≪총설논문≫ 한국진공학회지 제16권 3호, 2007년 5월, pp.161~166

Brief Review of Silicon Solar Cells

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(Received February 6, 2007)

Photovoltaic (PV) technology permits the transformation of solar light directly into electricity. For the last five years, the photovoltaic sector has experienced one of the highest growth rates worldwide (over 30% in 2006) and for the next 20 years, the average production growth rate is estimated to be between 27% and 34% annually. Currently the cost of electricity produced using photovoltaic technology is above that for traditional energy sources, but this is expected to fall with technological progress and more efficient production processes. A large scale production of solar grade silicon material of high purity could supply the world demand at a reasonably lower cost. A shift from crystalline silicon to thin film is expected in the future. The technical limit for the conversion efficiency is about 30%. It is assumed that in 2030 thin films will have a major market share (90%) and the share of crystalline cells will have decreased to 10%. Our research at Sungkyunkwan University of South Korea is confined to crystalline silicon solar cell technology. We aim to develop a technology for low cost production of high efficiency silicon solar cell. We have successfully fabricated silicon solar cells of efficiency more than 16% starting with multicrystalline wafers and that of efficiency more than 17% on single crystalline wafers with screen printing metallization. The process of transformation from the first generation to second generation solar cell should be geared up with the entry of new approaches but still silicon seems to remain as the major material for solar cells for many years to come. Local barriers to the implementation of this technology may also keep continuing up to year 2010 and by that time the cost of the solar cell generated power is expected to be 60 cent per watt. Photovoltaic source could establish itself as a clean and sustainable energy alternate to the ever depleting and polluting non-renewable energy resource.

Keywords: Photovoltaic, Solar Cell, Crystalline, Silicon, Energy

I. Photovoltaics - Introduction and Trends

"Sustainable energy systems are achievable, but the challenges are many and need to be tackled urgently if sustainability is to be achieved in this century." This was the principal conclusion reached by the 19th World Energy Congress, held in Sydney, Australia in September 2004. Photovoltaic energy is one of prominent candidates capable to lead the world towards the sustainability. Photovoltaics (PV) or solar cells as they are often referred to, are semiconductor devices that convert sunlight into direct current (DC) electricity. Groups of PV cells are electrically configured into modules and arrays, which can be used to charge batteries, operate motors, and to power any number of electrical loads. With the appropriate power conversion equipment, PV systems can produce alternating current (AC) compatible with any conventional

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appliances, and interconnected to the utility grid. PV technology permits the transformation of solar light directly into electricity. PV systems can deliver electrical energy to a specific appliance and/or to the electricity grid. It has the potential to play an important role in the transition towards a sustainable energy supply system of the 21^{st} century and to cover a significant share of the electricity needs of the globe. It could contribute to the security of future energy supply, provide environmentally benign energy services and enhance economic and social welfare. Alongside other renewable energy technologies and energy efficiency, photovoltaics could become a key technology for the future.

The sun provides more than 10,000 times the energy humanity consumes, meaning that there are few limits to the potential of photovoltaic technologies. For the last five years, the photovoltaic sector has experienced one of the highest growth rates worldwide (over 30% in 2003) and for the 20 next years, the average production growth rate is estimated to be between 27% and 34% annually. Still PV is far from competitiveness in grid and needs proper incentives for its adoption in accessible urban or suburb areas. On the other hand, it is often competitive to supply electric power to remote areas compared to grid extension or diesel generators but faces difficulty to be financed in developing countries. Currently the cost of electricity produced using photovoltaic technology is above that for traditional energy sources, but this is expected to fall with technological progress and more efficient production processes. Still, by the end of 2006, more than 3,500 Megawatts (MW) of solar photovoltaic power had been installed world wide, generating enough electricity to power more than 1,500,000 households with an average European consumption. The latest world market survey records show that 298 types of modules being produced by 78 different manufacturers in more than a dozen different countries. The environmental and operational benefits that an economical PV electrical generation would provide must be worth the effort to further develop PV. Among other benefits the following should be noted: no chemical reaction, no thermodynamic cycles, no movable parts, simply a surface exposed to the Sun. It can be placed where the need for electricity exists, it can be installed easily and maintenance is negligible.

II. Development - Materials and Technology

The first conventional photovoltaic cells were produced in the late 1950s, and throughout the 1960s were principally used to provide electrical power for earth-orbiting satellites. In the 1970s, improvements in manufacturing, performance and quality of PV modules helped to reduce costs and opened up a number of opportunities for powering remote terrestrial applications, including battery charging for navigational aids, signals, telecommunications equipment and other critical, low power needs. At present mainly crystalline silicon solar cells are used in commercial applications. These are rigid cells. Recently some new technologies have entered the market: the triple-juntion amorphous silicon by United Solar, HIT by Sanyo, Ribbon Silicon by ASE and Thin Silicon by Astropower [1]. Still under technological development and in the early demonstration phase are thin film cells such as amorphous silicon cells, CIS- and CdTe-cells and the Grätzel-cell (based on a dye-sensitized colloidal titanium dioxide film). It is expected that eventually thin-film cells can be produced in a less material and labor intensive way, combined with a higher conversion efficiency (not for single layer amorphous silicon cells) of solar irradiation to electricity (reducing the size per Wp) and thus in a cheaper way than crystalline silicon cells. Furthermore it is possible to apply thin film cells on a flexible support layer that opens up new applications

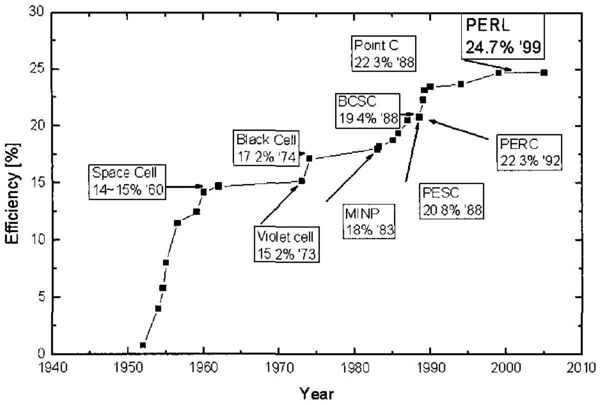

Fig. 1 Historical development of solar cell and its conversion efficiency(PESC: Passivatd Emitter Solar Cell, MINP: Metal Insulator N-type P-type, BCSC: Buried Contact Solar Cell, PERC: Passivated Emitter and Rear Cell, PERL: Passivated Emitter Rear Locally-diffused Cell)

and ways of integration. Therefore, a shift from crystalline silicon to thin film is expected in the future. The technical limit for the conversion efficiency is about 30%. It is assumed that in 2030 thin films will have a major market share (90%) and the share of crystalline cells will have decreased to 10%.

Several technologies are struggling now to get the cost of the PV power generation down. The uncertainty over which will be the long-term lowest cost technology in solar photovoltaics is now centered in three main basic routes, high efficiency crystal silicon, thin films and concentration. In this context, a large scale production of solar grade silicon material of high purity could supply the world demand at a reasonably lower cost. A cost less than 25 USD / kg can be regarded as a realistic target in this context.

Fig. 1 shows historical progress in solar cell efficiency [2-5]. It shows the highest conversion efficiencies attained by different designs of the cells in the research level. Fig.2 shows the conversion efficiency of commercial silicon solar cells of various designed, as obtained by the survey of National Renewable Energy Laboratory of USA in 2004 [6]. Longer-term photovoltaic module technology planning strategies in United States, Europe, and Japan seem

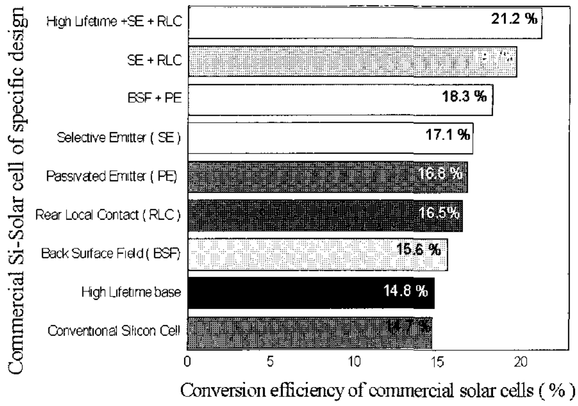

Fig. 2 Conversion efficiencies of different commercial silicon solar cells

to all be in agreement that at some point in the future, PV modules will transition from Si wafer or ribbon based technologies to true thin film technologies. The obvious benefit would be elimination of wafer or ribbon costs, which typically amounts to about 40% of PV module cost. This means that a thin-film module eliminates about 40% of module cost, if the efficiencies are equivalent [6].

Ⅲ. Our Research on Crystalline Silicon Solar Cell

We have basically confined our research on low cost and high efficiency approaches for the crystalline silicon fabrication. We have established a research center as a joint venture project of Sungkyunkwan University and KPE(Kyungdong Photovoltaic Energy) Company of Korea. The company has started producing crystalline silicon solar cells with its full fledged annual production capacity of 35 MW. Our approach basically falls in the category of Passivated Emitter (PE) with Back Surface Field (BSF). Fig 3 shows the process flow chart of our solar cell fabrication line. The p-type, crystalline silicon with resistivity of about 0.5 - 2 Ω · cm was used in our production. In our NaOH texture, the solution was heated. We have used conventional $POCl_3$ diffusion; plasma enhanced chemical vapour deposition (PECVD) for silicon nitride (SiNx) deposition as anti-reflection coating (ARC) and screen printed metallization for crystalline silicon solar cell fabrication. All textured p-type silicon wafers were diffused by pentavalent impurity (Phosphorus) in open-tube furnace using conventional $POCl_3$ diffusion source. After PSG removing by short time dipping in BHF solution followed by DI-water rinsing and drying. Next all textured crystalline wafers were oxidized. After edge isolation and oxide layer removing, about 70 nm layer of SiN_x was deposited on the front side by means of PECVD at 450℃ for ARC. The front and back metallization of the diffused silicon wafers were carried out using standard Ag-paste and Al paste for screen printed metallization technique followed by baking and co-firing in a conveyer belt furnace.

We have recently completed a national project on 3 kW PV module system based on multicrystalline silicon solar cells. Currently, we are involved in a national project of low cost and high efficiency crystalline silicon solar cell. Fig. 4 and 5 show the illuminated Current - Voltage characteristics of single and multi-crystalline silicon solar cells fabricated in our research center with screen printing metallization.

Despite the technical limitations and short term research experience in the field of photovoltaics, we have been able to arrive very close to the world's best commercial silicon solar cell efficiency. Also, we have been able to establish our venture company (KPE) as Korea's best company in terms of qualitative as well as quantitative production. Our achievements of the research and successful production from the 35 MW plant encouraged us to expand the production capacity with an additional plant of annual capacity 60 MW. The new plant is expected to start its production from the beginning of 2008. The new plant will be based on the modern system of in-line processing of the

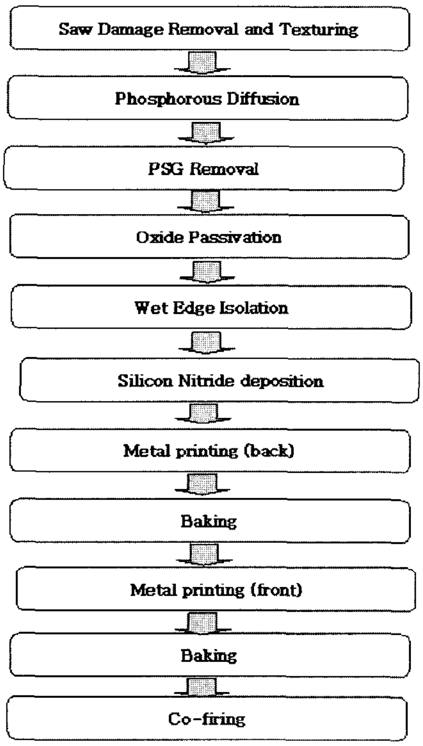

Fig. 3 Process sequence of our crystalline silicon solar cell fabrication

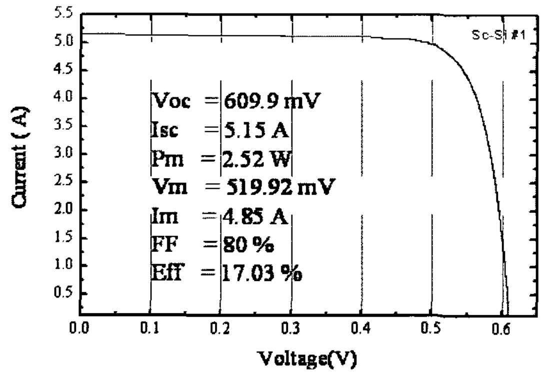

Fig. 4 Illuminated Current – Voltage characteristics of our sc-Si cell

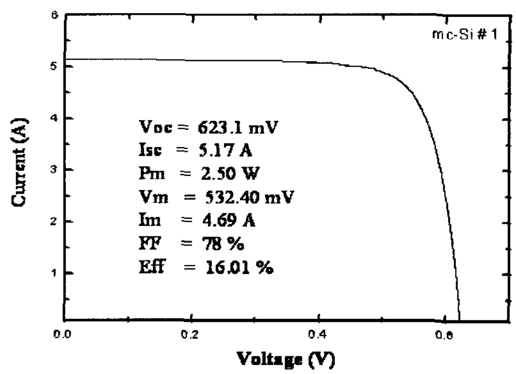

Fig. 5 Illuminated Current – Voltage characteristics of our mc-Si cell

wafers instead of conventional batch process.

Ⅳ. Future Prospects

Solar cell application in the residential houses of urban areas, public buildings, schools, apartment complexes will become a dominant application area. Many nations such as Japan, USA, Germany, Italy, Austria and EU have already initiated solar roof-top applications. Japanese exploration of the technical issues relevant to residential use has been followed similarly by a steady market development exercise.

Beginning in 1994 with 577 private residential systems each of 3 kilowatts rating, the installation of systems in 1995 and 1996 were encouraged by a 50% government subsidy. As of July 2003, Japan installed solar roof over 150,000 households. Germany took the lead in the residential use of photovoltaics with the initiation of the "100,000 roof" program. Various government programs, particularly in the demonstration area, are implemented to help identifying and removing the obstacles. However, local barriers to the implementation of this technology may also keep continuing up to year 2010 and by that time the cost of the solar cell generated power is expected to be 60 cent per watt.

Looking at the overall trend of the solar cells at present, we can outline the future track of the photovoltaic world. The process of transformation from the first generation to second generation solar cell should be geared up with the entry of new approaches but still silicon seems to remain as the major material for solar cells for many years to come. The small area cells (103 mm × 103 mm) will be displaced by large area cells (210 mm × 210 mm) or modules. Market force, industries as well as Research and Development teams must usher new areas with the encouraging policies and the subsidies from the governments of the global community for the innovative approach of high efficiency, low cost solar cells. This is how we can promise people of the third millennium for a clean and sustainable substitute for the depleting and polluting conventional non-renewable energy resources.

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≪Review Paper≫ Journal of the Korean Vacuum Society Vol.16 No.3, May 2007, pp.161~166

실리콘 태양전지

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(2007년 2월 6일 받음)

태양광발전이란 태양에너지를 직접 전기 에너지로 변환시키는 것이다. 지난 5년 동안 태양광발전은 세계적으로 높은 성장률을 보여 왔다. 특히 2006년에는 30% 이상의 성장을 가져왔으며 앞으로 20년 동안 평균 생산 성장률은 매년 27% - 34%가 될 것으로 예상하고 있다. 현재까지는 태양광발전을 이용해 생산된 전력의 가격은 기존 전력발전의 가격보다 높지만 태양광 기술의 발전과 효율의 향상으로 점점 그 가격이 떨어지고 있다. 뿐만 아니라 태양전지용의 실리콘 기판의 대량생산은 점점 더 태양전지의 가격 저하를 가져오고 있다. 태양전지의 변화효율의 한계는 30%이다. 현재에는 결정질 실리콘 태양전지가 주를 이루고 있지만 미래에는 박막 실리콘 태양전지가 주도를 이룰 것이다. 2030년에는 박막 태양전지가 90% 이상을 이루고 결정질 태양전지는 10% 이하로 떨어질 것을 예상하고 있다. 성균관대학교에서는 결정질 실리콘 태양전지의 저가화와 고효율화를 주 연구로 수행하고 있다. 현재 성균관대학교에서는 스크린 프린트를 이용해서 16% 이상의 다결정 실리콘 태양전지와 17% 이상의 단결정 실리콘 태양전지를 성공적으로 제작하였다. 제 1세대에서 다음 세대의 태양전지 발전의 과정은 새로운 접근법으로 확대되지만 여전히 실리콘이 지금까지 주된 재료로 쓰이고 있다. 2010년까지 이러한 기술들에 대한 격차는 여전히 있지만 태양광발전을 통한 전력생산의 가격은 60 cent/watt 정도로 예상하고 있다. 태양광발전은 청정에너지로서 재생불가능 하고 고갈되어가고 환경오염을 일으키는 다른 에너지와 비교하여 점점 대체에너지로서의 자리를 확립해 가고 있다.

주제어 : 태양광발전, 태양전지, 결정질, 실리콘, 에너지

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