates at low temperature (<100^{o}C). Camphor trees abundantly grow in almost all sub-tropical countries including Nepal, India, China and Japan. They also thrive in Egypt, the Canary Islands, Argentina, Europe, California, Formosa etc. Approximately 3 tones of camphor can be extracted from a single matured tree. The process of extraction being very simple, camphor is quite cheap, approximately 2 US$/kg [**4**].

Carbonaceous thin films have been deposited by various techniques such as pulsed laser deposition (PLD), radio frequency (r.f.) microwave plasma chemical vapor deposition (CVD), ion beam sputtering (IBS) and microwave surface-wave plasma (MW-SWP) CVD. MW-SWP CVD is a newly developed deposition technique for its advantages of the quality film deposition and the possibility of mass production over other techniques.

In this paper, we report our research progress on carbon-based solar cell over the last ten years together with the information review of the current energy situation of the world and efficiency/cost status of different type of solar cells available in the market. At the end, future research plan for the fabrication of carbon-based solar cell is explained with a proposed solar cell structure.

2. World power demand and energy sources

Fig.1 illustrates world power demand and total power available over the next century based on the observation and estimation reported by Andrew Swicker, member of Scientists Advocating Fusion Energy Research (SAFER) [**5**].

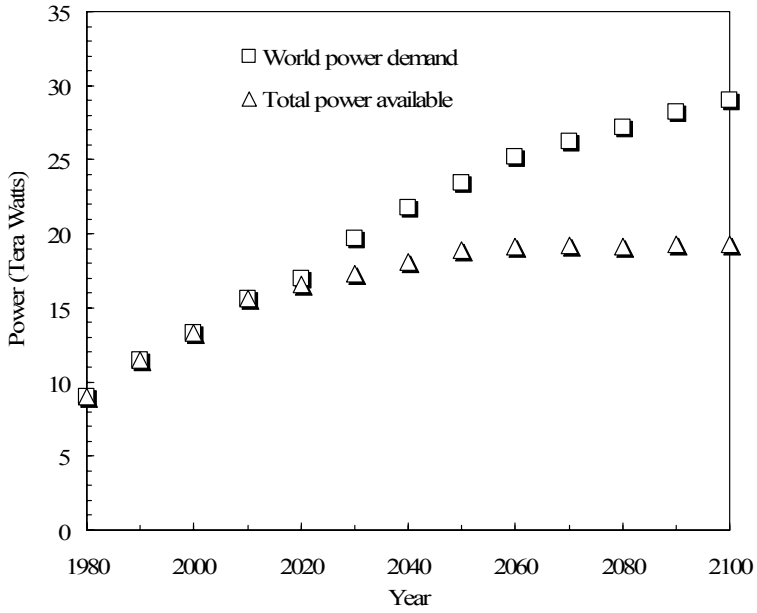

Fig.1 World power demand versus total power available.

It is assumed that both total power available and power demand will increase with same ratio until 2010 year, however, after that, demand will increase significantly in comparison to total power available. As fossil fuels like oil, coal, natural gas start to decline irreversibly, which indicates that the world will be facing energy crises after a decade. In order to meet the power demand scientists are doing researches on the possibility of safe, reasonable and environment friendly energy sources.

Renewable energy technologies (solar, wind and others) have emerged as conceivable alternatives to worldwide energy problems, as they are nonpolluting, inexhaustible, available to both developed and developing countries. Unlike, traditional fossil fuels, which contribute a lot of environmental problems, such as air pollution, water and soil contamination, renewable energy contributes very little or no such problems. Among the renewable energy technologies, photovoltaic (PV) solar energy conversion is the most popular and reliable to meet the power demand of the future.

The direct conversation of solar radiation into electricity through the process of photovoltaics has a number of advantages to solve power demand. PV conversion systems tap an inexhaustible resource, which is free of charge and available any where in the world. The energy supply from the sun is truly enormous; on average, the Earth's surface receives about 1.2×10^{17} W of solar power. This means that in less than one hour, enough energy is supplied to the Earth, which is sufficient for energy demand of the human population over the whole year [**6**].

Fig. 2 shows the principle energy sources currently being used by mankind, which shows the mankind's heavy dependence on fossil fuels. The excessive use of fossil fuels has indeed resulted the air pollution problems people are facing today.

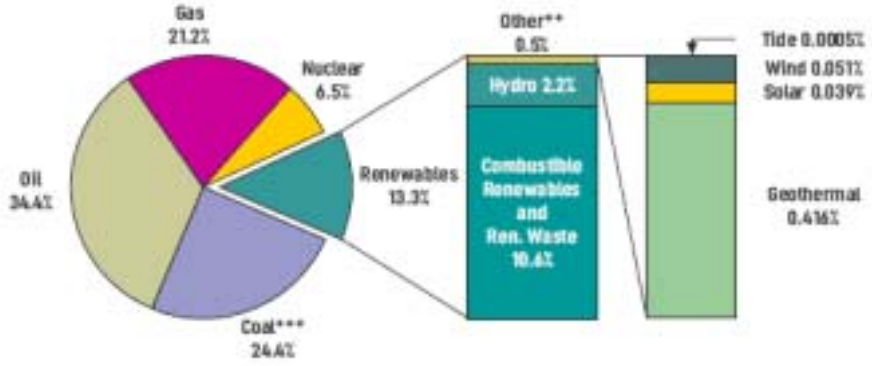

Fig. 2 Energy source condition to the global energy needs (Source: IEA Energy Statistics)

3. Solar cells

A solar cell is a device that directly converts sunlight into electrical energy through the process of photovoltaics. Fig. 3 shows power conversion efficiency of different types of solar cells [**7**], it seems that the efficiency of silicon-based solar cell has increased remarkably, however, due to its high manufacturing cost people cannot install PV system in their home.

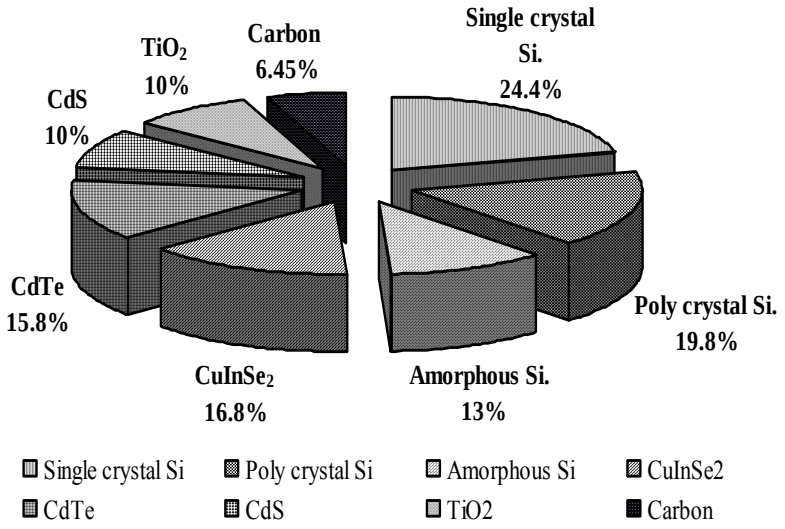

Fig.3 Power conversion efficiency (%) of different types of solar cells.

Total cost of silicon solar cell consists of 50% in making semi-conducting grade silicon and the remaining 50% in fabrication of p:n junction and the panel. Cost for making p:n junction, irrespective of material used, may be approximately same. Hence there is almost no scope for cost reduction of silicon-based solar cell.

3.1. Camphoric amorphous Carbon-based solar cell

Camphor, a natural source, is obtained from the latex of cinnamomun camphora tree of lauraceae family. It is white crystalline solid that sublimates at room temperature and can melt at 180 ^{o}C. It is commonly used in homes as an insect repellent and also in sweets to keep them disinfected from germs. It has long been valued for its great medicinal uses in East but remained less known in Europe and America. Being a green plant product, camphor is quit an eco-friendly source and can be easily cultivated in as much quantity as required. Abundantly found in Asian countries, camphor is very cheap and non-toxic nature. Carbon is a remarkable element existing in a variety of stable forms ranging from insulator/semiconductor diamond to metallic/semi-metallic graphite to conducting/semi-conducting nano/microtubes to fullerences of highest order of symmetry, which shows many interesting physico-opto-electronic properties [**8**]. In addition, it is also possible that many more forms of carbon are yet to be discovered. The various forms of carbon have attracted a great deal of interest in recent years because of their unique structure and properties. Among various application of carbonaceous material, recent study of heterojunction diodes [**9,10**] and solar cells [**11-13**] are quite interesting in terms of its electronic application. Recent results on semiconducting camphoric carbon and photovoltaic cell promote carbon material to be one of the future scopes of economically viable high efficiency solar cell.

Fig.4 shows the current density-voltage characteristics of photovoltaic solar cells of configuration, n-C/p-C/p-Si with varying p-C layer thickness fabricated from camphoric carbon source. These solar cells were studied both under dark and illumination, at AM 0 and 1 sun conductions.

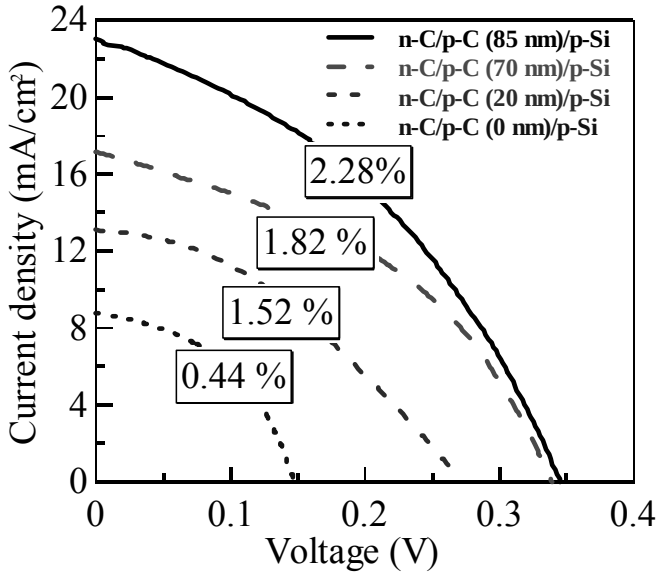

Fig. 4 Current-voltage characteristic of n-C/p-C/p-Si solar cells.

Photovoltaic parameters, such as the short circuit current (Jsc), open circuit voltage (Voc) and efficiency (η) were significantly improved with increasing thickness of p-C layer (see Table 1). The highest efficiency obtained about 2.3%. The process for making carbon thin film deposition is very simple, as it can be deposited at very low temperature (<100 ^{o}C) compared to silicon (1400 ^{o}C), and the precursor of carbon (especially camphor) can be easily obtained from nature. Another advantage of carbon-based solar cell is that it is more flexible and lighter than silicon-based solar cell. The carbon-based solar cell can be 10 times cheaper than silicon based solar cell [personal communication; Prof. M. Sharon, Birla College, Kalyan, India].

Table 1 Photovoltaic parameters of the various structured solar cells.

Structure	Jsc (mA/cm^2)	Voc(V)	FF (%)	η (%)
n-C/p-C(20 nm)	13.33	0.272	56.7	1.52
n-C/p-C(70 nm)	17.14	0.339	42.3	1.82
n-C/p-C(85 nm)	23.04	0.346	38.7	2.28
n-C/p-Si	8.77	0.147	45.6	0.44
p-C(20 nm)/n-Si	7.44	0.213	21.6	0.26
p-C(70 nm)/n-Si	8.51	0.299	19.0	0.36
p-C(85 nm)/n-Si	11.88	0.298	20.1	0.53

4. Present research activity

Our research work is progressing and by using improved film deposition technique (MW-SWP CVD), we hope to increase the efficiency of carbon-based solar cell by about 10-15% in next decade, which will encourage more commercial manufacturing. Here at Umeno laboratory, Department of Electronic and Information Engineering, Chubu University, our research team is using Argon (Ar) and Helium

(He) as carrier gases, and camphor ($C_{10}H_{16}O$) dissolved with ethyl alcohol (C_2H_5OH) composition, Methane (CH_4), Ethylene (C_2H_4) and Acetylene (C_2H_2) as carbon sources, for carbon thin film deposition. Phosphorous and Boron doping facilities have been incorporated in the MW-SWP CVD system in order to deposit n-type and p-type carbon thin films respectively.

5. Conclusion and future research plan.

Although power conversation efficiency of carbon-based solar cell is still low our research results show high prospect of the fabrication of cheap, light, environment friendly and reasonably efficient solar cell in the near future. We plan to develop the deposition of high photosensitive carbon thin films on plastic substrate. In addition, the investigation of conduction control and formation of p-n junction of the films will be carried out simultaneously to realize carbon-based thin film flexible solar cell.

References

[1] R.C. Neville, Solar energy conversion the solar cell, 2nd edition, Elsevier science B. V., Amsterdam, Netherlands (1995).

[2] T. Soga, T. Jimbo, K.M. Krishna, M. Umeno, International Journal of Modern Physics B (2000).

[3] S.M. Mominuzzaman, K.M. Krishna, T. Soga, T. Jimbo, M. Umeno, Carbon 38 (2000) 127-131.

[4] http:// www.champor-allied.com.

[5] National Fusion Energy Science, web site.

[6] T. Markvart, Solar Electricity, 2nd edition, University of Southampton, UK, Chapter 1, pp. 1.

[7] M. Rusop, Ph.D. thesis, Nagoya Institute of Technology, Japan (2003).

[8] K.M. Krishna et al., Solar Material and Solar Cells, 48, 1997, 25-33.

[9] V. S. Veerasamy, G.A.J. Amaratunga, J.S. Park, H.S. MacKenzie, W.I. Milne, IEEE Trans. Electron. Develop. 42 (1995) 577.

[10] V.S. Veerasamy, G.A.J. Amaratunga, J.S. Park, W.I. Milne, H.S. MacKenzic, Appl. Phys. Lett. 64 (1994) 2297.

[11] H.A. Yu, Y. Kaneko, S. Yoshimura, S. Otani, Appl. Phys. Lett. 68 (1996) 547.

[12] H. Yonehara, C. Pac, Thin Solid Films 278 (1996) 108.

[13] K. Murata, S. Ito, K. Takahashi, B.M. Hoffman, Appl. Phys. Lett. 68 (1996) 427.