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The Third Generation of Solar Photovoltaic Electricity

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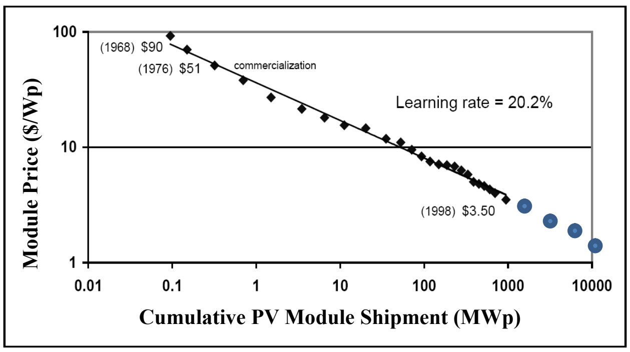
1. Introduction

According to the report of OECD/IEA World Energy Outlook 2007, the demand of world energy in 2030 is predicted to reach 17,721 Mt (oil), which is 1.55 times larger than that of 2005.[1)] The indiscriminate use of fossil fuel has introduced a significant risk of global warming, threatening human existence. The financial crisis has damaged the world economy badly since Oct. 2008 and new efforts to re-stimulate industry are now globally performed. Electrical energy efficiency (EEE) is important not only for saving energy but also to vary the system for the future. Given the recent financial turmoil, it is a good time to consider the shift from conventional energy supply chain to the new solutions in OECD countries and developing countries. Such innovation is gaining popularity throughout the world and is growing rapidly than previously expected.

Among renewable energy technologies, Photovoltaic (PV) electricity is expected to be one of promising candidates, not only in developing countries but in developed countries, like Germany, Japan, Spain, and US. PV has been dramatically widespread by various dissemination ways, like feed-in tariff, tax credit and governmental aid. The total installation exceeds 10 GW in the world. [2)] Japanese government shows the plan of introduction of PV of 28GW by 2020 following the G8 endorsement. Although the PV system cost has been falling down following Moore's law as shown in Fig.1, its cost has been still in higher level than those of conventional energy technology. It should be noted that map of production has changed drastically, Germany China and Taiwan Manufactures have increased the share in the shipment.



The price might drop more rapidly after the financial crisis.

Fig.1 Module Price vs. Cumulative PV Shipment.

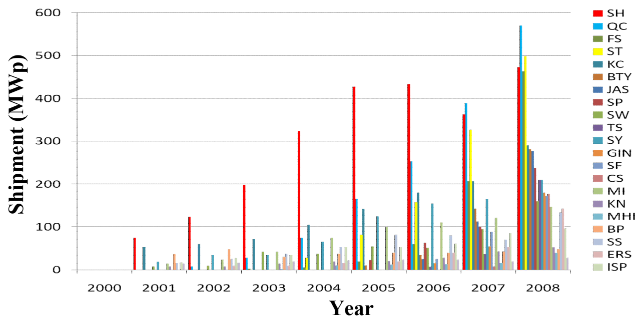


Fig.2 PV cell and Module shipments by manufacture

2. Device Architecture and Materials

Crystalline silicon technology, as the 1st generation architecture, has been still dominant. The issues of long-term supply of low-cost silicon wafer needs to be secured. There are some proposals of metallurgical silicon productions in Japan, Europe, Canada and China. Author has proposed idea of new silicon to realize mass production and cheaper cost. Step by step efforts have been continued in crystal growth and slicing techniques. Yamatsugu et al have exhibited CDS for new method of silicon wafer.[3)4)] The significant improvements have been seen in cell conversion efficiency by Sanyo, Kyocera and Mitsubishi Electric Co.in PV Japan exhibition. Soldering technique for cell-assembly needs to be noted as critical for improving its reliability.

It should be noted is that various thin film technology such as a-Si,CdS/CdTe, CIGS has exhibited the presence into the market by various suppliers. Such technology has been positioned as the 2nd generation architecture. The issue is in the improvement of conversion efficiency, because thin film modules is hard to clear 10% in mass production. New trend is to make use of 3-5 compound multi-junction cells, which leads efficiency enhancement The highest data records 42% in Franhofer Institute for a concentrator. Okada has exhibited the enhancement of *I*ph in lower wavelength in GaAs cell with InAs quantum dots shown in Fig.3. [5)] Fukui has proposed novel GaAs quantum wire structure.

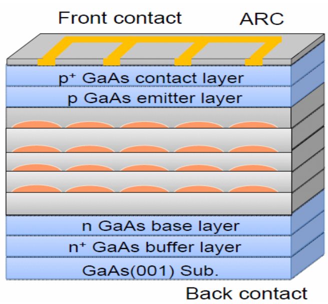


Fig.3 The structure of GaAs solar cell with InGaAs Quantum dots.

3. PV Architecture and System Design

The enhancement of conversion efficiency is important in PV system because of the reduction of BOS (Balance of System) cost. Author has proposed novel architecture for multi-junction cells, which enables to increase its conversion efficiency by the method of impedance conversion method6) to pull out of the output from each cell/module, preferably consists of silicon alloy and quantum dots. PV design is free from the restriction of current match and lattice matching, and even organic cell would be applicable. Output data can be monitored by power line communication shown in Fig.4. Well-designed concentrator enables to correct irradiation efficiently by using mirror or Fresnel lens and saving solar cells increasing the conversion efficiency. Waste-heat energy can be utilized as source of a heat-pipe implemented in concentraotr and the PV output power can be controlled by ambient temperature which is again controlled by heat pipe.

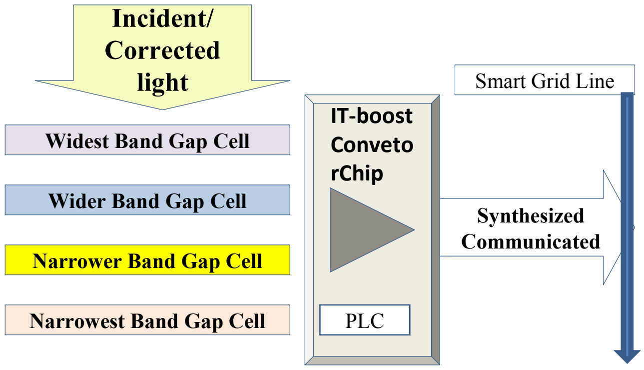
Another issue is in the connection with grid line, with some actual problems, such as voltage fluctuation / slip-out that occurs in the change of weather, the difficulty of reverse tidal current case of increasing rapid voltage grid line, short circuit capacity, the detection / reduction. Once PV generated power exceeds 30% in the grid, advanced control of output will become necessary. New standardization to solve the technical problems of grid connections is highly required. A "smart grid" can be seen from three aspects in Table 1. Each architecture of PV generation differ from each other, and compared in Table 2.

Table 1 Aspect of Smart Grid

1. Further exploitation of IT technologies to the grid.
2 .Coupled with decentralized power generation, supposing these are renewable power sources, and storage systems, elaborate grid management can be possible,
3. Elaborate grid management system allows elaborate power transactions over time, location and others including local incentives.

4. Conclusion

Current PV technology is reviewed and for the first time new architecture to achieve high conversion efficiency has been proposed as the 3rd generation. Solar PV electricity is basically promising for large scaled power generation and its exploits need to be considered as more electrical point of view. The cost of solar PV electricity will be reduced drastically to less than 10cents/kWh in 2040 and the share of 20% and electricity of more than 9000TGWh can be estimated in Fig.5.[6)] The advancement of smart grid will lead de-centralized power generation which reduce necessity to install long distance grid line and improve EEE. The feature of such system possesses many variations of the combination with various technologies e.g., wind and grid, fuel cell and solar, micro turbine gas turbine power generation and nuclear. In particular, many of green technologies could be applied in the future.



The output from each physically stacked cell is maximized by the control of load impedance and increased to one voltage by high efficient converter and synthesized . One cell is silicon at least.

Fig.4 Architecture of new PV System

Table 2 Comparison of PV Generation

Generation	1st	2nd	3rd
Cell	Silicon	Thin Film	Multi-Junction
Module	Soldering	Evaporation	Cu-Connect
System	Flat	Flat	Concentrator/Flat
IT	None	None	Controlled
Grid Intimacy	Guide-line	Guide-line	Friendly
Heat	No-use	No-use	Positive Usage

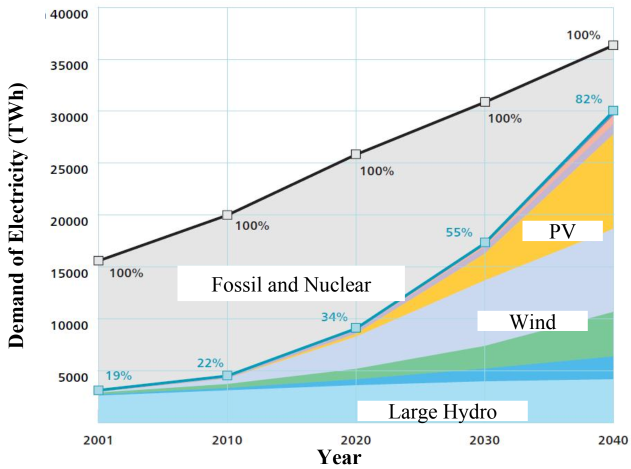


Fig.5 Demand of Electrical Energy in OECD

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〔6〕 K.Kanai and S.Matsumoto IEEE WCPEC'06 **2**(2006)2174.
〔6〕 GENNAI investigation referring to Europe Renewable Energy Association. *GENNAI is a think tank in SOLAR QUEST.*