Opportunities for Development of a Mature Concentrating Photovoltaic Power Industry

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Abstract

As the solar industry grows, there is interest in exploring a wide variety of approaches, Of these, concentrating photovoltaic power (CPV) is qualitatively different, using lenses or mirrors to reduce the amount of semiconductor material needed to produce each kW. The development of multijunction, III-V concentrator cells with efficiencies > 40% enables this approach by increasing the value of the optics. This paper explores the opportunities and challenges faced by this segment of the solar industry.

INTRODUCTION: THE PROMISE OF CPV

Today's photovoltaic (PV) industry is growing at a rapid rate, but the industry would grow even faster if costs could be reduced for both the final products and the capital investment required for scale-up. One strategy for reducing module cost is to reduce the amount of semiconductor material needed (the cost of the silicon solar cells can be more than one-half of the module cost). Many companies are thinning the silicon wafers to reduce costs incrementally; others use thin-film coatings on low-cost substrates (such as amorphous/microcrystalline silicon, cadmium telluride, or copper indium gallium diselenide on glass or other substrates). CPV follows a complementary approach and uses concentrating optics to focus the light onto small cells. The optics may be designed for low or high concentration. Low-concentration concepts use silicon or other low-cost cells; high-concentration optics may use more expensive, higher-efficiency cells. The higher-efficiency cells can reduce the cost per watt if the cost of the small cells is minimal. The high- and low-concentration approaches are described in Parts I and II of this report, respectively.

HIGH-CONCENTRATION CPV USING HIGH-EFFICIENCY, MULTIJUNCTION SOLAR CELLS

Recently, concentrator cells have been reaching increasingly impressive efficiencies, inspiring new interest in the high-efficiency, high-concentration approach. The current record efficiency is 40.8% for a three-junction GaInP/GaInAs (1.3 eV)/GaInAs(0.9 eV) cell.[1] A historical summary of champion cell efficiencies is shown in Fig. 1. Multijunction concentrator cells have achieved much higher efficiencies than any other approach. This is not surprising for two reasons: (1) the highest theoretical efficiencies may be achieved if multiple semiconductor materials (with a range of bandgaps) are chosen to match the spectral distribution of the sun, and (2) the compound semiconductors used in these cells are direct-gap materials and can be grown with near-perfect quality. The multijunction approach has been described extensively in the literature.[2-11]

When compared with solar thermal approaches, CPV provides a qualitatively different approach, typically with lower water usage, greater flexibility in size of installation, and the ability to respond more quickly when the sun returns on a cloudy day.

Ten years ago, there was little commercial interest in CPV for the following reasons:

- The PV market was dominated by building-integrated or rooftop applications, whereas most CPV products are better suited to solar farms.
- The champion concentrator cell was only ~30% efficient, compared with ~40% today.
- The total size of the PV industry was about one-tenth of what it is today, making near-term, high-volume CPV deployment unlikely.
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In the last 10 years, the solar industry has mushroomed, and the CPV industry is now growing rapidly. Cumulative investment in CPV is now on the order of $1 billion. Solar fields, which often use tracked systems, are becoming more common, providing a potentially huge market for CPV products. With the overall PV market growing in the gigawatt range, CPV has an opportunity to enter the market with production of tens or hundreds of megawatts per year. This is significant because CPV is unlikely to achieve low costs when manufacturing at less than tens of megawatts per year. Ten years ago it would have been difficult for companies to have confidence that they could find markets for the needed volume. The growth of the market, and especially growth of the market segment that uses trackers, is an important contributor to the increased interest in CPV.

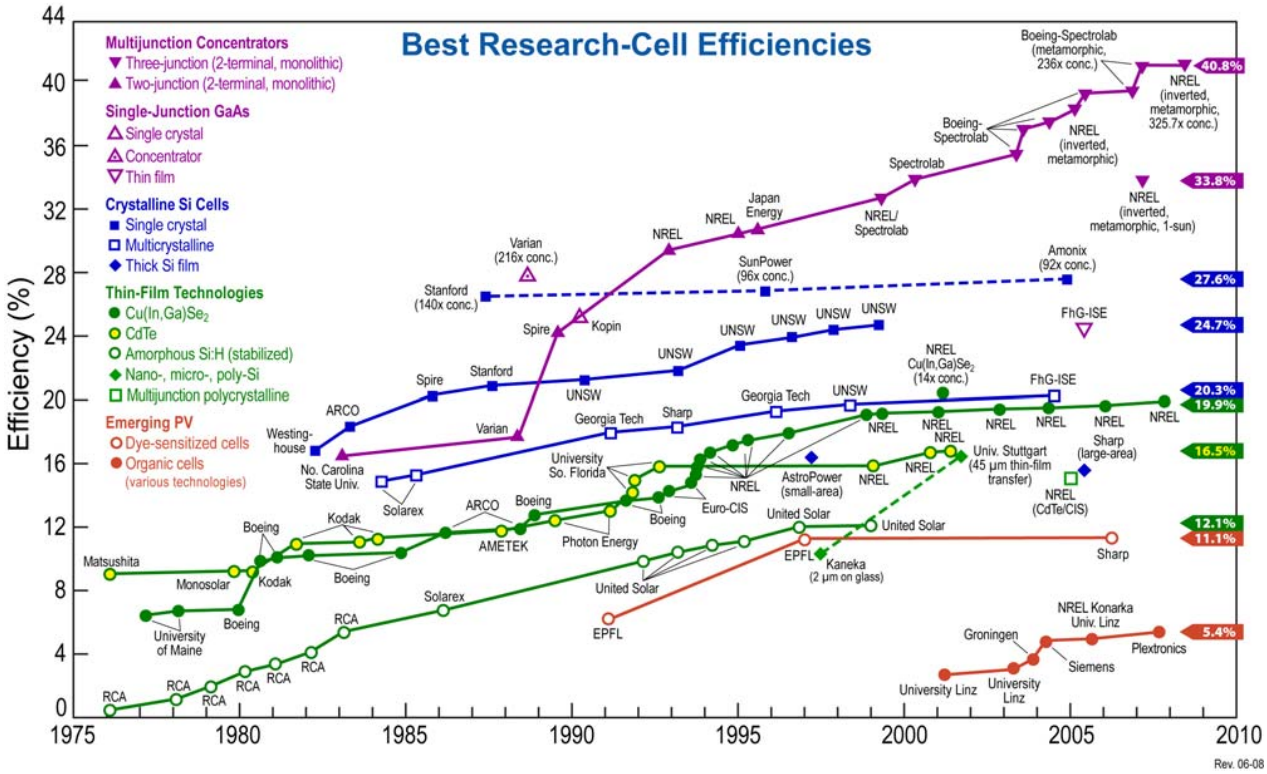

FIG. 1. HISTORIC SUMMARY OF CHAMPION CELL EFFICIENCIES FOR VARIOUS PHOTOVOLTAIC TECHNOLOGIES.

The potential for CPV industry growth has been widely discussed in recent years.[4-6]

Some cost analyses have predicted that using high-efficiency concentrator cells can lead to very low costs for solar electricity.[5,6] These studies imply that there is a potential for cost-effective implementation of high-concentration systems even in locations such as Boston, Massachusetts.[6] Other studies have also estimated the costs associated with CPV systems.[5] The energy payback of some CPV systems has also been studied.[12] Demonstration that these cost structures can be achieved will require development of a reliable CPV product followed by large-scale deployment. Many are watching for the success of this demonstration.

An additional potential advantage of the CPV approach is the reduced need for capital investment (scalability). The growth of the silicon PV industry has been challenged by the need for capital investment, especially in silicon purification facilities. By reducing the amount of semiconductor material, the capital investment need is also reduced, improving the scalability.

CURRENT STATUS OF CPV INDUSTRY

Table 1 provides a partial list of today's CPV companies. This list has grown substantially in the last 5 years. Perhaps more important than the length of the list is the level of investment in the industry and the movement toward large-scale production. The industry has been projecting installations in the megawatt range for 10 years. In 2007, for the first time a CPV company delivered on such a projection: Guascor Foton installed 6 MW of high-concentration, silicon-based systems, using Amonix's CPV technology.[13] A company that might have attracted a $1-million investment 10 years ago may hope to attract $100 million today. Not surprisingly, the larger investment rates are enabling faster progress in the development, with multiple companies now reporting stable on-sun operation for months or years.

Most PV technologies have required years of development before showing success on a large scale. First Solar's current expansion is based on years of development work. The multijunction CPV industry may be preparing to emerge from the development phase. As the CPV companies transition from the prototyping phase of development to scaling up manufacturing, they will encounter the standard

problems. A summary of these is posted on line at http://www.nrel.gov/docs/fy08osti/43208.pdf.

TABLE 1. SUMMARY OF CPV COMPANIES

Company	Type of System	Location	On Sun in 2007
Abengoa Solar	Multiple designs	Spain, USA	
American CPV		Orange, CA, USA	
Amonix	Lens, pedestal	Torrance, CA, USA	>100 kW (Si)
Arima Ecoenergy	Lens, pedestal	Taiwan	
Boeing	Mirror, Pedestal	Seal Beach, CA, USA	
Concentracion Solar La Mancha	Lens, pedestal	Ciudad Real, Spain	
Concentrating Technologies	Small mirror, pedestal	Alabama	>1 kW
Concentrix Solar	Lens, pedestal	Freiburg, Germany	~100 kW
Cool Earth Solar	Inflated mirrors	Livermore, CA, USA	>1 kW
CPower	Lens, pedestal	Ferrara, Italy	
Daido Steel	Lens, pedestal	Nagoya, Japan	
Emcore	Lens, pedestal	Albuquerque, NM, USA	>10 kW
Energy Innovations	Lens, carousel	Pasadena, CA, USA	
Enfocus Engineering	Lens, flat pivot	Sunnyvale, CA, USA	
ENTECH	Lens, pedestal	Keller, TX, USA	>1 kW in 2003
ESSYSTEM	Lens, pedestal	Gwangju-city, Korea	
EverPhoton	Lens, pedestal	Taipei, Taiwan	
Green and Gold	Lens, pedestal	South Australia	
GreenVolts	Small mirror, carousel	San Francisco, CA, USA	>1 kW
Guascor Foton	Lens, pedestal	Ortuella, Spain	~10 MW (Si)
IBM	Lens	Armonk, NY	
Isofoton	Lens, pedestal	Malaga, Spain	
Menova	Modified trough	Ottawa, Ontario, Canada	
OPEL International	Lens, pedestal	Shelton, CT, USA	
Pyron	Lens, carousel	San Diego, CA, USA	>1 kW
Sharp	Lens, pedestal	Japan	
Sol3g	Lens, pedestal	Cerdanyola, Spain	>10 kW
Solar Systems	Dish, pedestal	Victoria, Australia	>100 kW
SolarTech	Lens, pedestal	Phoenix, AZ, USA	
Solar*Tec AG	Lens, pedestal	Munich, Germany	
SolFocus	Small mirror, pedestal	Mountain View, CA, USA	>10 kW
Soliant Energy	Lens, flat pivot	Pasadena, CA, USA	
Xtreme Energetics	Multiple designs	Livermore, CA, USA	

CELL SUPPLY

Historically, Spectrolab and Emcore have been the primary suppliers of multijunction concentrator cells. The number of companies supplying, or developing the capability to supply, multijunction concentrator cells has increased in recent years. These are summarized in Table 2.

TABLE 2. SUMMARY OF COMPANIES WITH CAPABILITY FOR EPITAXIAL GROWTH OF MULTIJUNCTION CELLS*

Company Name/Web Link	Comment
Spectrolab	Datasheet describes minimum average 36% cells and cell assemblies at 50 W/cm^2
Emcore	Datasheet describes typical 36% cells and receivers at 470 suns
Spire (Bandwidth)	Datasheet describes typical 35% cells at 500 suns
Cyrium	North America
Microlink Devices	North America
Azur Space (RWE)	Europe
CESI	Europe
Energies Nouvelles et Environnement (ENE)	Europe
IQE	Europe
QuantaSol	Europe
Arima	Asia
Epistar	Asia
Sharp	Asia
VPEC	Asia

*List does not include companies in R&D or stealth mode.

A quick review of the companies in Table 2 implies that the supply of cells could quickly mushroom. The efficiencies from the new companies are expected to be inferior to those from Emcore and Spectrolab, but may be acceptable to some CPV companies. Although all of the companies on this list have some capability for growing multijunction cells, not all of them have demonstrated a capability for high-yield manufacturing.

Just as some silicon PV companies are moving toward vertical integration, many of the CPV companies are considering vertical integration with cell companies to ensure adequate cell supply. In contrast, the cell companies are trying to avoid vertical integration in order to retain their ability to supply many CPV companies. The situation may become very complex as companies attempt to define whether to merge or separate these efforts. Examples: Emcore (cell and system supplier) has announced a spin-off of its CPV systems company; Spectrolab (cell supplier) is owned by Boeing (system supplier); Arima Ecoenergy is developing CPV systems alongside of Arima's development of multijunction cells. Discussions of mergers appear to be ongoing.

Expansion of the manufacturing volumes should allow reduction in cost because of economies of scale. This consideration would tend to associate lower cell costs with a small number of cell companies. In 2007, cell supply was a primary concern among CPV representatives. With the growing number of companies with cell capability, this concern is substantially reduced.

SUBSTRATE SUPPLY

The manufacture of multijunction space cells in the last decade has been based primarily on germanium wafers supplied by a single company: Umicore (Brussels, Belgium). Now, multiple companies are developing a germanium wafer capability, including AXT (Fremont, California); Sylarus (St. George, Utah); and PBT (Zurich, Switzerland). Umicore has announced plans to build a second plant in Quapaw, Oklahoma, to help service this growing market. In addition, if the inverted method[11] of fabricating the multijunction cells becomes popular, the substrates may be reused or the material recycled. Although it is possible that the industry could be so successful as to create a shortage of wafers, this is not currently on the horizon.

SUMMARY

The use of concentrated sunlight on very small, but highly efficient (~40%) solar cells has the potential to provide cost-effective, large-scale, solar-electricity generation, especially in sunny locations. More than a dozen companies have learned to fabricate multijunction concentrator cells, positioning themselves to respond to the growing demand for these cells. About 30 companies are developing concentrator photovoltaic systems, and many have already deployed 1–100 kW in the field. This industry is showing signs of being poised for substantial growth in the next years as the world enthusiastically embraces solar energy.

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ACRONYMS

CPV: Concentrating Photovoltaic
PV: Photovoltaic