太陽光発電技術開発の現状と将来展望
ー2050年に向けて

"Present Status and Future Prospects of Photovoltaics
- Toward 2050"

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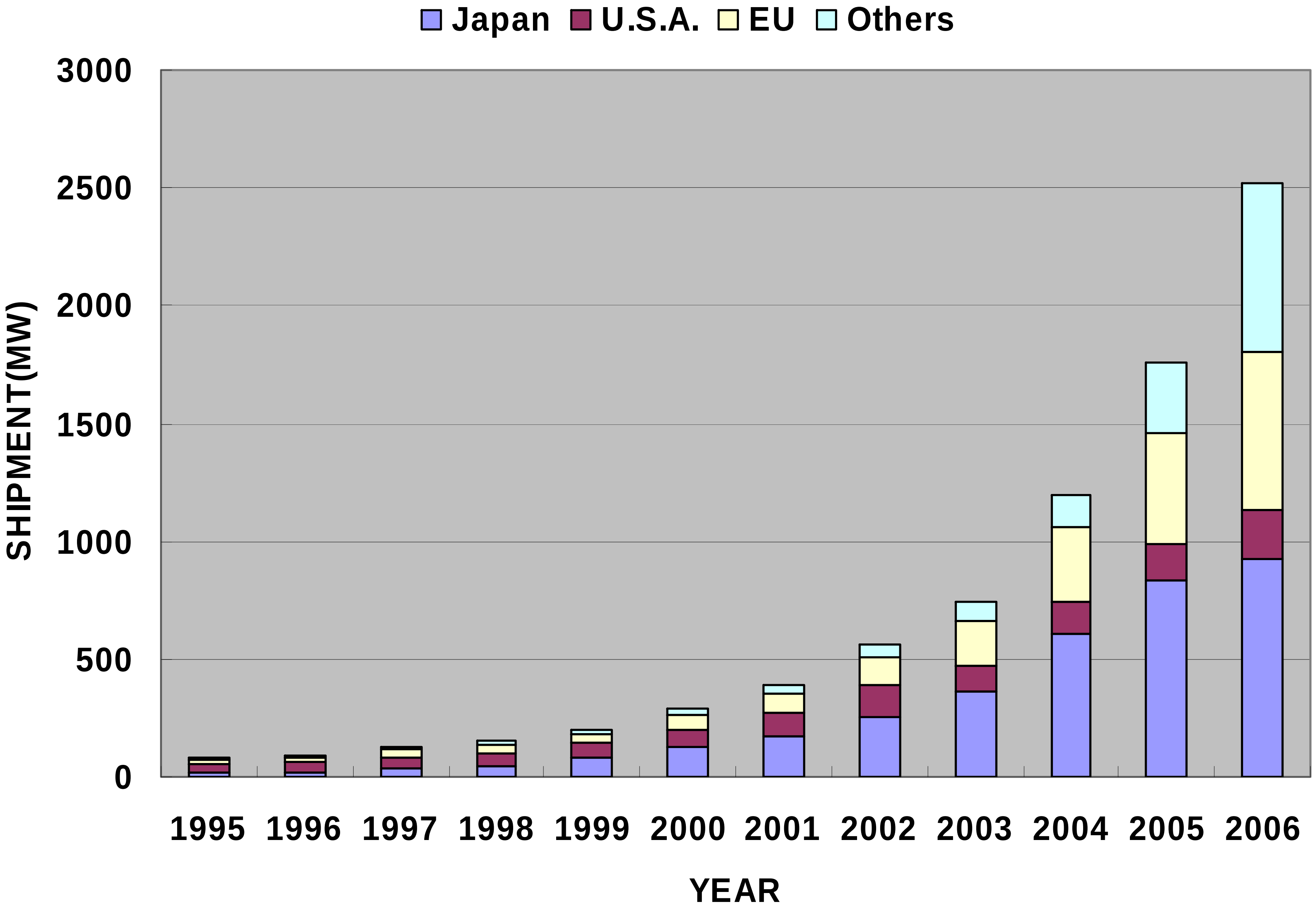
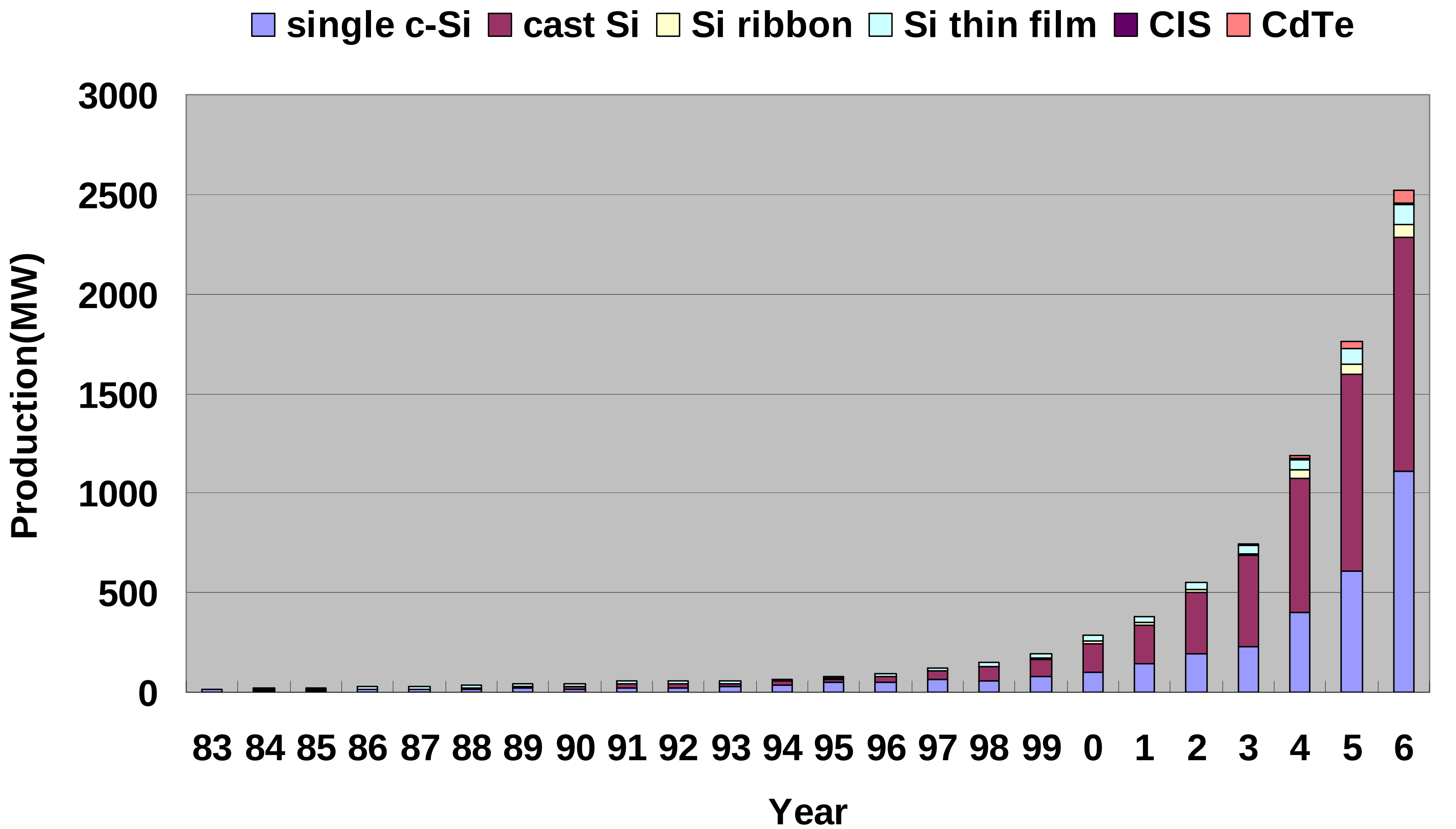
Department of Physical Electronics,
Tokyo Institute of Technology

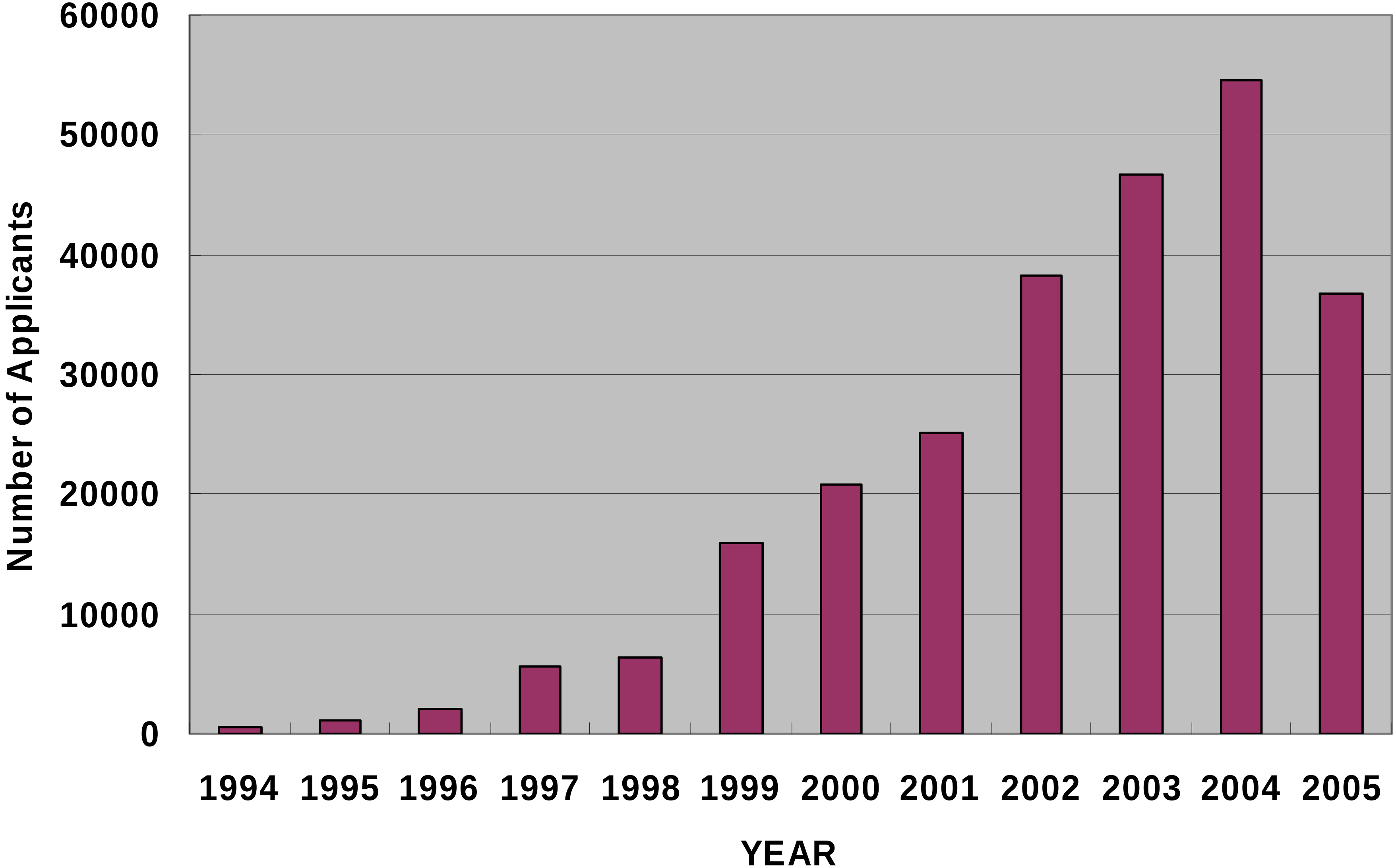
World Shipment of Solar Cells



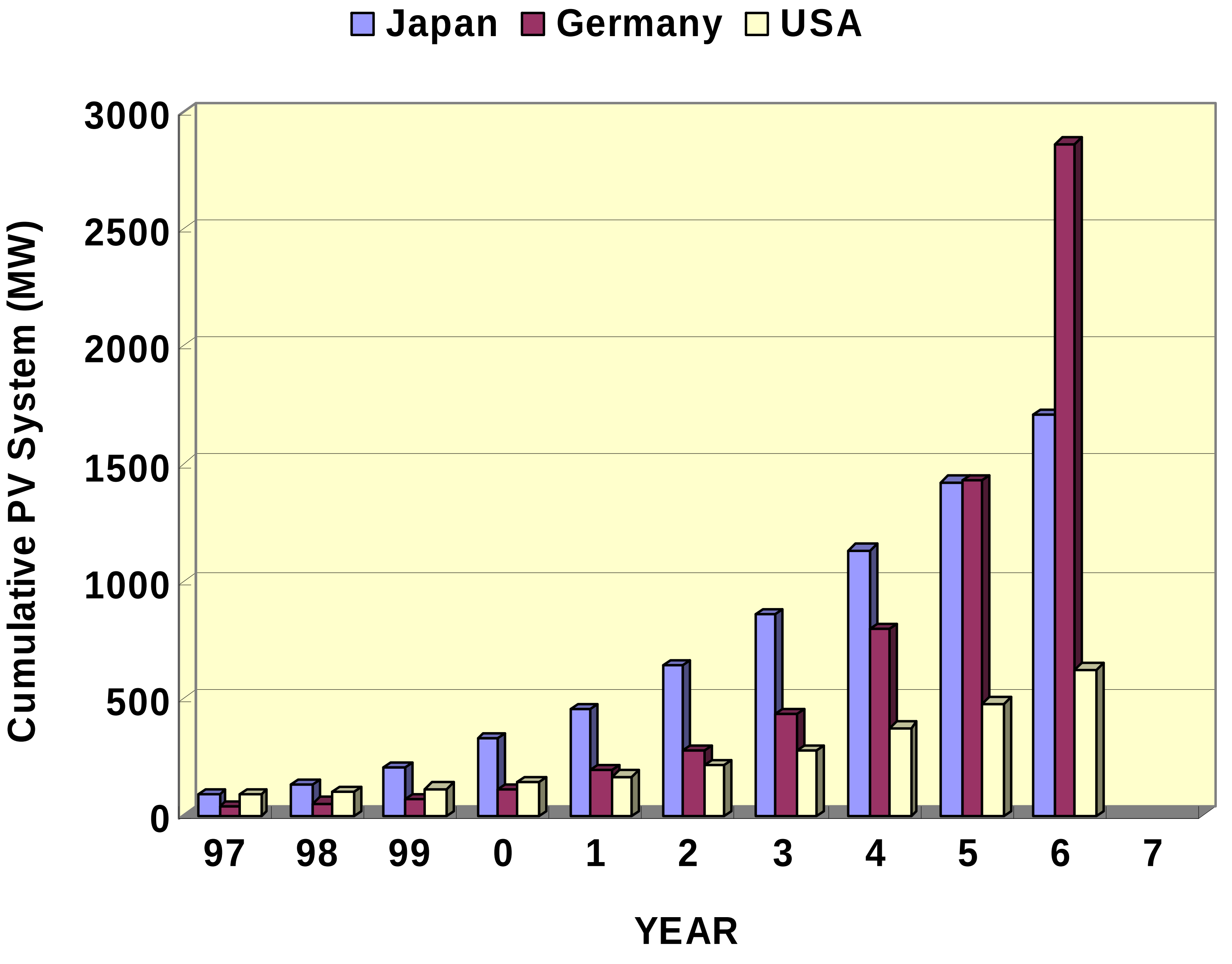
World Shipment of Solar Cells



Number of Applicants for Residential PV Subsidy Program



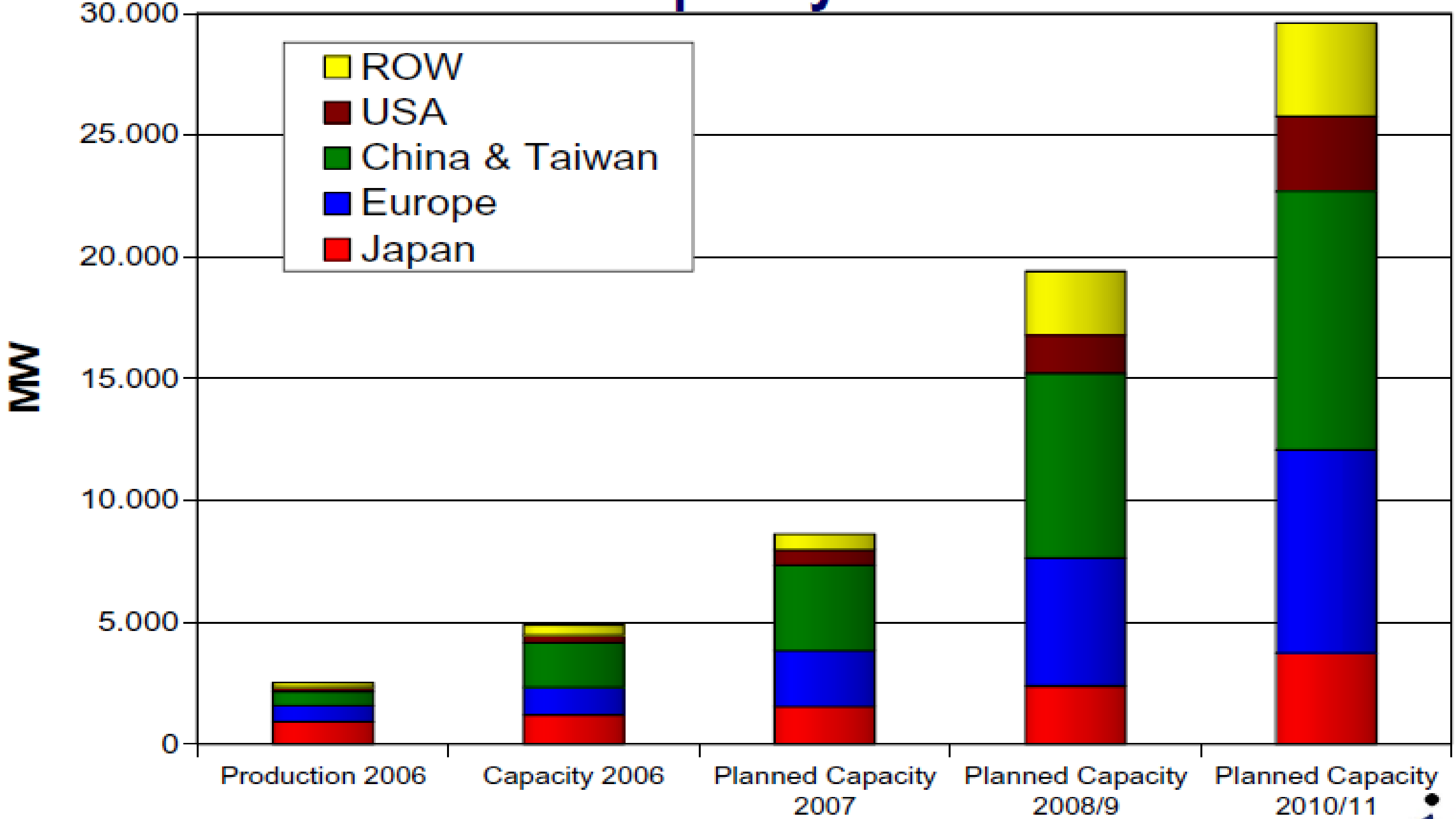
Cumulative PV System



EUROPEAN COMMISSION
DIRECTORATE-GENERAL
Joint Research Centre

Joint Research Centre

World-wide PV Production 2006 and Announced Capacity Increases



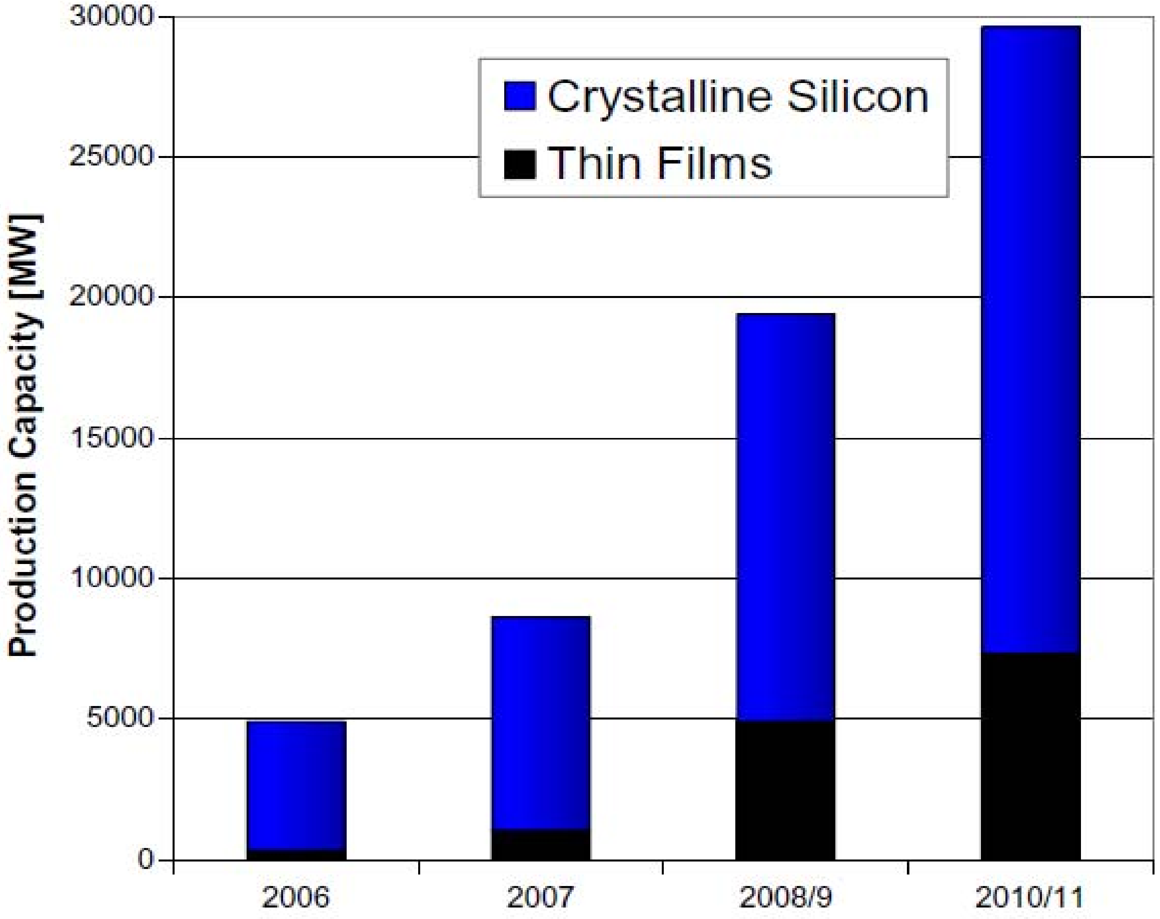
Production data: PV News

Renewable Energies

Institute for Energy

Joint Research Centre

Announced Capacity Increases



Renewable Energies

Institute for Energy

EUROPEAN COMMISSION
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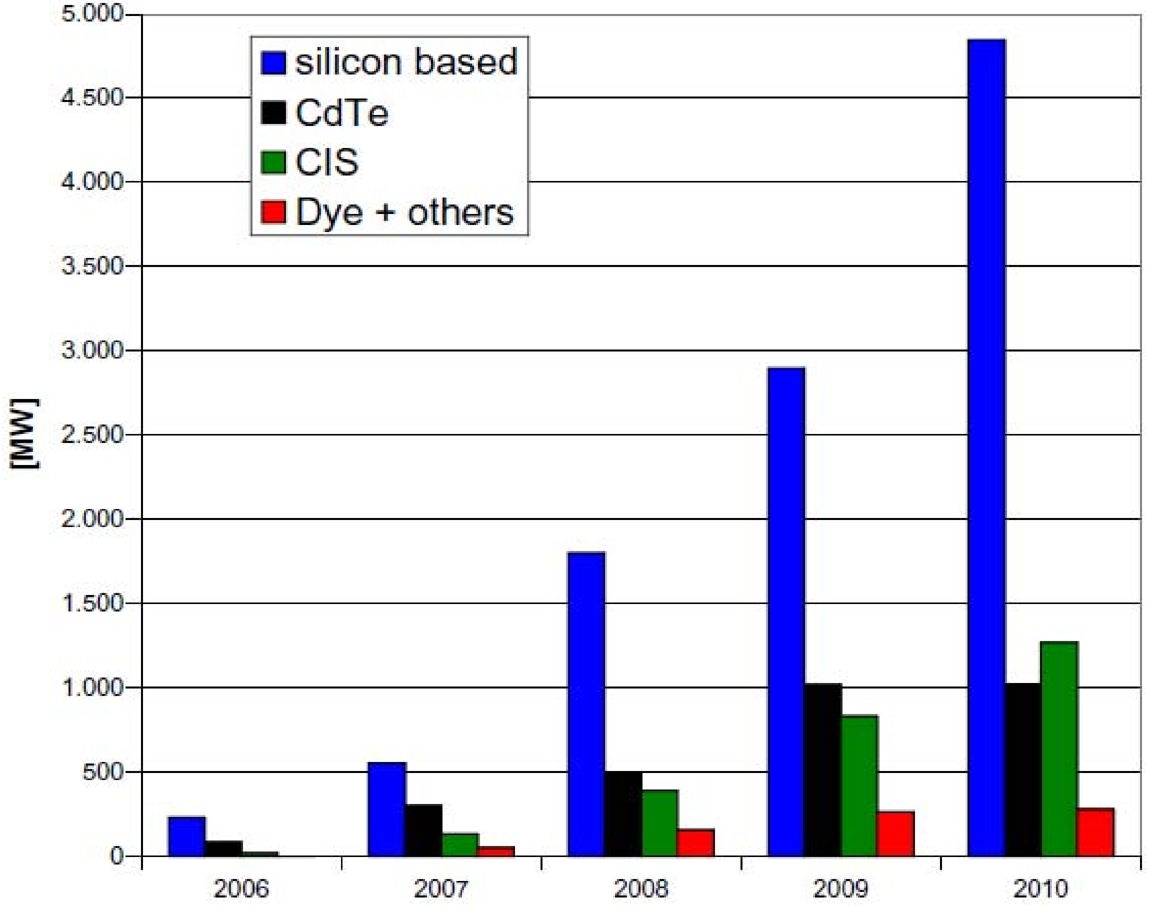
Announced Production Capacities by Technology



Joint Research Centre

Renewable Energies

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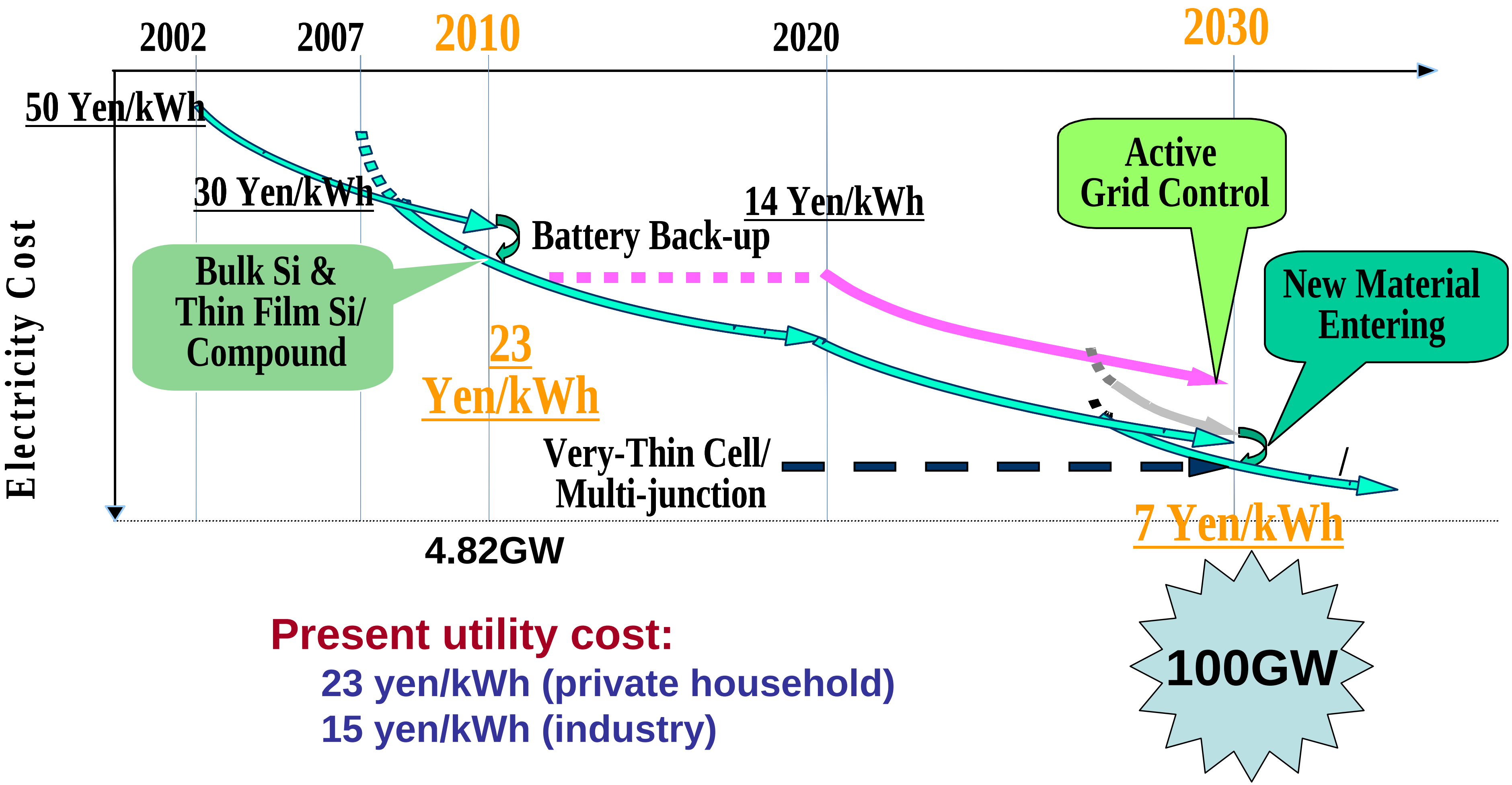
Japanese PV Roadmap until 2030



Present utility cost:

23 yen/kWh (private household)

15 yen/kWh (industry)

Electricity generation cost:

5-6 yen/kWh (Nuclear)

9 yen/kWh (hydro)

1US$= 120 JPY

Japanese PV Roadmap until 2030 (NEDO)

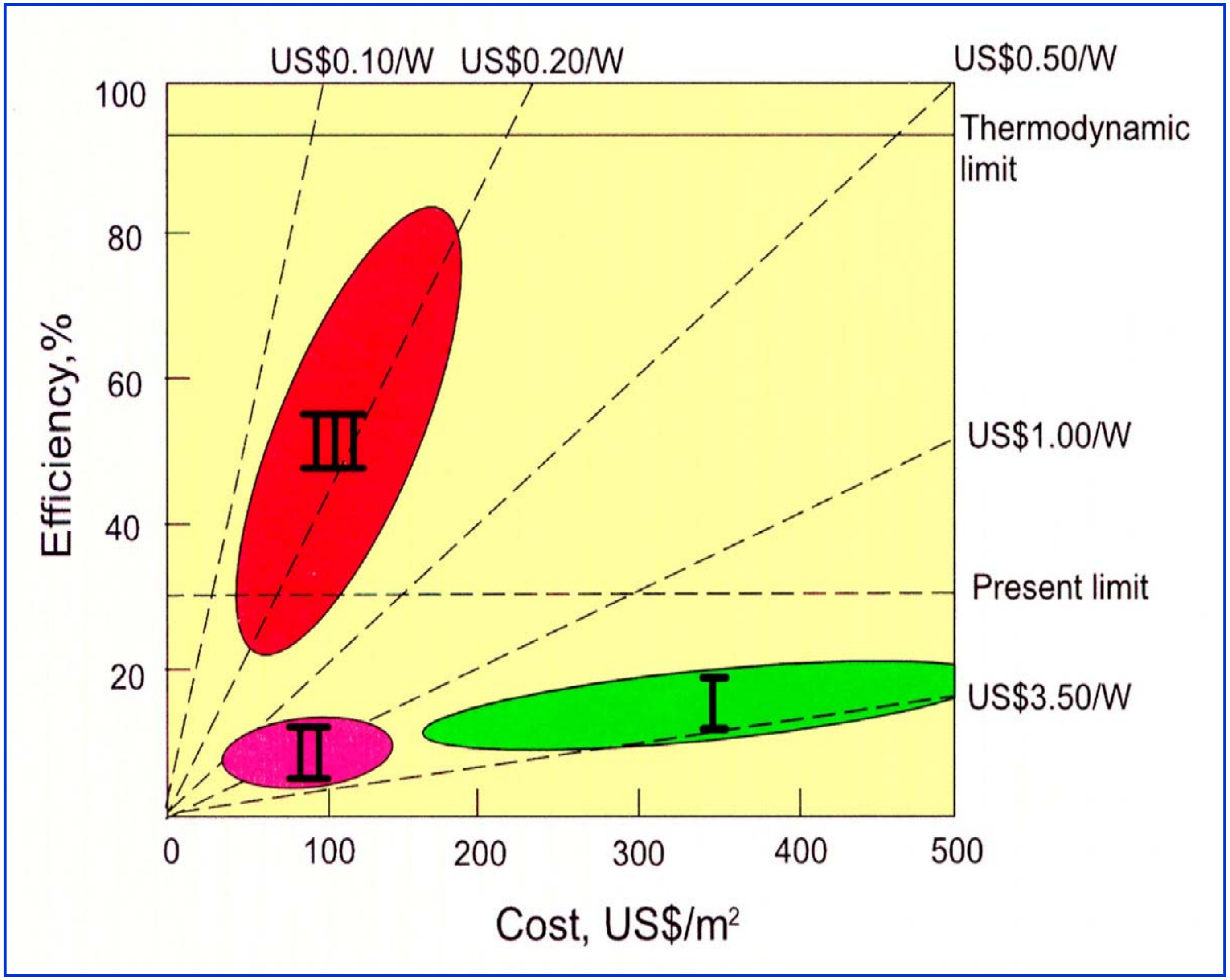
Item	Target (Target Year)
Module Cost Reduction	100 yen/W (2010),75 yen/W(2020) <50 yen/W(2030)
Module Durability	30 Year Life (2020)
Stable Material Supply	Unit Si Consumption:1g/W (2030)
Inverter Cost	15,000 yen/kW (2020)
Storage Battery	10 yen/Wh (2020)

Module efficiency target(%) (production level) (Cell efficiency)

Cell Type	2010	2020	2030
Thin-Bulk Multi-c-Si	16(20)	19(25)	22(25)
Thin-Film Si	12(15)	14(18)	18(20)
CIS Type	13(19)	18(25)	22(25)
Super-High η	28(40)	35(45)	40(50)
Dye-sensitized	6(10)	10(15)	15(18)

Cost/Efficiency of Photovoltaic Technology

Prof.M.Green, "the third generation PV"

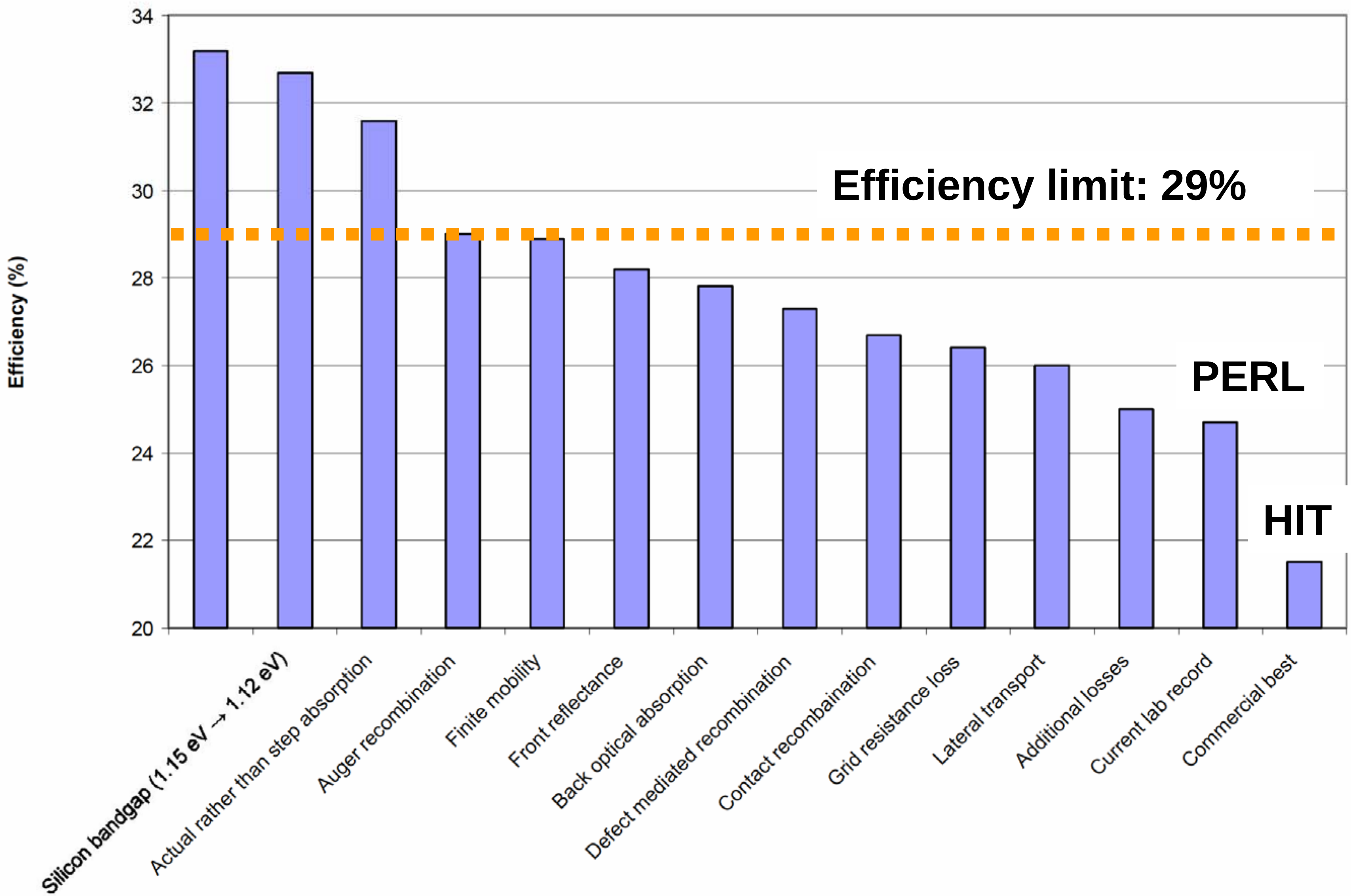


Confirmed terrestrial cell and submodule efficiencies measured under the global AM1.5 spectrum(1000W/m²) at 25ºC (Progress in Photovoltaics)

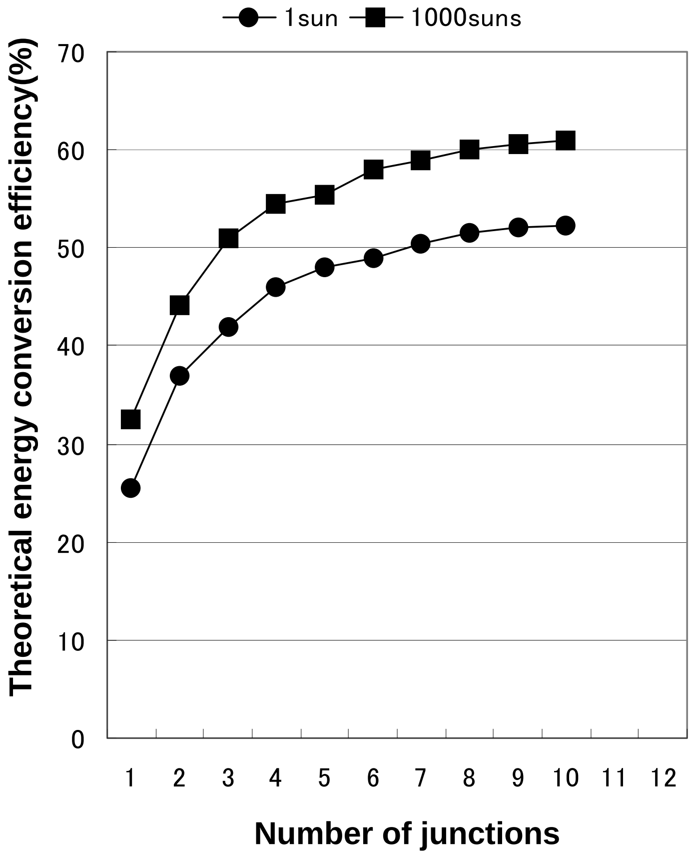
Classification	Effic. (%)	Area (cm^2)	Voc (V)	Jsc (mA/cm^2)	FF (%)	Test Center (and date)	Description
Si(crystalline)	24.7±0.5	4.00(da)	0.706	42.2	82.8	Sandia(3/99)	UNSW PERL
Si(multicrystalline)	20.3±0.5	1.002(ap)	0.664	37.7	80.9	NREL(5/04)	FhG-ISE
Si(thin-film transfer)	16.6±0.4	4.017(ap)	0.645	32.8	78.2	FhG-ISE(7/01)	U.Stuttgart (45μm thick)
Si(thin-film submodule)	9.4±0.3	94.9(ap)	0.493	26/0	73.1	Sandia(4/06)	CSG Solar (1-2μm on glass)
GaAs(crystalline)	25.1±0.8	3.91(t)	1.022	28.2	87.1	NREL(3/90)	Kopin, AlGaAs window
GaAs(thin film)	24.5±0.5	1.002(t)	1.029	28.8	82.5	FhG-ISE(5/05)	Radboud U.,NL
GaAs(multicrystalline)	18.2±0.5	4.011(t)	0.994	23.0	79.7	NREL(11/95)	RTI,Ge substrate
InP(crystalline)	21.9±0.7	4.02(t)	0.878	29.3	85.4	NREL(4/90)	Spire,epitaxial
CIGS(cell)	18.4±0.5	1.04(t)	0.669	35.7	77.0	NREL(2/01)	NREL,CIGS on glass
CIGS(submodule)	16.6±0.4	16.0(ap)	2.643	8.35	75.1	FhG-ISE(3/00)	U.Uppsala, 4 serial cells
CdTe(cell)	16.5±0.5	1.132(ap)	0.845	26.7	75.5	NREL(9/01)	NREL, mesa on glass
Si(amorphous)	9.5±0.3	1.070(ap)	0.859	17.5	63.0	NREL(4/03)	U.Neuchatel
Si(nanocrystalline)	10.1±0.2	1.199(ap)	0.539	24.4	76.6	JQA(12/97)	Kaneka (2μm on glass)
Dye sensitized	10.4±0.3	1.004(ap)	0.729	21.8	65.2	AIST(8/05)	Sharp
Dyesensitized(submodule)	6.3±0.2	26.5(ap)	6.145	1.70	60.4	AIST(8/05)	Sharp
Organic polymer	3.0±0.1	1.001(ap)	0.538	9.68	52.4	ASIT(3/06)	Sharp,fullerene derivative
GaInP/GaAs	30.3	4.0(t)	2.488	14.22	85.6	JQA(4/96)	Japan Energy
GaInP/GaAs/Ge	32.0±1.5	3.989(t)	2.622	14.37	85.0	NREL(1/03)	Spectrolab(monolithic)
GaAs/CIS(thin film)	25.8±1.3	4.00(t)				NREL(11/89)	Kopin/Boeing
a-Si/CIGS(thin film)	14.6±0.7	2.40(ap)				NREL(6/88)	ARCO
a-Si/μc-Si (thin submodule)	11.7±0.4	14.23(ap)	5.462	2.99	71.3	AIST(9/04)	Kaneka(thin film)

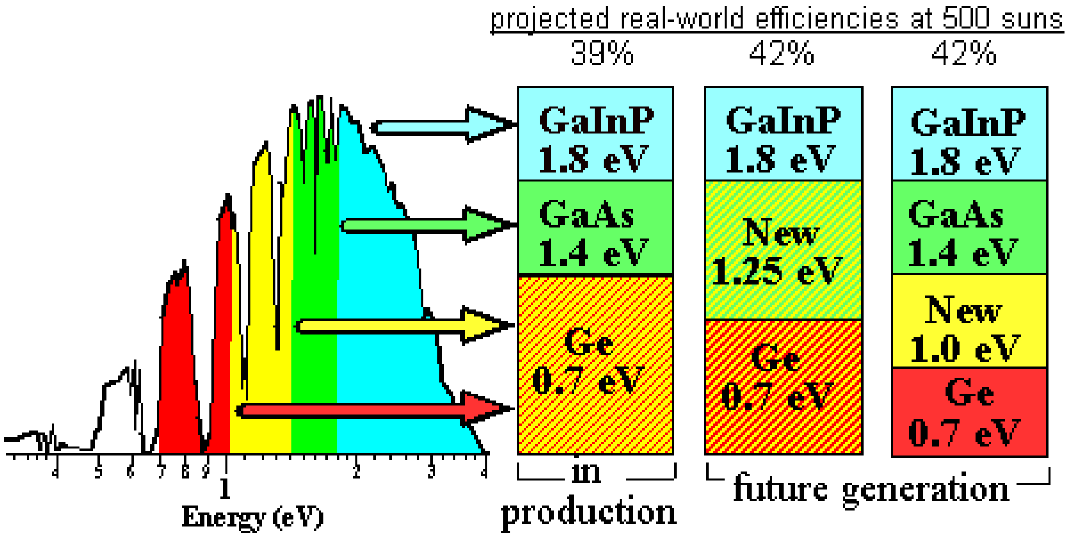
Approaching the 29% limit efficiency of Silicon solar cells

R.M.Swanson, SunPower Corporation



How to improve energy conversion efficiencies - I. multijunction





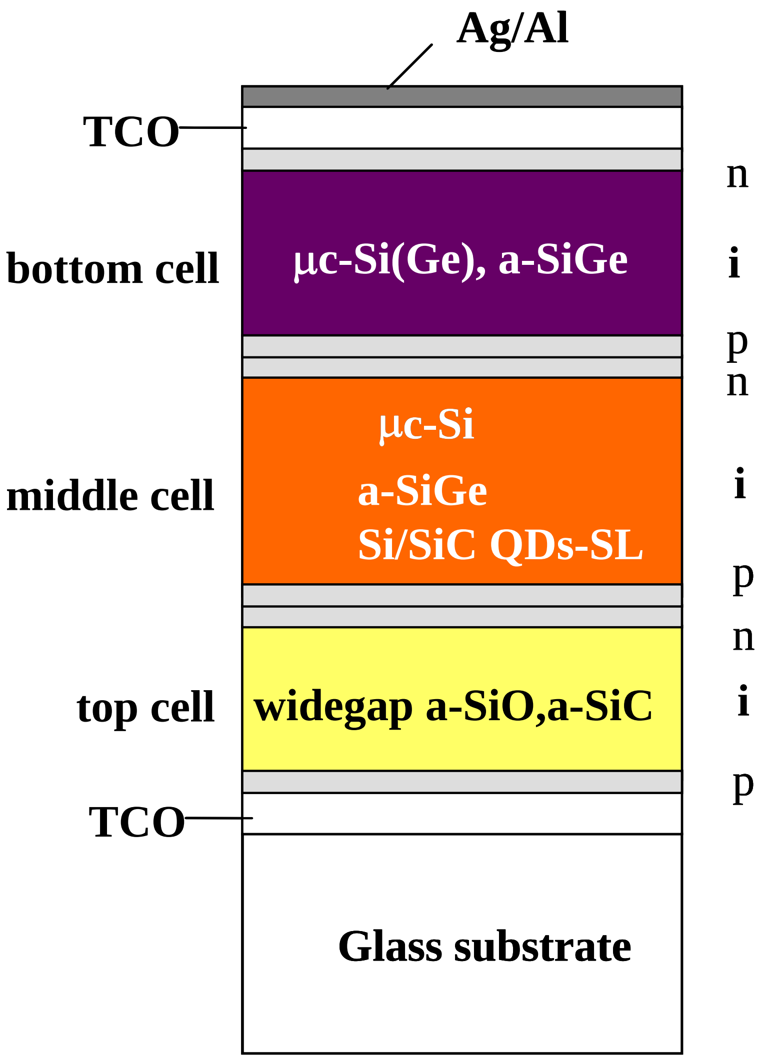
GaInP/GaInAs/Ge triple-junction solar cells:

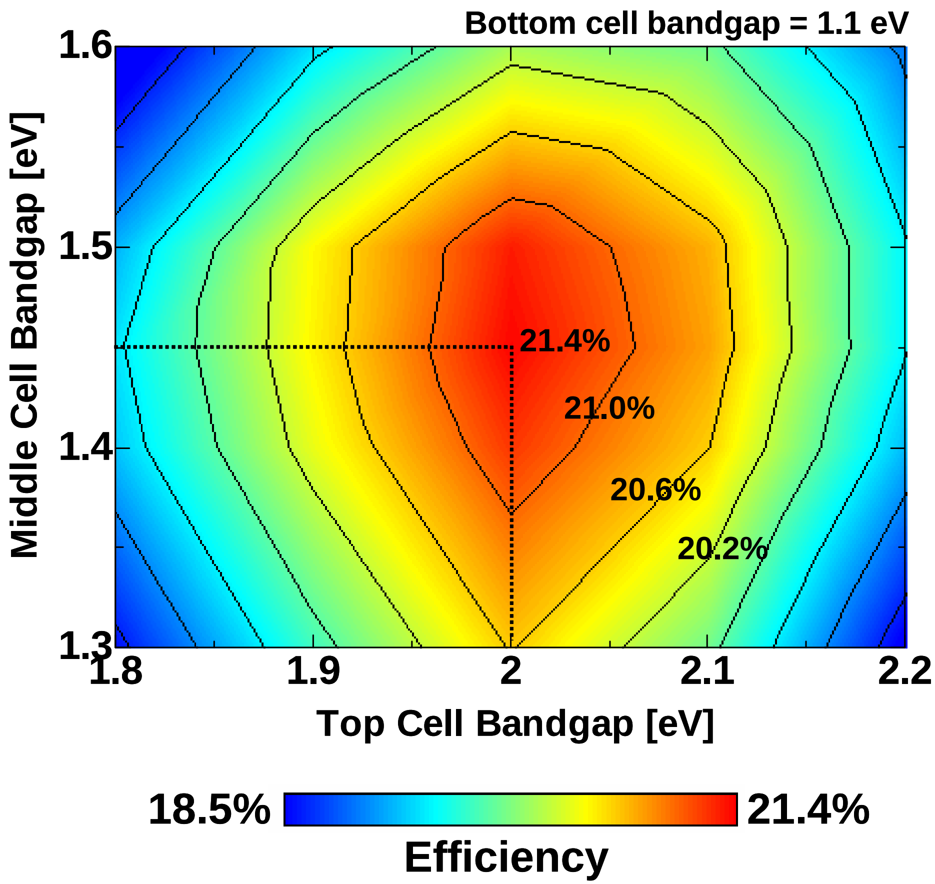
An efficiency of 40.7% for 240 suns has been demonstrated by Spectrolab.

A.Bennett and L.C.Olsen,

13th IEEE PVSC, Washington,D.C.,(1978) 868

Theoretical Analysis of Triple-Junction Thin-Film Solar Cells

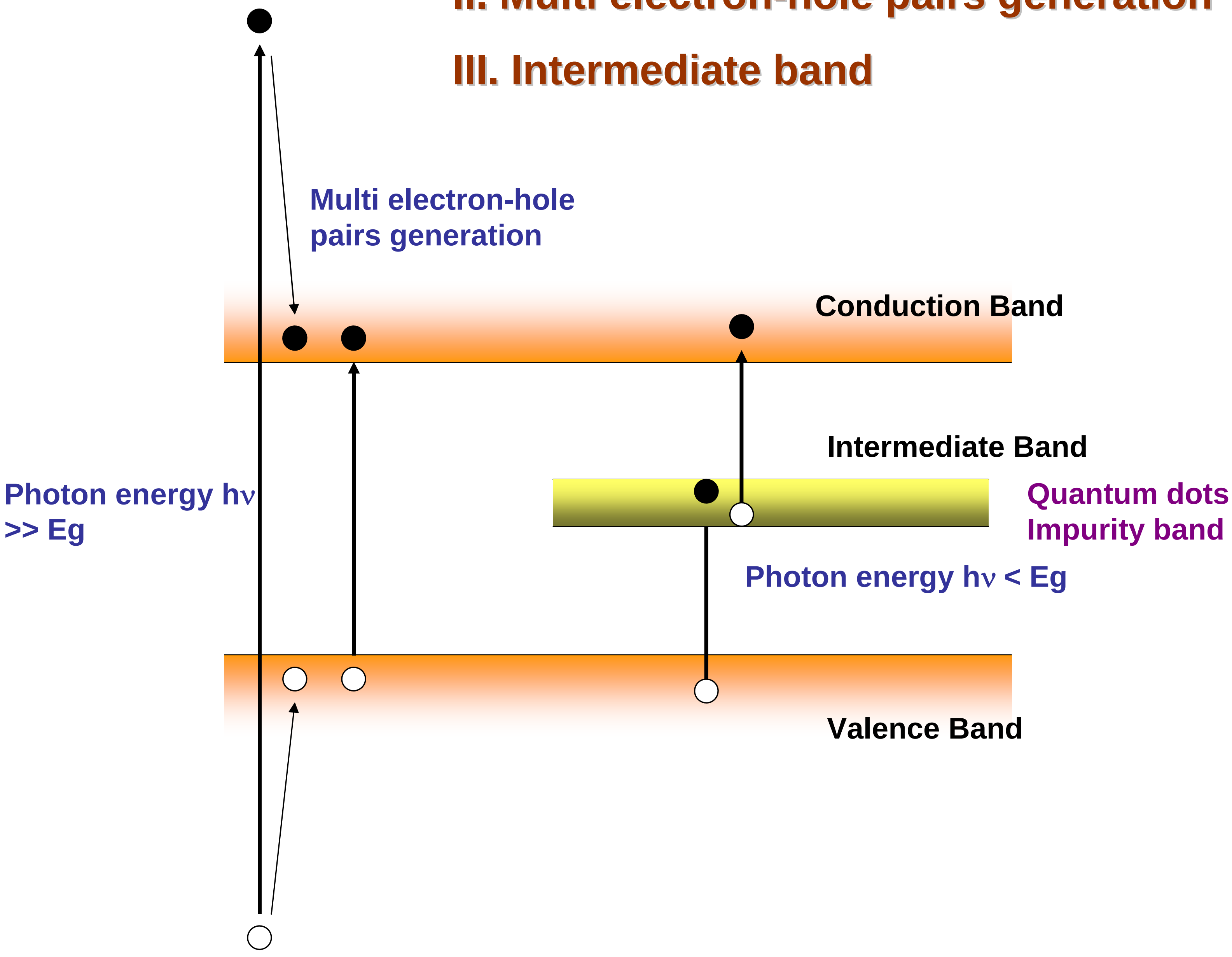




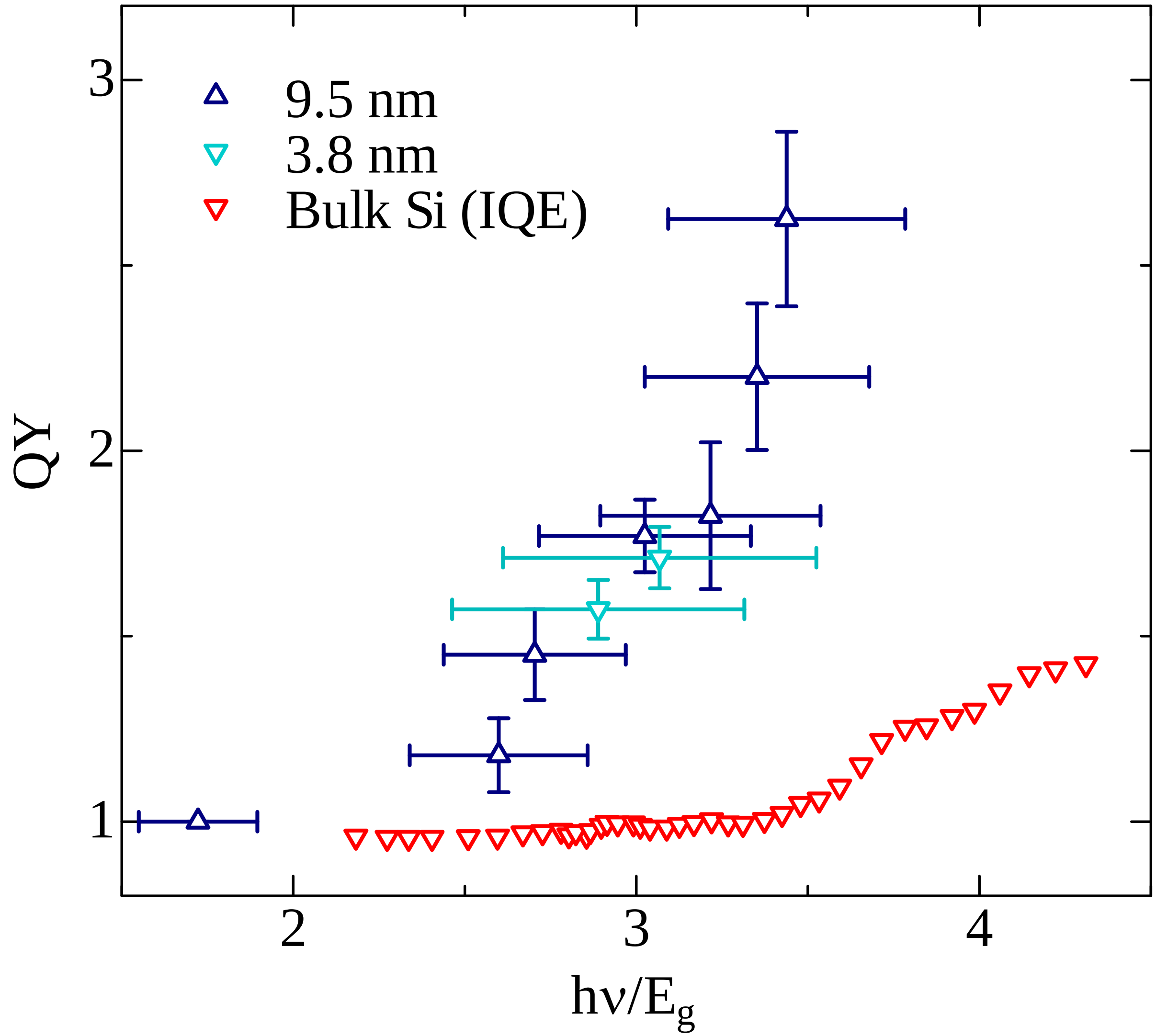
How to improve energy conversion efficiencies

II. Multi electron-hole pairs generation

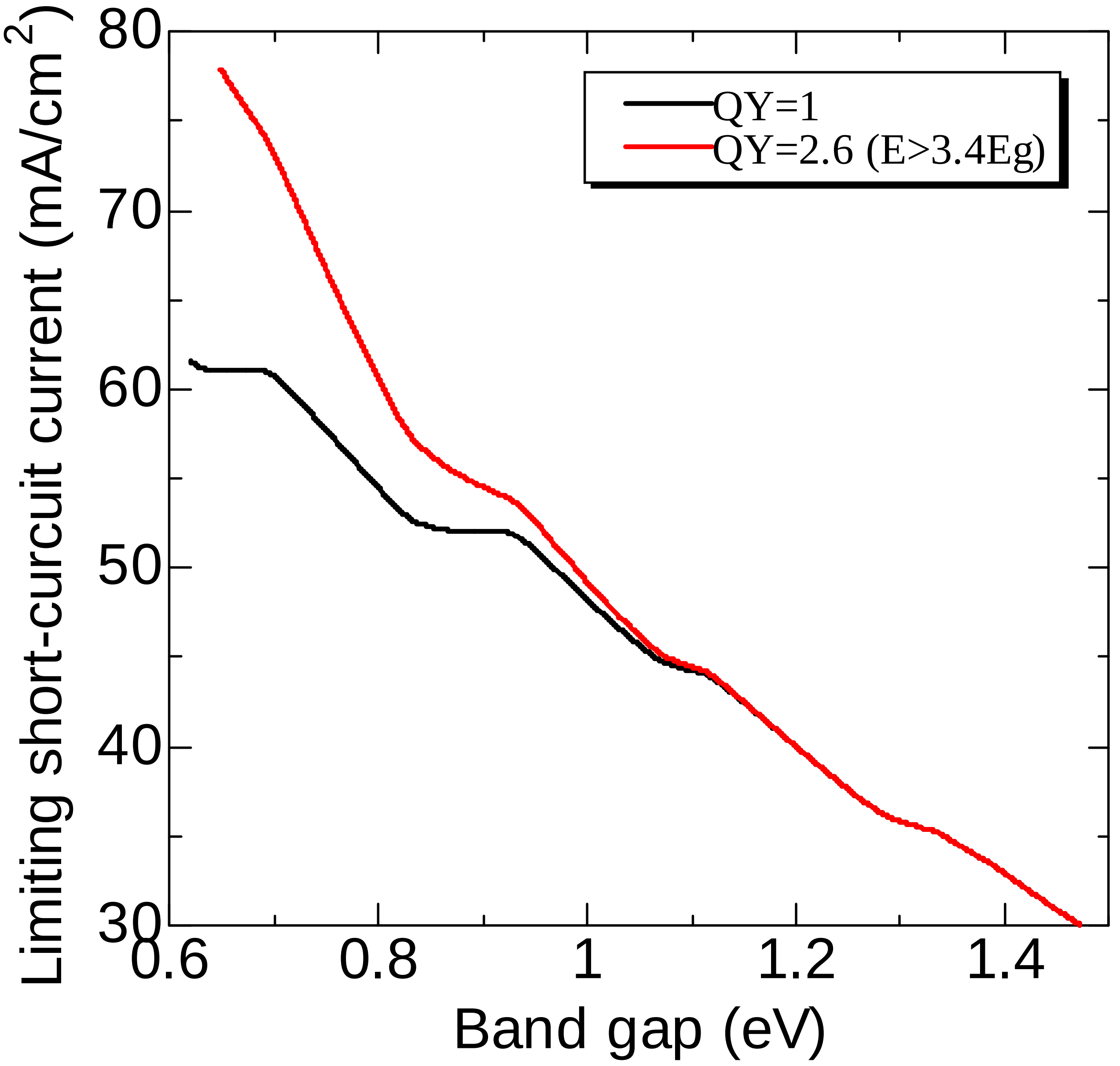
III. Intermediate band



Demonstration of multi-exciton generation

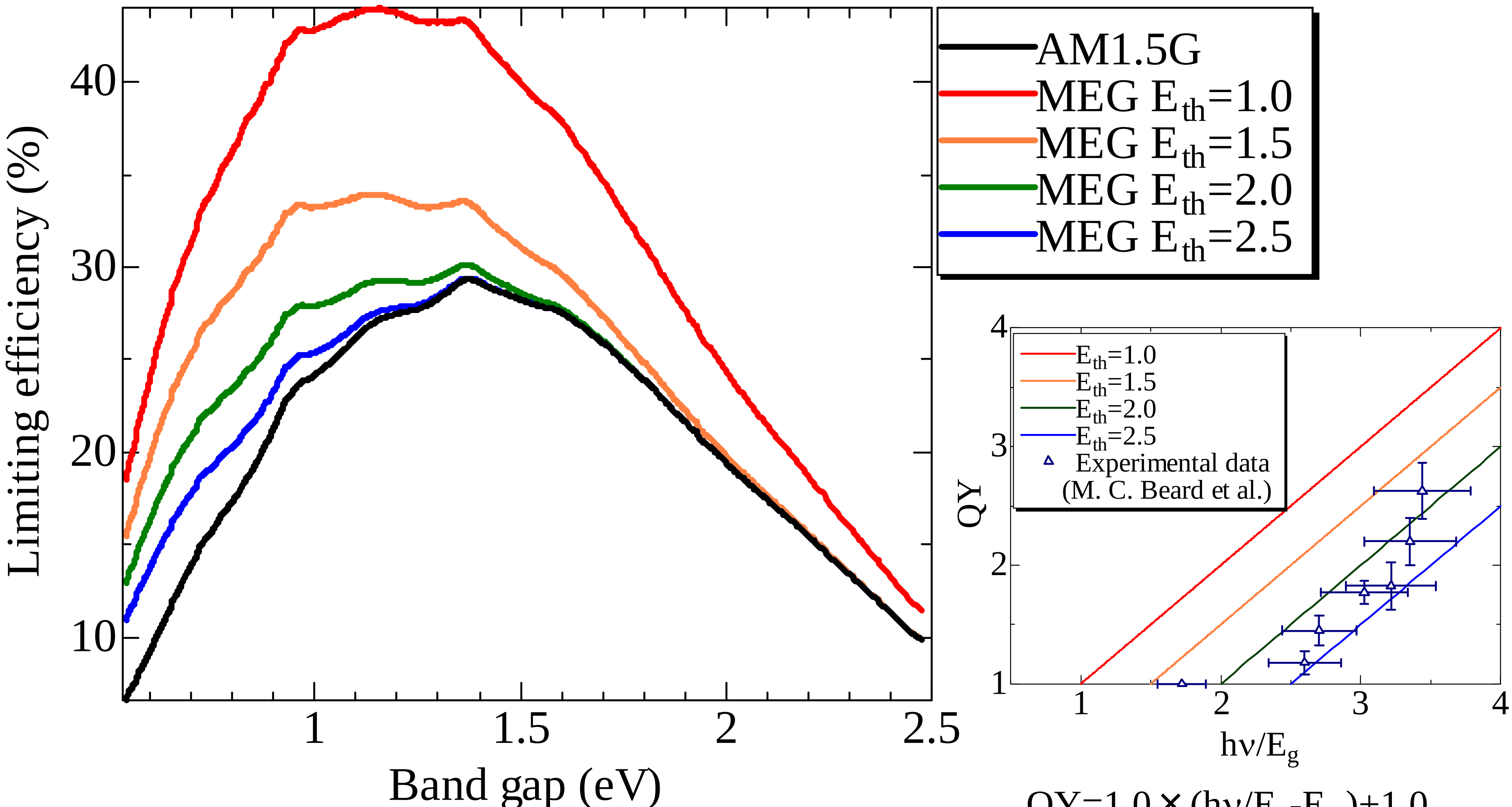


M. C. Beard, K. P. Knutsen, P. Yu, J. M. Luther, Q. Song, W. K. Metzger, R. J. Ellingson, and A. J. Nozik: Nano Letters 7 (2007) 2506.



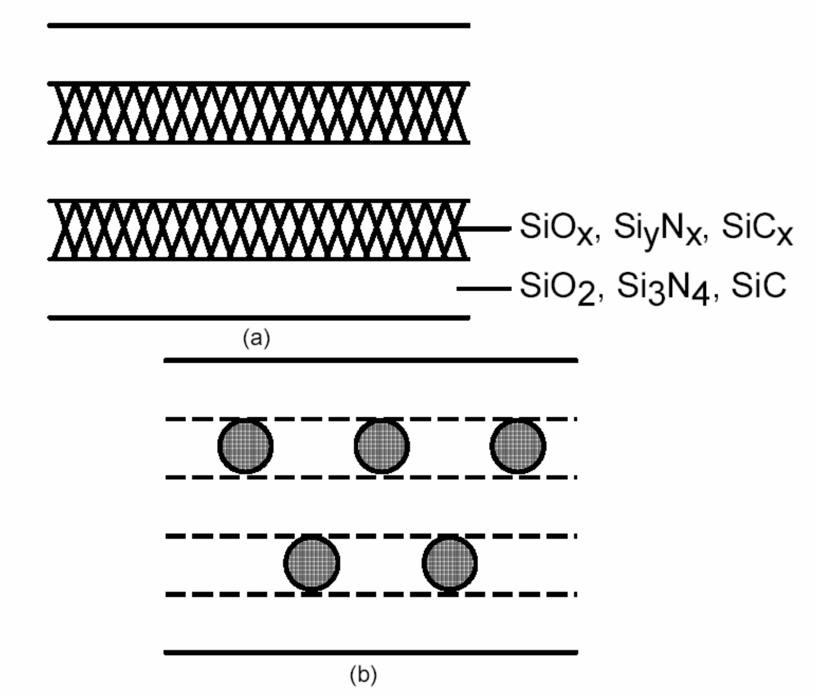
Limiting short-curcuit current (mA/cm^2)
80
70
60
50
40
30
0.6
0.8
1
1.2
1.4
Band gap (eV)
QY=1
QY=2.6 (E>3.4Eg)

Theoretical limit of energy conversion efficiencies of single-junction solar cells based on multi-exciton generation

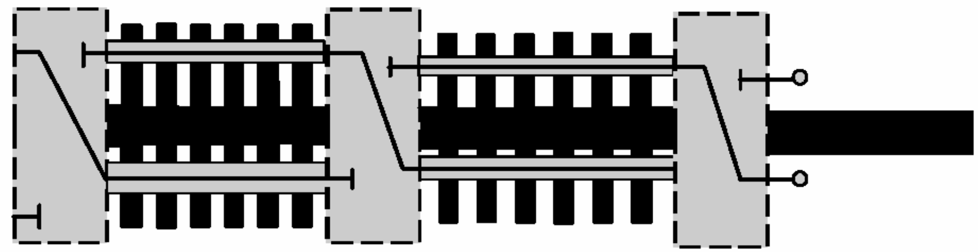


$$QY = 1.0 \times (h\nu/E_g - E_{th}) + 1.0$$

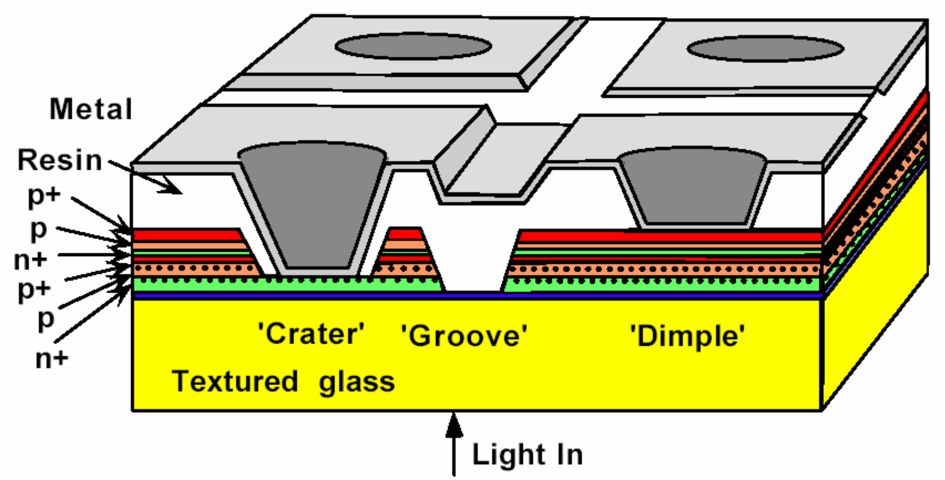
THIRD GENERATION PHOTOVOLTAICS (Prof.M.Green)



(a) Deposition of stoichiometric regions separated by silicon-rich regions; (b) segregation into spherical silicon quantum dots on heating.

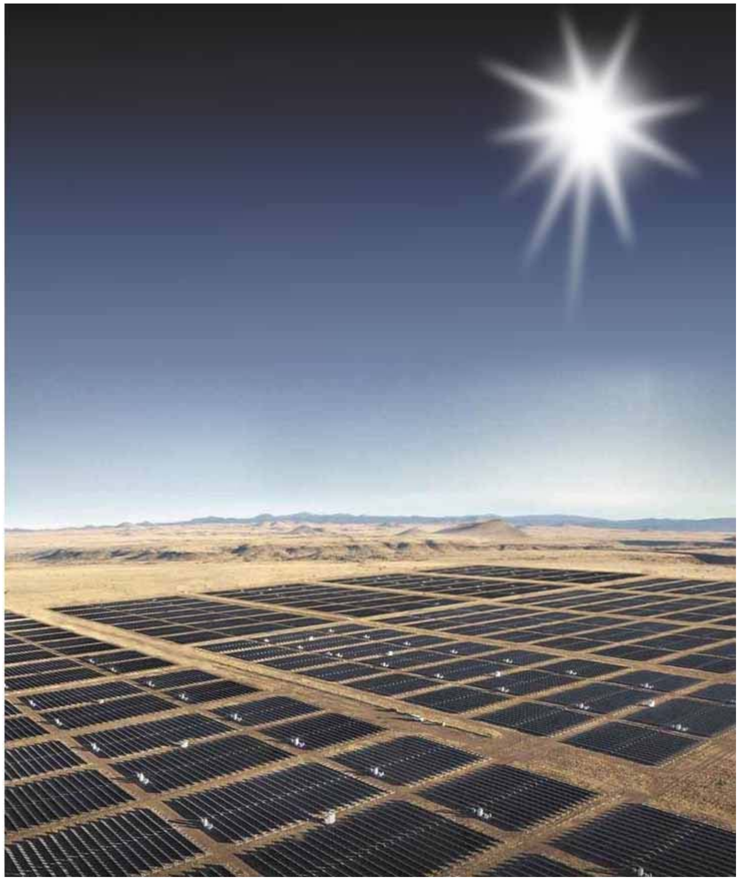


All-Silicon Quantum Dot Superlattice Tandem Cell (SQOT).



CSG 2-cell SWOT interconnection scheme.

Additional proposal:
Nano-Based Solar Energy Materials and Solar Cells for Low Latitudes Application



Photovoltaic system in low latitudes
(by courtesy of Prof.Kurokawa)

In Japan, photovoltaic systems with a capacity of 100 GW will be installed by 2030. This number is equal to a 1 kW solar power generation per one citizen.

Let us consider that solar cells with a cumulative capacity of 1 kW will be needed for one people in the world on average. According to an estimation of United Nations (UN), the world population will be about 9.3 billion in 2050. Simply saying that the world population in 2050 will be 10 billion, then solar cells with a capacity of 10 billion kW (10 TW) will be required.

Where should we install these 10 TW photovoltaic systems? In general, the PV systems should be installed close to the users. Based on the prediction of the UN, from these 10 billion world population, 5.4 billion of them are the Asian population. Hence, most of the PV systems will be installed in the Asia region, particularly in the low latitudes region.

The development of solar energy materials for applications in the low latitudes region, the research on physics and optimum design of solar cells, the demonstration and fabrication of solar cells, as well as the research on PV system applications, will be required.