

Outlook for Photovoltaic Developments in Taiwan

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This paper describes the various aspects of photovoltaic developments in Taiwan, which include applications of space and terrestrial solar cells, solar cell production and research on advanced thin-film solar cell materials. The advanced materials are hydrogenated polycrystalline silicon films deposited at low substrate temperatures and ternary chalcopyrite films with the potential for intrinsically stable and ultra-high-efficiency solar cells having a conversion efficiency in the vicinity of AMI 35%.

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INTRODUCTION

It is widely expected that the coming 21st century will be a new era for realization of the renewable energies, especially after more than 40 years of intensive research.

In the last two decades Taiwan has been an active participant in photovoltaic (PV) activities, even though the scope of the R&D has never been large, but the uninterrupted effort has laid down the foundation to expand into full-scale developments if the time of photovoltaics truly arrives.

An article co-authored by Hwang and Hong in 1984 outlined the strategy for PV development in Taiwan.¹ Due to the lack of strong and steady government commitments in the long-term financial support for PV activities, Taiwan adopted a policy in manufacturing and sales of amorphous Si solar cells for consumer products, which is the distinct feature and strength of Taiwan's industry. Although it is still not a big business, its cost effectiveness provides continuity and justification for PV developments in Taiwan.

The essential PV activities were focused in the development of PV systems and their applications, and also in advanced thin-film solar cell materials research. When communication via satellite became indispensable, Taiwan took the course of developing its own satellites at a time when space solar cells were in desperate need in the market place, which therefore provided impetus for further PV developments. When PV development has come to a kick-off stage, Taiwan should be ready to emerge as a major contender and to engage itself with the mainstream of terrestrial PV cell production and applications. In this article, selected topics are chosen for illustration to indicate the crucial aspects of the key developments.

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APPLICATIONS

Development of ROCSAT solar cell arrays

ROCSAT projects were born in 1991 and are scheduled to develop the manufacturing technologies of the key components for three satellites to be launched during 1998–2003. One important issue is to develop key satellite components by ROC manufacturers that could ultimately form the core of the ROC space industry. Through carefully selected local manufacturers and their technology transfer from the experienced foreign satellite component manufacturers, NSPO (National Space Program Office) designed these projects to obtain the necessary expertise for local production of space-qualified and reliable satellite components, including solar array panel assembly, remote interface unit, antenna, filter/duplexes, on-board computer, etc. The solar array panel assembly for ROCSAT-1 (the first scientific satellite) was successfully designed, fabricated and tested to zero defects by Shih-lin Electric Company and Tze-Chiang Foundation of Science and Technology with technology transfer from TRW. Figure 1 shows the worst case total power output in various modes.

Application of solar PV systems in Taiwan and their economic considerations

A house employing 4-kW PV modules was built by the Industrial Technology Research Institute (ITRI) in Taiwan as early as 1980. The recent ITRI projects aim at the development of system applications of the PV modules for private houses, office buildings and factories, which would relieve the burden on utility peak loads; data on the return of investment (ROI) for investing these PV systems are also provided. In particular, the projects investigated:

- (i) a 3-kW grid-connected solar module system for power generation;
- (ii) an inverter efficiency of 90–92%;
- (iii) a PV system lifetime of 15–20 years;
- (iv) a total PV system installation cost of US\$10 000 kWp^{-1}
- (v) house loads of type 1 to type 6;
- (vi) an average solar isolation of Kao-shuing;
- (vii) an electrical bill of US\$0.1 kWh^{-1} for summer time and US\$0.085 kWh^{-1} for the rest of the year.

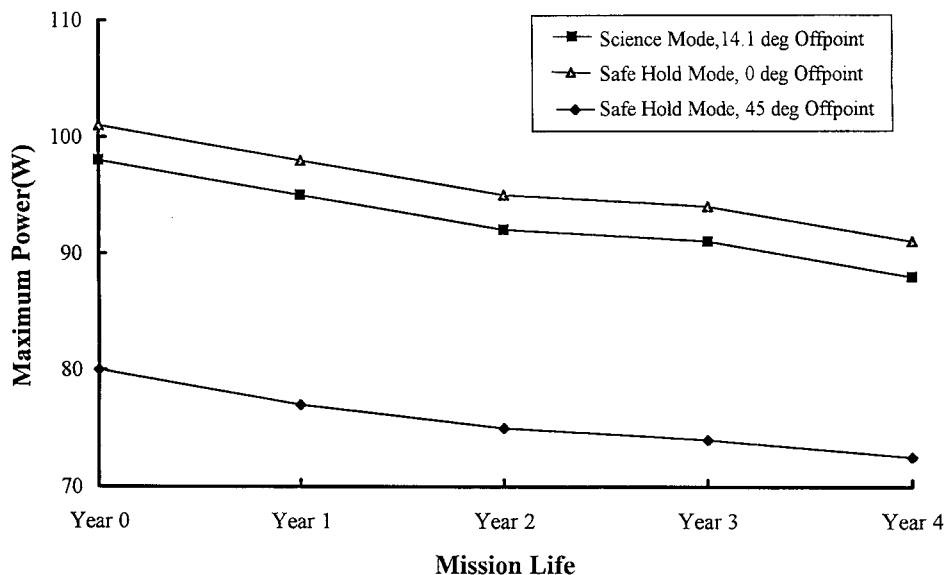


Figure 1. Simulated worst-case power output per circuit of ROCSAT-1 in various modes

Figure 2 shows the data actually measured for a PV power generation system for a private home; the power output generated from the PV modules is clearly depicted. The relationship of the ROI as a function of the solar PV system installment cost is shown in Figure 3. For a minimum 5% per year ROI the affordable installment cost of the PV system can be estimated, and a government promotion programme could be planned by subsidizing a certain percentage of the PV installment expenses based on this analysis.

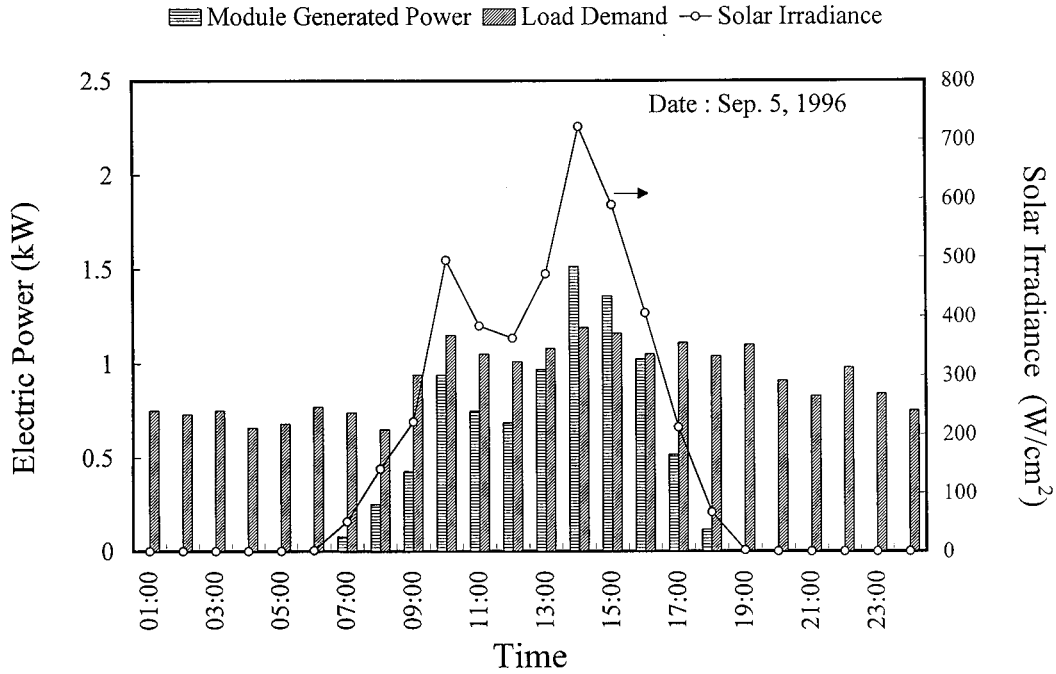


Figure 2. The measured data of a photovoltaic power generation system for a private house

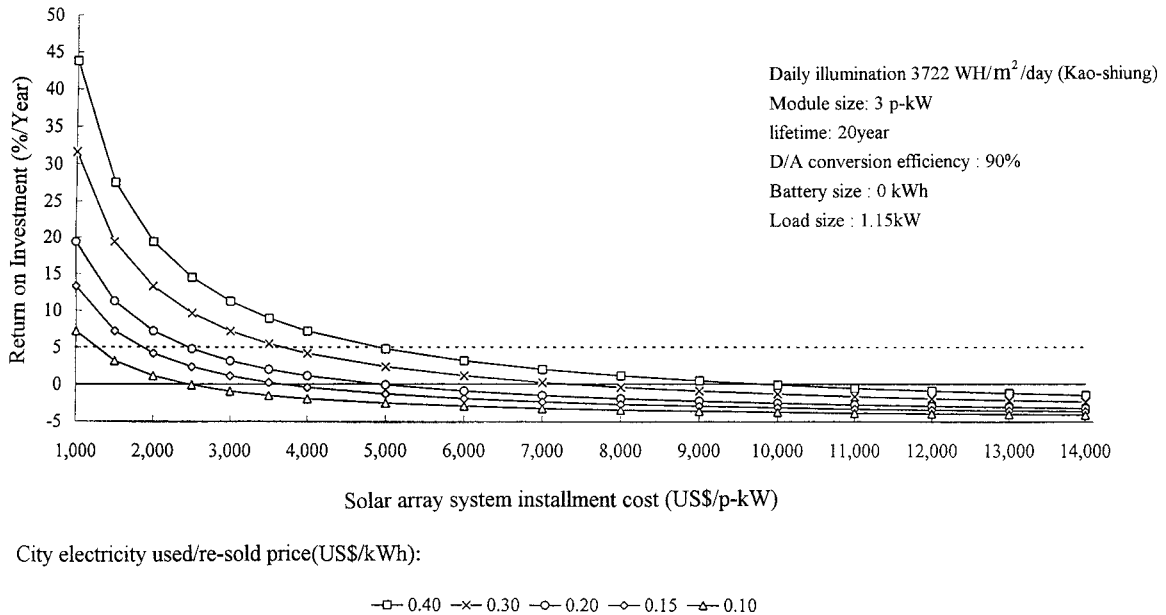


Figure 3. The relationship between the return on investment (ROI) and the instalment cost of solar array systems

PRODUCTION

Amorphous silicon solar cells

In the last decade, Sinonar Corp. in Hsin-chu Science Park has been engaged in the production of amorphous silicon PV modules. Standard p-i-n structure cells deposited on glass substrates were manufactured routinely using sputtering for Al metallization and automated glass cutting and cell testing facilities. Today, Sinonar is the world leader in producing amorphous Si solar cells for indoor applications, including calculators, watches/clocks, temperature sensors and other consumer electronics applications. Also, Sinonar have produced PV modules for stand-alone and grid-connected systems.

Light-pen-based digital boards

A unique technology for light-pen-based digital boards has been developed for industrialization by the Tsing Hua group, in which light-pen-based digital boards and their novel applications were explored. The digital board is made of hydrogenated silicon–germanium structures, and the pen is a light-emitting one. One of the major obstacles to the wide acceptance of personal computers by many people is the inconvenience of their use, and in recent years digital boards have been developed to solve this problem. However, the usual digital boards are made from two-dimensional arrays either with pressure contact or electrical induction, both of which have difficulties in resolution and can only be used in rather restricted and small areas. The light-pen-based digital boards use a PV concept with certain modifications, and the successful development of these devices and their signal processing units is leading to the set-up of a production facility in Hsin-chu Science Park, which represents a good example of university–industry cooperated research projects of the National Science Council of ROC.

RESEARCH

Space solar cells

There are at least six companies in Taiwan that have organometallic vapour phase epitaxy (OMVPE) production capability and the number is still growing; such a capability could form the basis for developing III–V solar cell production. It is noted that in Taiwan at least three groups have been engaged in developing III–V solar cells, the most active of which is led by Professor Wei-I. Lee of National Chiao Tung University sponsored by the National Science Council of ROC for space satellites. Four structures have been developed, including:

- (i) a GaAs solar cell structure with an AlGaAs window layer;
- (ii) a GaAs solar cell structure with an AlGaAs window layer and back surface film;
- (iii) a GaAs solar cell structure with a GaInP window layer;
- (iv) a GaAs solar cell structure with a GaInP window layer and back surface film.

Figure 4 shows one of the structures having an AM1.5 conversion efficiency of 19.9%, as shown in Figure 5. Also led by Professor H. L. Hwang of National Tsing Hua University, $2 \times 2 \text{ cm}^2$ space Si solar cells having AM1 efficiencies in excess of 14% were fabricated.

Advanced solar cell materials

Polycrystalline Silicon (poly-Si) films deposited on SiO_2 or glass substrates having grain sizes in the micrometre range were successfully made by Tsing Hua group at low temperature (250°C) by electron cyclotron resonance chemical vapour deposition with the hydrogen dilution method. These large grains have a special leaf-like shape. No amorphous Si band appeared in the Raman spectra, so the crystalline fraction of these poly-Si films is close to 100%. The hydrogen contents were detected to be less than

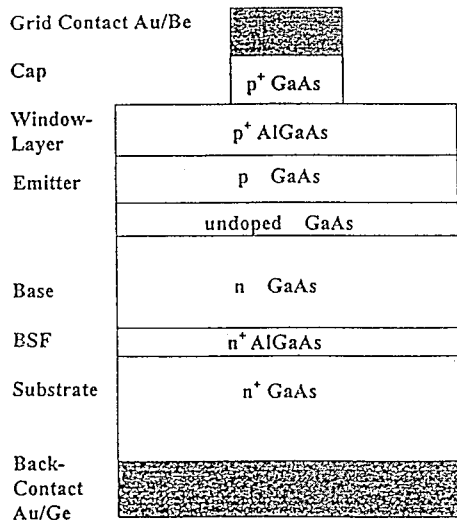


Figure 4. GaAs solar cell structure with AlGaAs window layer and back surface film

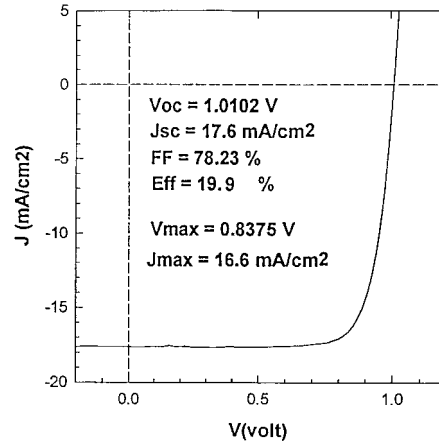


Figure 5. The illuminated $I-V$ characteristics of a solar cell having the structure depicted in Figure 4

0.8 at%, which decreased as the hydrogen dilution ratio was decreased. Phosphorus doping studies have been carried out with the highest doping efficiency of 11%, and in-depth studies on grain information and their improvements are being carried out. This project explores the possibility of even larger grain silicon films suitable for high-performance solar cells, which could avoid the fundamental instability problems of amorphous Si:H solar cells.

Two groups at Sun Yat-Sen University are devoted to ternary chalcopyrite semiconductor research: CuInSe_2 and CuGaSe_2 thin films are regularly produced by the molecular beam deposition method.

Luminescence characteristics with different film compositions have been studied. Film structure studies with morphology modification by Sb incorporation during the film deposition with an additional Sb source have been carried out.² Thin films of CuInSe_2 with Sb incorporation have been subjected to sulphurization treatments by immersing in $(\text{NH}_4)_2\text{S}_x$ solution. In addition to surface passivation, the CuInSe_2 could be transformed into large-gap (1.3 eV) $\text{CuIn}(\text{S,Se})_2$ thin films to obtain a higher open-circuit voltage (V_{oc}).³

In the last two decades, the Tsing Hua group have been continuously working on various aspects of material preparation and the physics and chemistry of CuInS_2 , with special emphasis on non-stoichiometry and related defect studies and control.⁴ Recent advances are in the making of good-quality $\text{Cu}(\text{Ga,In})\text{S}_2$ thin films by reactive sputtering for very large area thin-film production of stable terrestrial solar cells.⁵ Fine adjustments of the film compositions are made by metal-organic reactive sputtering, and a defect model relating the film characteristics and solar cell performance is under development. The tandem cell structures reported by Loferski's article⁶ (also reproduced in this issue) will be used as a guide to achieve a solar cell efficiency of 35%.

CONCLUSIONS

Over the years Taiwan's PV developments have taken a low profile, but with limited man-power Taiwan has successfully developed its PV industry and the basic technologies for bulk crystalline and thin-film solar cells. The ITRI have also explored the prospects of using PV modules in National Parks and private houses in Taiwan. The recent focus on the cost-effectiveness of using 3-kW PV modules in private houses will help to formulate a national policy to subsidize the expense of PV systems purchased by Taiwan citizens.

In recent years, the development of ROC satellites has advanced III–V and Si solar cell research and development, which again enhances the development of profit-driven PV industries in Taiwan.

This paper describes all such activities, and it is now believed by the general public in the famous quote of J. J. Loferski that ‘sunshine is the last frontier of mankind’, and Taiwan will definitely not miss the show when the time comes.

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