UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
I.C.T.P., P.O. BOX 586, 34100 TRIESTE, ITALY, CABLE: CENTRATOM TRIESTE

SMR.704 - 8

Workshop on Materials Science and Physics of Non-Conventional Energy Sources

(30 August - 17 September 1993)

"Recent Progress of Amorphous Silicon Solar Cells - Device Physics and Technology"

Yoshihiro Hamakawa
Faculty of Engineering Science
Osaka University
Toyonaka, Osaka 560
Japan

These are preliminary lecture notes, intended only for distribution to participants.

MAIN BUILDING STRADA COSTIERA, 11 TEL 22401 TELEFAX 224163 TELEX 460392 ADRIATICO GUEST HOUSE VIA GRIGNANO, 9 TEL 224241 TELEFAX 224531 TELEX 460449
MICROPROCESSOR LAB. VIA BEIRUT, 31 TEL 224471 TELEFAX 224163 TELEX 460392 GALILEO GUEST HOUSE VIA BEIRUT, 7 TEL 22401 TELEFAX 224559 TELEX 460392

for Nonconventional Energy.
TRIESTE ICTP, August 1993

RECENT PROGRESS OF AMORPHOUS SILICON SOLAR CELLS – DEVICE PHYSICS AND TECHNOLOGY –

Yoshihiro HAMAKAWA

Professor of Osaka University
Faculty of Engineering Science, Osaka University
Toyonaka, Osaka 560, Japan

ABSTRACT

A review is given on the current state of the art in amorphous silicon (a-Si:H) and thin film solar cell R & D efforts and their photovoltaic system applications. Firstly, progress in a-Si alloy production technologies are overviewed with their significancies as the champion material for a low cost solar cells. Secondly, some new approaches and key technologies to improve solar cell efficiency with stabilized performance by new amorphous materials such as a-SiC:H, c-SiC:H, a-SiGe:H are demonstrated. Recent aspect of some other new material devices such as CIS and CdS/CdTe are also introduced. Progress of the conversion efficiency in various types of amorphous silicon solar cells are surveyed and summarized. In the final part of paper, aspect of the PV system developments and application fields are introduced. Near term and long term forecast on the market size expansion will be discussed together with cell cost reduction prospect as a promised candidate of the renewable energy technology for future.

KEYWORDS

Solar photovoltaics; Amorphous silicon; Thin film solar cells; Heterojunction solar cells; Stacked solar cells, Photovoltaic system.

INTRODUCTION

Developing clean energy resources as alternative to oil has become one of the most important tasks assigned to modern science and technology. The reason for this strong motivation is to stop air pollution resulting from the mass consumption of fossil fuels and to keep the ecological cycles of the biosystems on the earth. Views of future energy envision that the emerty structure in the 21st century will be characterized as a "Best Mix Age" of different energy forms. Among a wide variety of renewable energy projects in progress, photovoltaics is the most promising one as a future energy technology. It is pollution-free and abundantly available everywhere in the world, even in space, and also can operate by diffused light.

A big barrier impeding the expansion of the large-scale power source

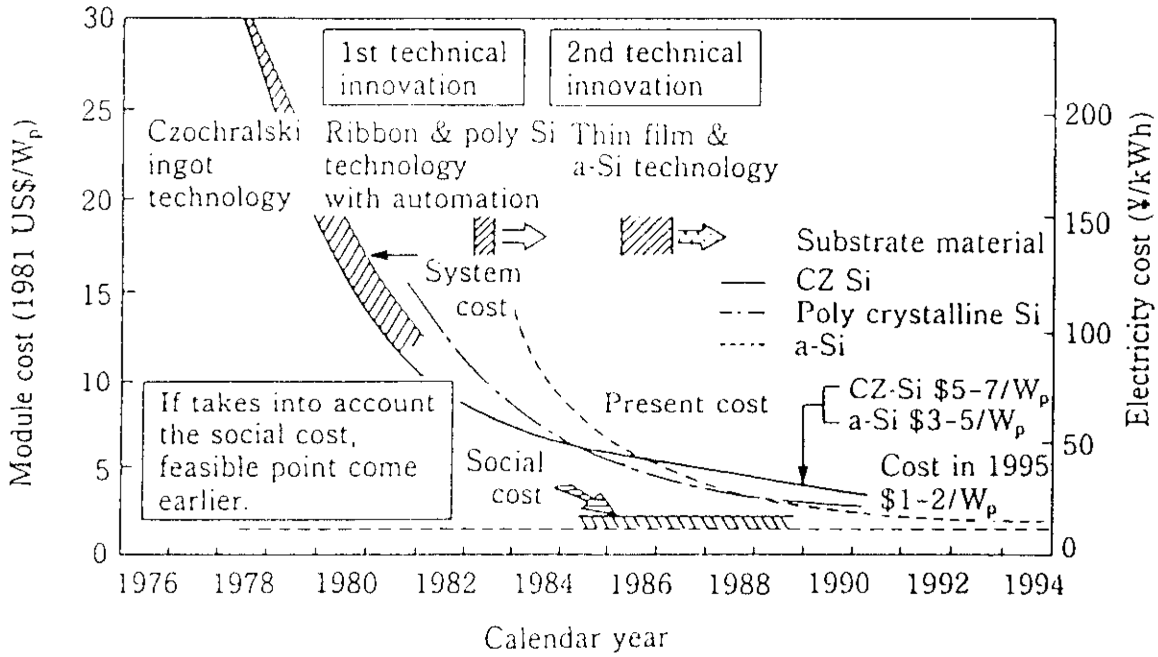

Fig. 1 Reduction of solar cell module cost with increasing production scale. The "scale merit" in the figure means the percentage of cost reduction with an increase of one order of magnitude mass-production scale in the factory.

application in the photovoltaic system was the high price of solar cell module, which was more than $50/W (peak watts) by 1974. Therefore, the cost reduction of the solar cell is of prime importance. To achieve this objective, tremendous R&D efforts have been made in a wide variety of technical fields, from solar cell material, cell structure, and mass production processes to photovoltaic systems over the past ten years. As the result, more than an order of magnitude cost reduction has been achieved, and now the module cost has come down less than $5/W in a firm bid for the large scale market. Figure 1 shows the cost transition of the solar cell module in the last ten years. As can be seen from this figure, it might be expected two steps of technological innovations. The first innovation in progress is based on low-cost poly crystalline technologies applicable to well-developed single crystalline silicon solar cell fabrication processes. Another remarkable innovation we have seen is a-Si technology.

In this paper, present status of the a-Si solar cell R & D with some new knowledges in the device physics are briefly overviewed in the first part. Then, some new approaches and key technologies to improve cell performances in progress are introduced. Finally, recent topics in the application and industrialization field are reviewed and discussed.

PROGRESS IN a-Si ALLOY THCHNOLOGIES

Since the recent success of valency electron control in the glow discharge-produced amorphous silicon carbon alloy (a-SiC:H) (Hamakawa et al., 1982), a new age in amorphous silicon alloys has opened up, and a group of new materials such as amorphous silicon-germanium (a-SiGe:H), amorphous silicon-nitride (a-SiN:H) and amorphous silicon-tin (a-SiSn:H) have been successively developed in the past few years. The significance of this material innovation is that one can control electrical, optical and also

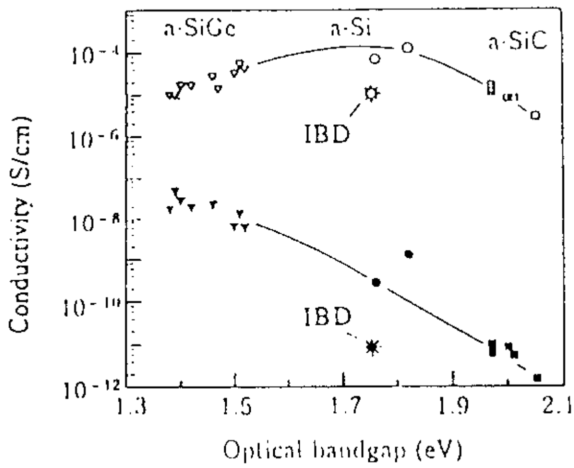

Fig. 2 Dark and photo-conductivities of a-SiGe:H (triangles), a-Si:H (circles), a-SiC:H (squares) versus optical bandgap.

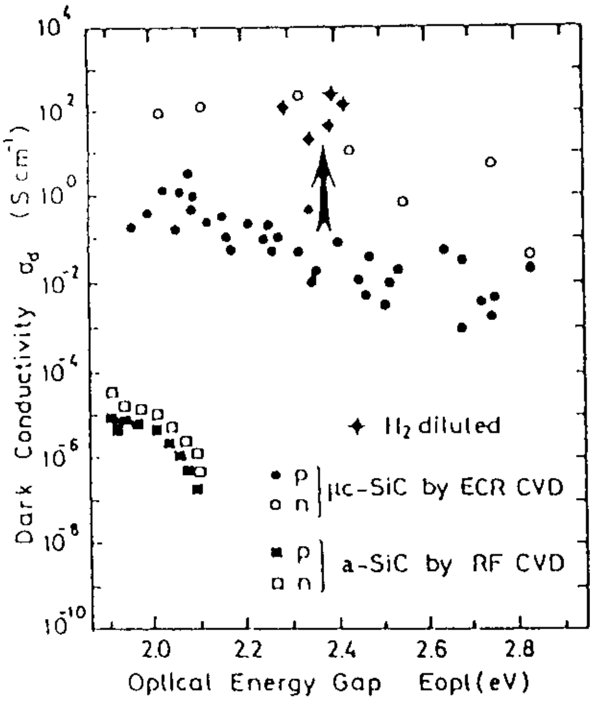

Fig. 3 Relationship between dark conductivity and optical gap of amorphous and microcrystalline SiC:H prepared by RF and ECR plasma CVD.

opto-electronic properties by controlling atomic compositions in the mixed alloys. Therefore, a wide variety of application fields has also been developed with these new electronic materials. In fact, a-SiC:H/a-Si:H heterojunction solar cells (Tawada et al., 1982), a-Si:H/a-SiGe:H stacked solar cells (Ovshinsky et al., 1985), superlattice devices (Tsuda et al., 1986), a-Si:H/a-SiN:H thin film transistors (for example, JARECT, 1983), photo-receptors (Shimizu, 1985), X-ray sensor (Wei et al., 1985), color sensors (Nakano et al., 1983), etc. have been developed, and some of them are already being in market.

Figure 2 shows the dark-and-photo conductivities versus the optical energy gap in non-doped a-Si alloy films deposited under high hydrogen dilution conditions of the plasma CVD (Nakata et al., 1990). As can be seen from the figure, a-$Si_{1-x}C_x$ alloy has a considerably high photoconductivities with the σ_{ph}/σ_d ratio more than 10^4.

Figure 3 summarized the relation between the dark conductivity and the optical energy gap of p- and n-type a-SiC prepared by conventional RF plasma CVD and p- and n-type c-SiC prepared by ECR plasma CVD (Hamakawa and Okamoto, 1989). As the optical energy gap increases, the dark conductivity of the films prepared by the RF plasma CVD rapidly decreases, while that of the films prepared by the ECR plasma CVD remains higher than 10^{-3} $S\cdot cm^{-1}$ even when the optical energy gap exceeds 2.5 eV. This fact implies that ECR plasma CVD produced μc-SiC is useful new material for not only the function of wide gap window but also transparent electrode.

Another topics in the material preparation technology field is the IBD (Ion Beam Deposition) method (Hamakawa et al., 1990). A high stability film against the light induced degradation with high deposition rate is still important key issue in the field. To overcome these problems, tremendous R&D efforts have been in progress by the wide varieties of approaches,

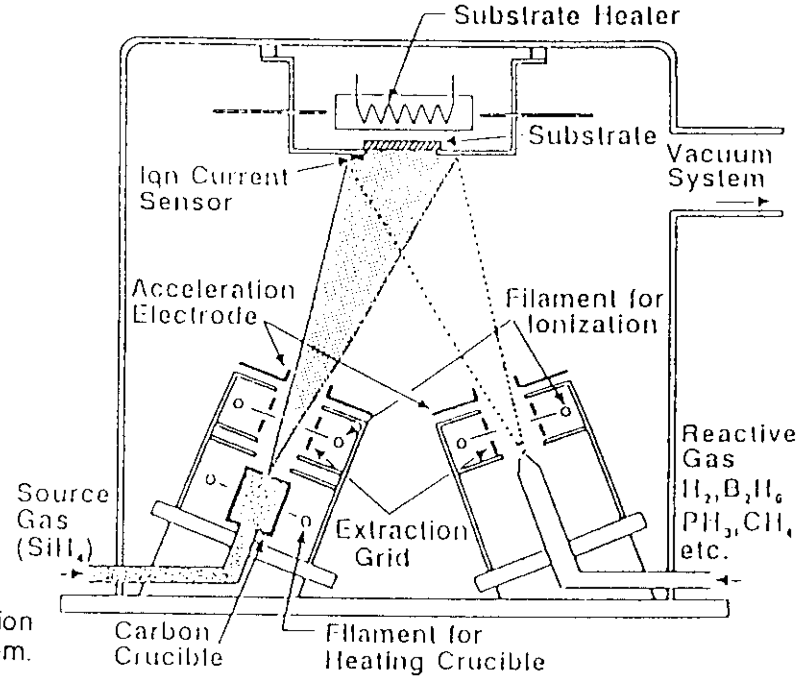

Fig. 4 A schematic representation of IBD (Ion Beam Deposition) system.

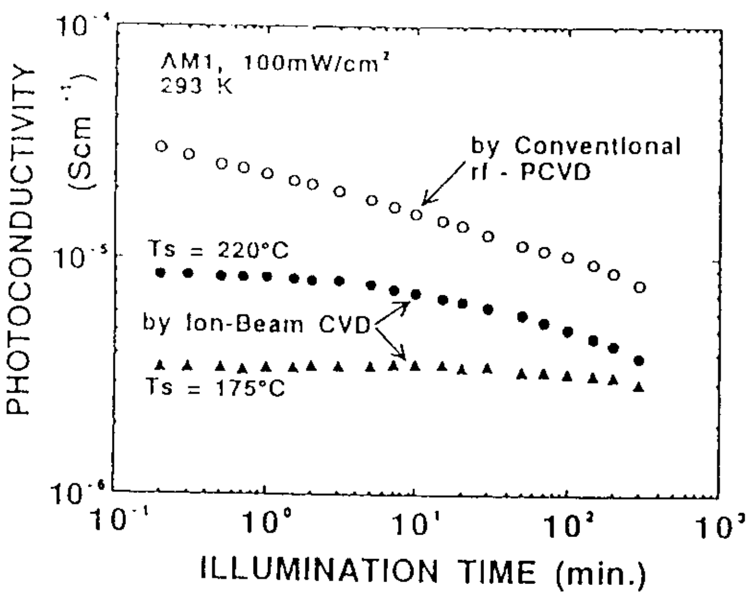

Fig. 5 Change in the photoconductivity with illumination time in IBD produced a-Si:H and PCVD produced a-Si:H films.

e.g.; the Chemical Annealing Treatment (CAT) (Shirai et al., 1990), Intense Xenon Light Pulse Assisted Plasma CVD (Tawada et al., 1990), IBD and so on. Among these, IBD method is a unique challenge in views of a wide range controllability on both hydrogen content and decomposed species ion energy.

Figure 4 shows a schematic illustration of the IBD system. A typical a-Si film growth condition in this system is: the ion acceleration voltage V_{acc}=100-300 V, ionic current Ie, with voltage Ve are 0.8 A at 400 V, and substrate temperature T_s = 100-300 °C, while chamber base pressure is 10^{-4} Torr or less.

As the preliminary experiment, a systematic investigations on the undoped a-Si film deposition has been made by a series of deposition parameters. The result shows a considerably good film quality having 10^4-10^6 photo- to dark-conductivity ratio σ_{ph}/σ_d with optical energy gaps of 1.7-1.8 eV. A noticeable feature of IBD produced film is a better stability against light exposure. Figure 5 shows a comparison of changes in the photoconductivity

σ_{ph} with AM1 light illumination for IBD produced film and conventional plasma CVD produced film (Hamakawa et al., 1990).

R&D EFFORTS ON PV PERFORMANCE IMPROVEMENTS

An improvement in cell efficiency is the prime importance, which is directly connected to cost-reduction in photovoltaic systems. Figure 6 shows a result of recent calculation for the theoretical limit of conversion efficiencies under AM1.5 global radiation for the several candidate solar cell materials (Hamakawa, 1988), where the theoretical limit means that the calculation has been made on the basis of 100 % quantum efficiency in the photo-carrier generation above the fundamental absorption edge and neglected all carrier recombination and ohmic loss factors. In the figure, the circle on each material line shows experimentally obtained maximum efficiency at room temperature. As can be seen in this figure, there are still big room to improve the experimentally obtained efficiency except for the crystalline Si and GaAs. The difference between the dots and circles indicate each level of the technological maturity for the respective semiconductor material.

A wide variety of R&D efforts hgave been in progress on each process of the

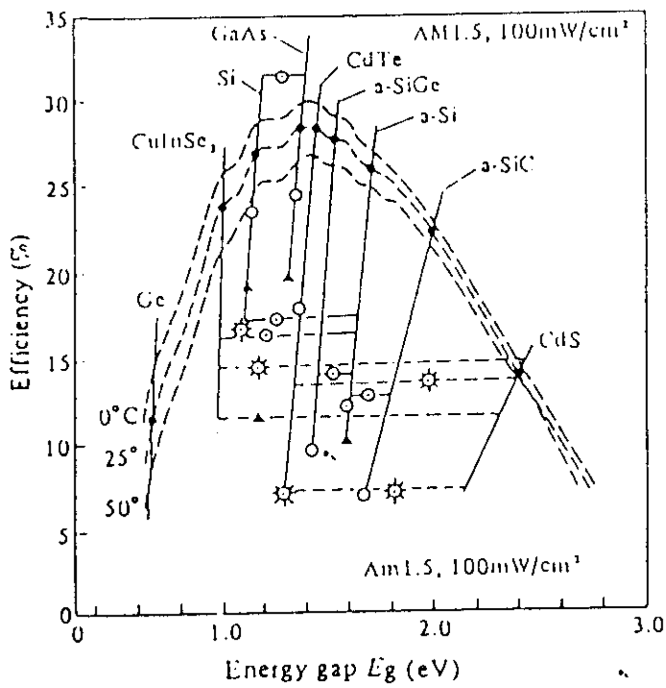

Fig. 6 Theoretical limit of the solar cell efficiencies calculated for AM-1.5, 100 mW/cm² in put power on various materials shown by closed circles. While open circles and filled triangles show the experimentally obtained highest efficiencies on the single junction cells and their in-line mass-production cells. The ⊙ and ☼ express the highest record of the tandem type cells with the same kind of material and polycrystalline materials.

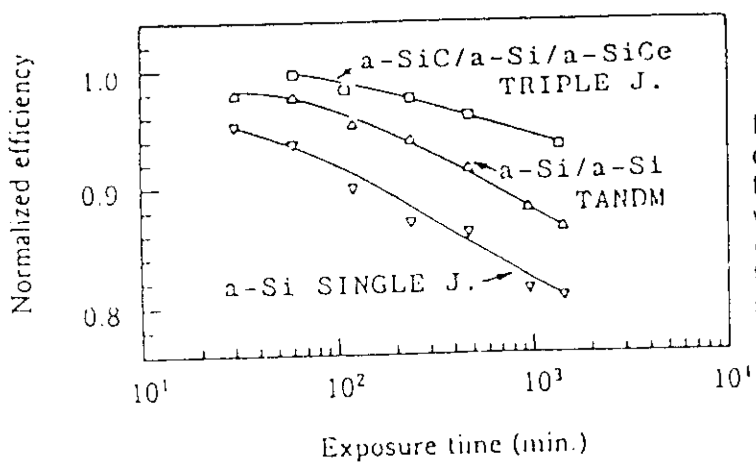

Fig. 7 Light-induced change in conversion efficiencies of single, tandem, and triple a-Si solar cells which is normalized by initial values. (inverted triangles:a-Si single cell, triangles: a-Si/a-Si tandem cell, squares:a-Si/a-Si/a-SiGe triple cell).

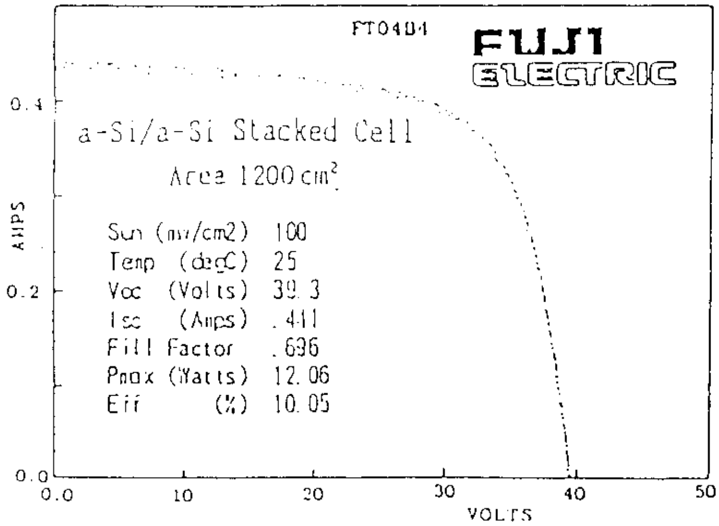

Fig. 8 V-I characteristics of large area a-Si/a-Si stacked cell having more than 10 % efficiency.

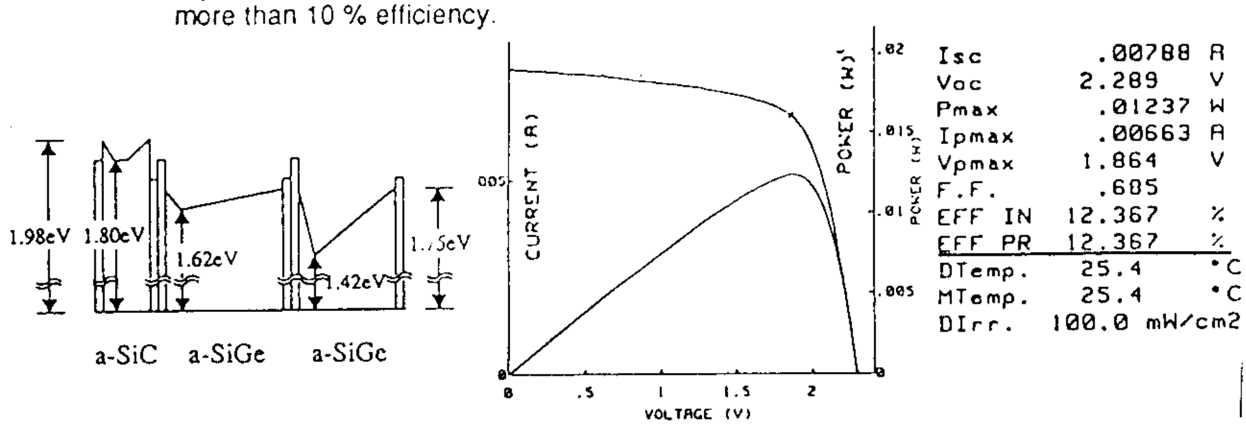

Fig. 9 Bandgap profile of a-SiC/a-Si/a-SiGe multi-bandgap stacked solar cell (a) and its voltage-current characteristics (b).

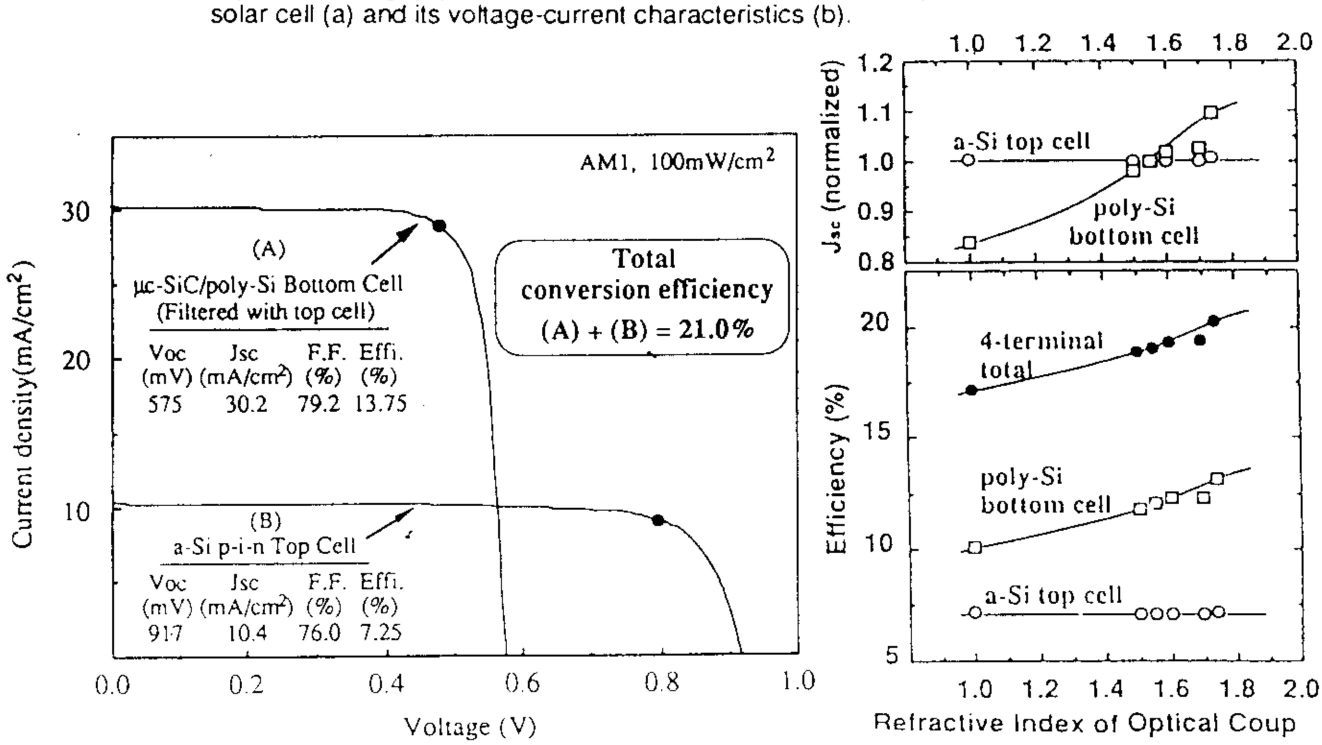

Fig. 10 Output characteristics of a-Si//poly-Si four-terminal tandem solar cell; top a-Si transparent solar cell and bottom μc-SiC/poly-Si heterojunction solar cell (filtered by the top cell).

PV conversion with the practical technologies. Among these, a remarkable advances has been seen in the technology of the wide gap windows heterojunction, graded band profiling, doping, superlattice, BSF treatment and also the stacked junctions with new materials such as a-SiC, μc-SiC alloys. As the results, amorphous silicon solar cell efficiency is improving day by day. According to a recent histogram of several thousands modules massproduction data (Fujikake et al., 1991), the In-Line efficiency is being reached to 9 %, and several institutes reported more than 10 % efficiency for the 100 cm^2 or more area as the top data in a recent few years. While, the laboratory phase efficiencies are more than 12 % with a-SiC/a-Si heterojunction.

As it has been reported elsewhere (for example, Tsuda et al., 1983) that the amount of percentage degradation increase with increasing i-layer thickness. The reason is that the volume recombination of the photo-generated carriers become relatively large with decreasing the lowest electric field in the i-layer. For the purpose of suppressing this effect, the tandem type solar cell has been recommended as a more reliable a-Si Solar Cell (Hamakawa, 1986). Figure 7 shows light induced change in the conversion efficiencies of a-Si single, a-Si/a-Si tandem and a-SiC/a-Si/a-SiGe trple tandem solar cells (Nakata et al., 1990). Figure 8 shows an example of large area (1200 cm^2) a-Si/a-Si stacked solar cell V-I characteristics having the efficiency of 10 % by Fuji Electric Co. Ltd. (Fujikake et al., 1991). The combination of a-Si with CIS ($CuInSe_2$) also looks a promised candidate of stacked solar cell, recent top record in this combinaitons is 15.6 % efficiency with four-terminal tandem cell (Mitchel, 1990).

Recently, a concept of the band profiling design has been initiated as an optimum design of the ambipolar carrier transport in i-layer of the multi-band gap junction. As an example of result, band profile of the a-SiC/a-

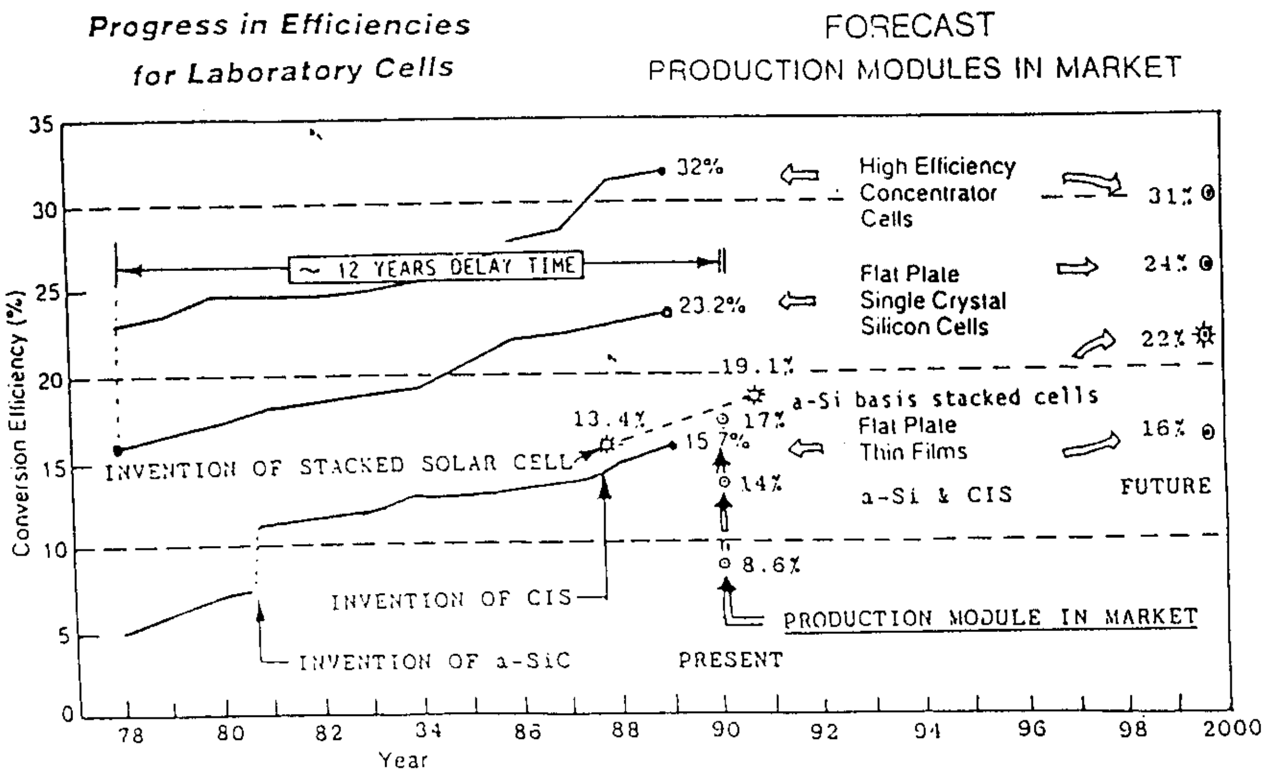

Fig. 11 Progress in efficiencies for laboratory cells and forecasted production module efficiencies toward 2000.

Si/a-SiGe triple band gap tandem solar cell is illustrated in Fig. 9 with its photovoltaic performance (Nakata et al., 1990). At the present stage of investigation, a conversion efficiency of 15.04 % with Voc=1.478 V, J_{sc}=16.17 mA/cm^2 and FF=63 % has been obtained on sensitive area of 5x6 mm^2 under AM1 illumination. Quite recently, by the same combination on four-terminal cell 19.1 % efficiency has been obtained by Ma Wen et al. as shown in Fig. 10. To show the present status of the solar cell efficiency improvement R&D efforts, some recent top efficiency year by year data in these ten years are plotted together with their forecast by 2000 in Fig. 11.

EXPANDING NEW APPLICATION SYSTEMS AND PROMISED FUTURE PROSPECT

As it has been discussed elsewhere, the cost reduction of the solar cells is the key issue in the PV project. Figure 12 represents cell cost versus massproduction scale in the past 15 years. As can be seen from this figure, a-Si solar cell has a largest scale merit of the 25 %. The extrapolation of each cell materials cost shows the module cost of 1-2 dollars/Wp will be achieved with 100 MW/year. Figure 13 shows photovoltaic market forecast by three companies. While GSC (Gland Solar Challenge) committee proposal on the Japanese domestic annual production forecast has also been plotted in the figure. Examining with this figure, The annual production of 600 MWp/year for the world wide would be corresponding the time of the 100 MW/year production in Fig. 12. The result shows a levelized cost against the conventional utility power electricity cost could be accomplished by the year of 2000.

Table 1 shows the cell and module efficiency records achieved as of May 1990 on three kinds of silicon basis substrate solar cells. While, laboratory phase small area top data are also shown in the parenthesis. On the basis of these module efficiency, the levelized electricity cost has been calculated by the similar method to that listed in DOE the Five Year Research Plan, the US DOE has established the goal of levelized current dollar cost of $0.12/kWh with the module cost of $1/Wp (US-DOE Five Year Research Plan, 1987). Japanese a-Si solar cell Technical Committee

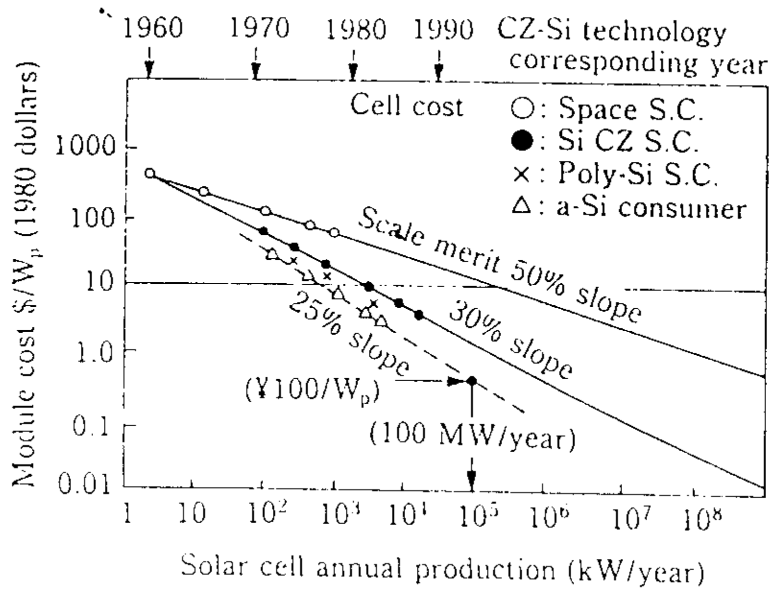

Fig. 12 Reduction of solar cell module cost with increasing production scale. The "scale merit" in the figure means the percentage of cost reduction with an increase of one order of magnitude mass-production scale in the factory.

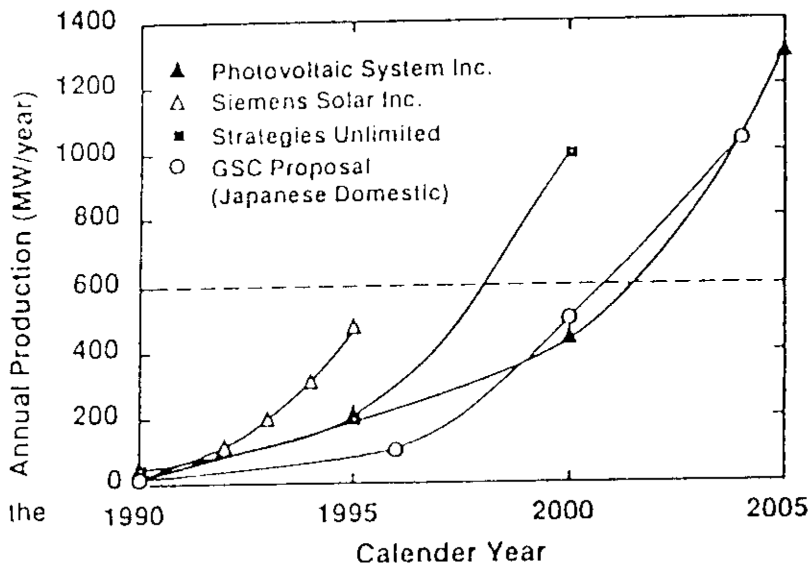

Fig. 13 PV market forecast by the 2005 year.

Meeting in Sunshine Project has also estimated separately long-term solar cell module cost target of 100-200/Wp (NEDO Contract Report, 1991), which roughly coincides with US DOE goal price, taking into account of the difference in electricity price.

As has been discussed in the previous section, cost reduction with mass production scale merit is an important factor. Full use of large scale merit in the a-Si solar cell production, a wide variety of new applications such as solar-powered consumer electronics, water pumping, traffic and rail way signals have been developed in the past 10 years. Semi-power applications like air ventilation in house and sun-roof of the automobile have recently made progress quickly. A roof top photovoltaic power generation hooked up to utility grids would be one of the most promising systems in the near future. For the purpose of system operation experiments and demonstrations, NEDO/Kansai electric power Co. funded the construction of 3 kWpx200 roof top solar house model plans by the 1992 (Yamaguchi, 1990). These projects have provided the feasibility of intermediate photovoltaic systems.

Table 1 Conversion efficiency data and technical milestones of PV.

Efficiency & PV Electricity Cost / Target Year		Present 1990	Near Term (1995年)	Long Term (2000年)
Solar Cell / Module Efficiency (%) 100cm²Area Level (Top Data in R&D)	Xstal-Si	19 /17.1 (23.2)	22 / 18*	24 / 21
	Poly-Si	15.7 / 13.5	20 / 16	21 / 18
	a-Si	10 / 8.7 (12.0)	12 / 10*	14 / 12*
	Stacked a-Si [4T // 2T]	10.6 / 9.2 [16.8 // 15]	14 / 11* [20//18]	18 / 15* *[22//18]
Production Scale(MW_p / year)		16.8	40	250
Module Cost (¥/ W_p)		650 ** ($5.0)	500* ($3.8)	100-200* ($1.5)
BOS Cost (¥/ W_p)		500 ($3.8)	350 ($2.7)	200 ($1.5)
System Life (Year)		20	22	25
Levelized Electricity Cost (¥/kWh)		52.3 [115] (¢40/kWh)	35.1 [72] (¢27/kWh)	14.5 [26] (¢11.1/kWh)

* Sunshine Project Milestone ** NEDO Procurement Price

*** Annual sunshine period 1100hrs / year are assumed [ ]: Included 6% interest for 20 years system life.

Semi-transparent a-SiC solar cells, and SEE-through type solar cells have a new application system such as sun-roof in motor car and decorated window etc. Solar powered air conditioning has a great deal of potential market more than 10 GW/year. A prototype a-Si powered solar air condition machine has been produced some photovoltaic industries (Kuwano, 1991). New challenges with full use of light-weight eletricity generator have also been applied in the sky, on sea and also on land. That is "TANPOPO-GO" amorphous silicon solar cell powered engine plane succeeded across North-American continent, San-Dieogo, California to Kitty Hawk, North Carolina, in 1990.

ACKNOWLEDGEMENT

The author wished to express his sincere thanks to the Sunshine Project a-Si solar cell contractors and some other a-Si solar cell groups for supplying recent top data. Author also gives his sincere gratitude to Director T. Goto of sunshine Project HQ Office, Director T. Ohno of the solar Energy division in NEDO and Executive Manager H. Kobayashi and Director S. Wakamatsu of PVTEC.

REFERENCES

Fujikake S., T. Sasaki, Y. Ichikawa and H. Sakai (1991). Proc. 22nd IEEE PVSC, Las Vegas 7B-4.
Hamakawa Y. and Y. Tawada (1982). Int. J. Solar Energy, 1 251.
Hamakawa Y. (1986). MRS '85 Spring Meeting, (Palo Alto) F-11.
Hamakawa Y. (1988). Proc. of Euroforum–New Energy Congress–, Vol. 1, Saarbrucken, Germany p. 194.
Hamakawa Y. and H. Okamoto (1989). Advances in Solar Enelgy, Vol.5, edited by K. Böer, Plenum, New York 1-98.
Hamakawa Y., K. Hattori and H. Okamoto (1990). a-Si Solar Cell Contractors Meeting, Sunshine Project, MITI, May 8-10.
JARECT (1983). ed. by Y. Hamakawa (Ohm-Sha & North-Holland, Tokyo and Amsterdam, 1983) 6, p.252.
Kuwano Y. (1991). Business Japan, Vol. 36, No.9 p. 58.
Ma W., T. Horiuchi, M. Yoshimi, K. Hattori, H. Okamoto and Y. Hamakawa (1991). Proc. of 22nd IEEE PVSC, to be published
Mitxhel K.W. (1990). Optoelectronics - Devices & Tech.-, 5, No. 2 275.
Nakano S., T. Fukatsu, M. Takeuchi, S. Nakajima and Y. Kuwano (1983). Proc. 3rd Sensor Symposium, Tsukuba 97.
Nakata Y., H. Sannomiya, S. Moriuchi, Y. Inoue, K. Nomoto, A. Yokota, M. Itoh and T. Tsuji (1990) Optoelectronics - Devices & Tech.-, 5 No.2 209.
NEDO Contract Report by NEF a-Si Solar Cells Committee Meeting (1991), "Feasibility Study on a-Si Solar Cells Industrialization" March 1991, pp. 200-274.
Ovshinsky S.R. (1985). MRS 1985 Spring Meeting, San Francisco 251.
Shimizu I. (1985). J. Non-Cryst. Solids, 77&78 1363.
Shirai H., D. Das, J. Hanna and I. Shimizu (1990). Tech. Digest of PVSEC-5, Kyoto 59.

Tawada Y., M. Kondo, H. Okamoto and Y. Hamakawa (1982). Solar Energy Mat., 6 299.
Tawada Y. and H. Yamagishi (1990). a-Si Solar Cell Contractors Meeting, Sunshine Project, MITI, May 8-10.
Tsuda S., N. Nakamura, K. Watanabe, T. Takahama, H. Nishiwaki, M. Ohnishi and Y. Kuwano (1983). Solar Cells, 9 No. 1-2, p.25
Tsuda S., H. Tatui, T. Matsuyama, H. Haku, K. Watanabe, Y. Nakashima, S. Nakano and Y. Kuwano (1986). Proc. 2nd Int. Photovoltaic Science and Engineering Conf., Beijing 409.
US-DOE Five Year Research Plan (1987-1991), "Photovoltaics–USA's Energy Opportunity, May (1987) DOE/CH100937.
Wei Gunag-Pu, H. Okamoto and Y. Hamakawa (1985). Jpn. J. Appl. Phys., 24 1105.
Yamaguchi J. (1990). Business Japan, Vol. 35, No.9 p. 60.

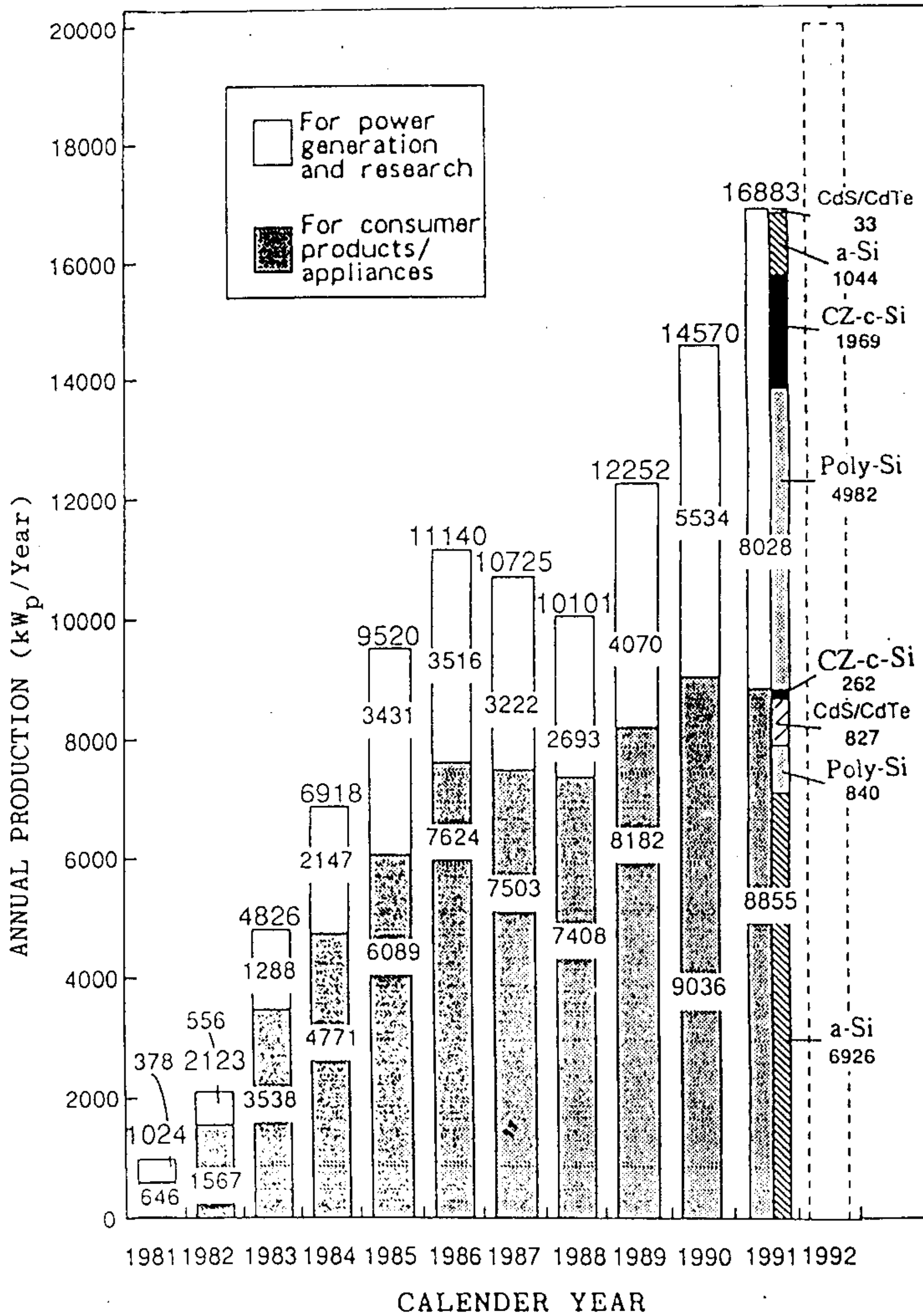

Fig.4. Transitions of solar cell annual production in Japan.

注）生産量の表示出力は各種太陽電池のAM1.5入射1kW／m²条件下で出力換算した値であり、各社のアンケート調査を集計したものである。

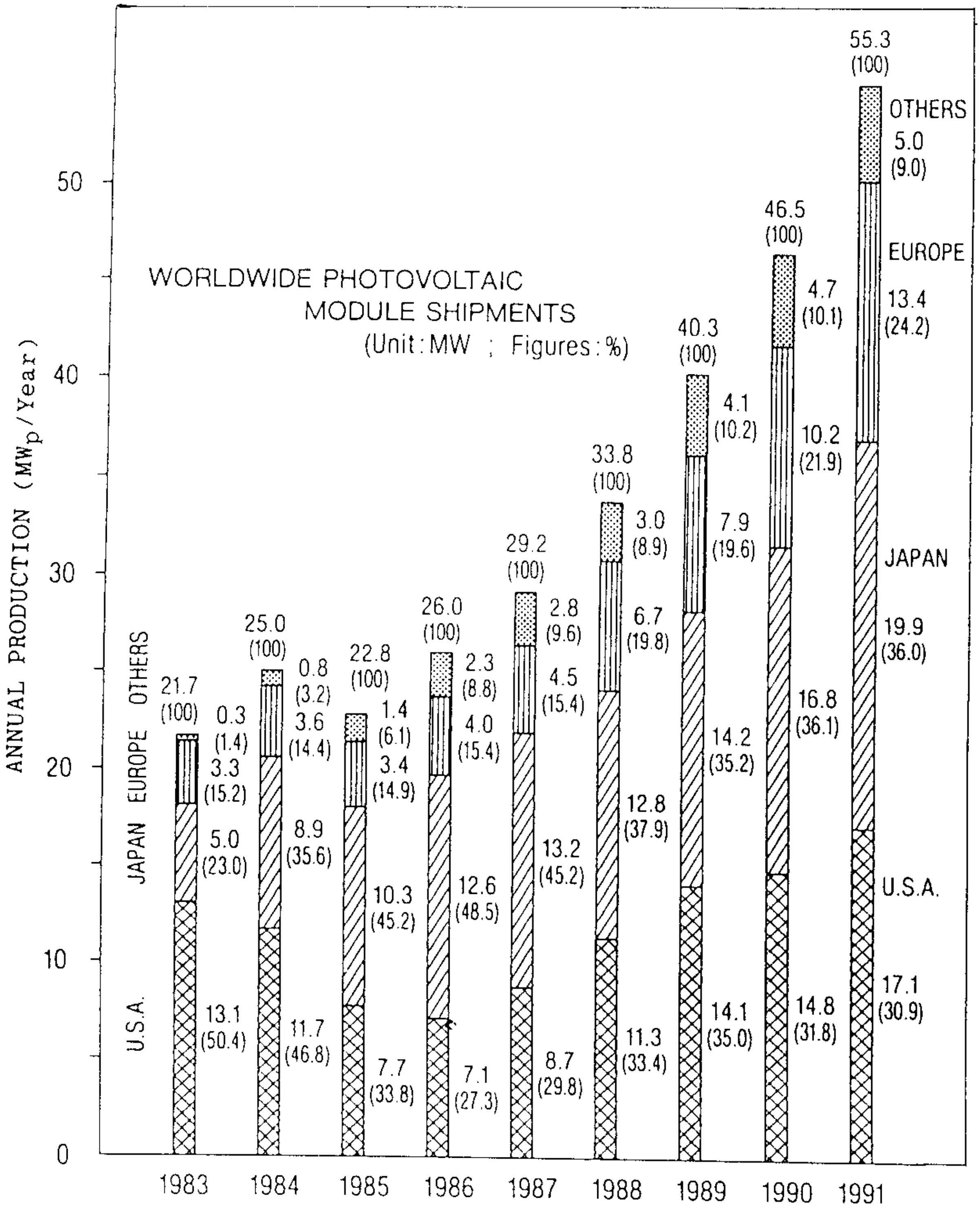

Fig.5. WORLDWIDE PHOTOVOLTAIC MODULE PRODUCTION

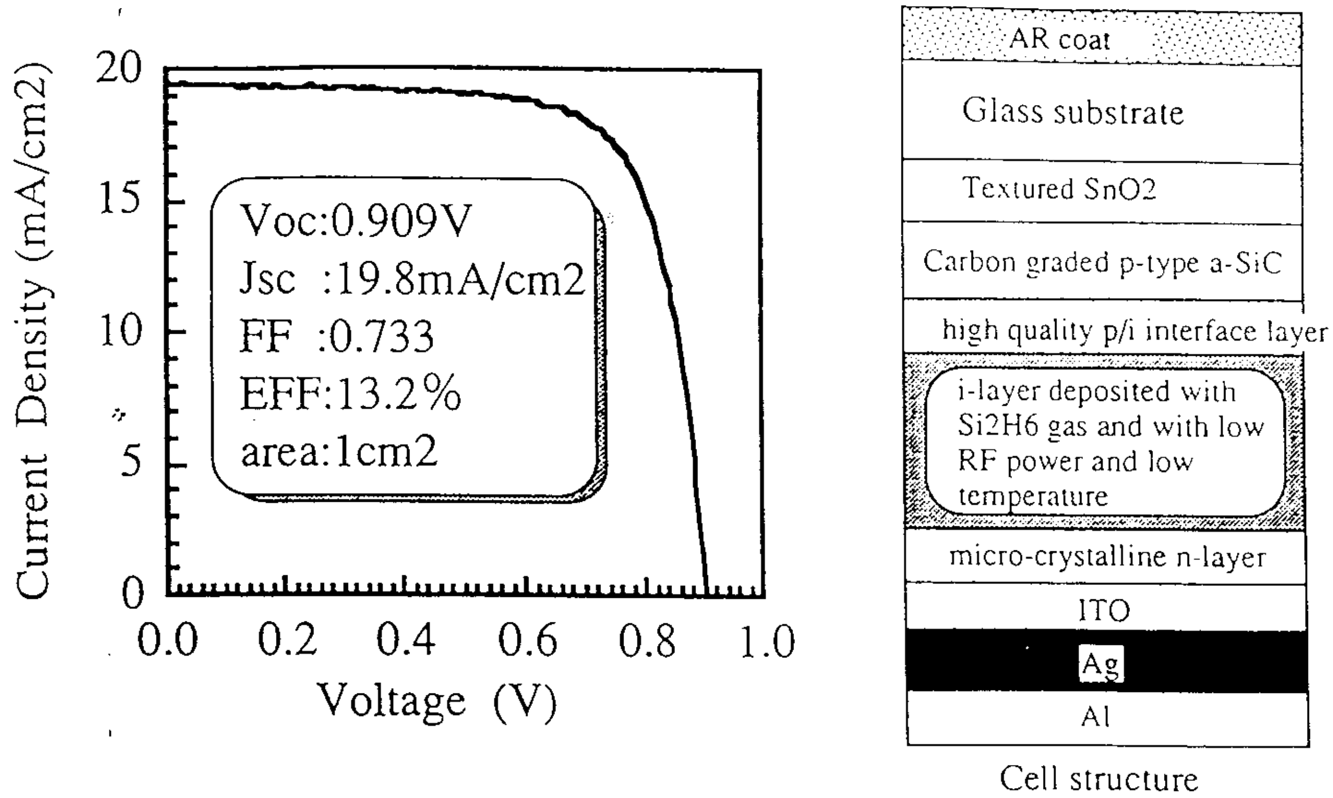

Fig.10. I-V characteristics of single junction pin type a-Si solar cell with highest conversion efficiency
(Mitsui Toatsu Chemicals, Inc.)

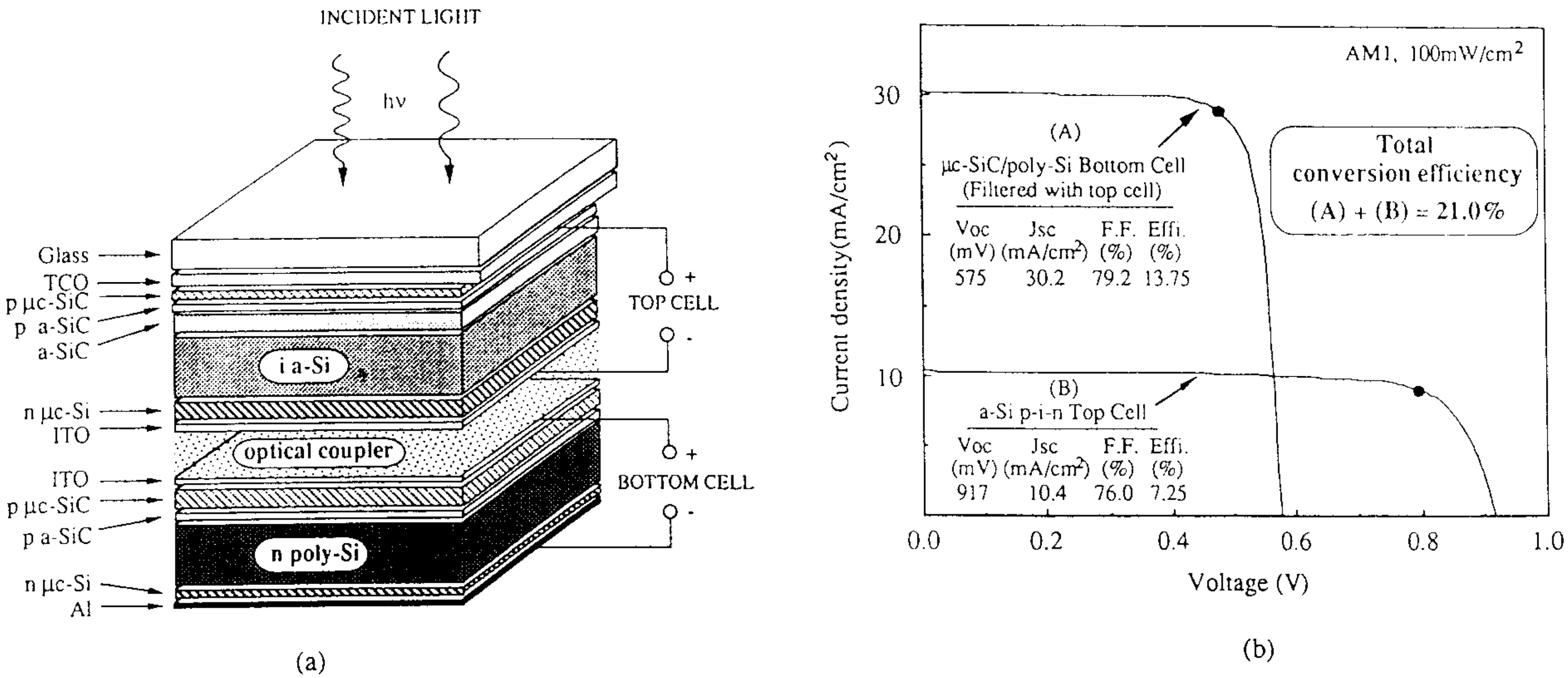

Fig.11 . Junction structure (a) and the output characteristics (b) of the a-Si // poly-Si four terminal tandem solar cell. (Osaka University)

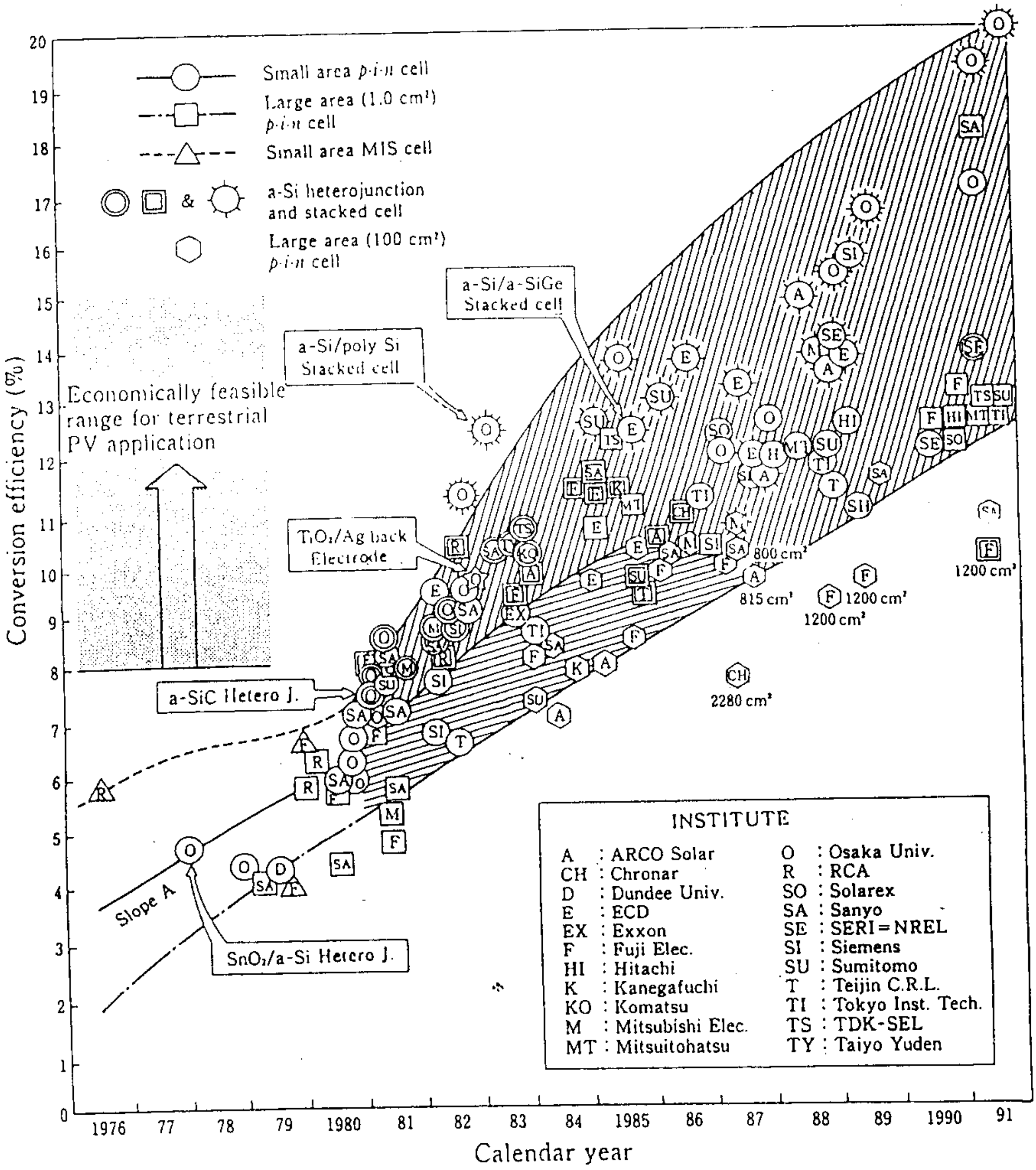

Fig.9. Progress of a-Si solar cell efficiencies for various types of junction structures as of August 1992. A steep slope change is seen with the appearance of a-Si alloys such as a-SiC, μc-Si, or a-SiGe

Table 5. Summary of the Recent Achievement of a-Si basis Solar Cell performance in Japan (As of April, 1993)

(a) a-Si Single Junction Solar Cells, R & D Phase

Voc (V)	Jsc (mA/cm^2)	F.F.	η (%)	A (cm^2)	Institute	Remarks	
0.967	17.7	0.703	12.0	0.033	Osaka U	p-μc-SiC (ECR)	['87]
0.857	18.7	0.749	12.0	1.0	Mitsui-T	multi-p layer	['90]
0.895	18.4	0.728	12.0	1.0	Hitachi	multi-p layer	['91]
0.89	18.3	0.74	12.0	1.0	Sumitomo		['90]
0.891	19.13	0.70	12.0	1.0	Solarex		['89]
0.927	18.4	0.705	12.0	1.0	Fuji-Elect	BF_3 Pulse CVD	['91]
0.90	18.9	0.72	12.3	0.09	TIT	δ-doped p layer	['90]
0.923	18.4	0.725	12.3	1.0	Fuji-Elect	Pulse CVD;p-a-SiC:H	
0.899	18.8	0.74	12.5	1.0	Fuji-Elect	p-a-SiO:H	['91]
0.885	19.13	0.747	12.65	1.0	SEL	Reverse Bias;Annealing	['91]
0.887	19.4	0.741	12.7	1.0	Sanyo	Superchamber	['92]
0.909	19.8	0.733	13.2	1.0	Mitsui-T	$(p\text{-}a\text{-}Si:H / p\text{-}a\text{-}C:H)_n$	['92]

(b) a-Si Solar Cells, Single Junction Submodule

Voc (V)	Jsc (mA/cm^2)	F.F.	η (%)	A (cm^2)	Institute	Remarks
12.53	130.1	0.735	12.0	10 x 10	Sanyo	TCO improvement
12.55	116.3	0.699	10.2	10 x 10	Sanyo	Superchmaber TMB
2.409	611.6	0.686	10.1	10 x 10	Mitsubishi	a-Si / a-Si / a-SiGe
53.9	328	0.714	10.05	30 x 40	Fuji-Elect	a-Si / a-Si, a-SiO p layer
39.41	426	0.67	9.3	30 x 40	Fuji-Elect	IVE
			10.0	10 x 10	Sanyo	Through Hole Contact Cell
			11.1	10 x 10	Sanyo	n / i interface H Treatment

(c) a-Si basis Stacked Junction Solar Cells

	Jumction Structure	Voc (V)	Jsc (mA/cm^2)	F.F. (%)	η (%)	Institute
	a-SiC / a-Si	1.75	8.16	71.2	10.2	Solarex
	a-Si / a-Si	1.80	9.03	74.1	12.0	Fuji
	a-SiC / a-SiGe / a-SiGe	2.20	7.90	68.0	11.8	Sharp
2 Terminal	a-Si / a-Si / a-SiGe	2.32	7.30	73.0	12.4	Sumitomo
	a-Si / a-Si / a-SiGe	2.55	7.66	70.1	13.7	ECD
	a-Si / poly-Si	1.33	15.6	64.0	13.3	Osaka Univ.
	a-Si / c-Si	1.48	16.2	63.0	15.0	Osaka Univ.
		0.871	16.4	72.0	10.3	
	a-Si // $CuInSe_2$	0.432	17.4	68.0	+ 5.3	ARCO
4 Terminal					15.6	
		0.917	10.4	76.0	7.25	
	a-Si // poly-Si	0.575	30.2	79.2	+ 13.75	Osaka Univ.
					21.0	