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LASER SCRIBING: A KEY ENABLING TECHNOLOGY FOR MANUFACTURING OF LOW COST THIN FILM PHOTOVOLTAIC CELLS

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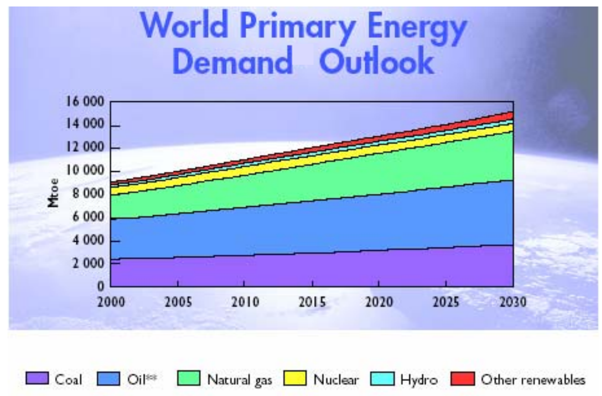
Abstract

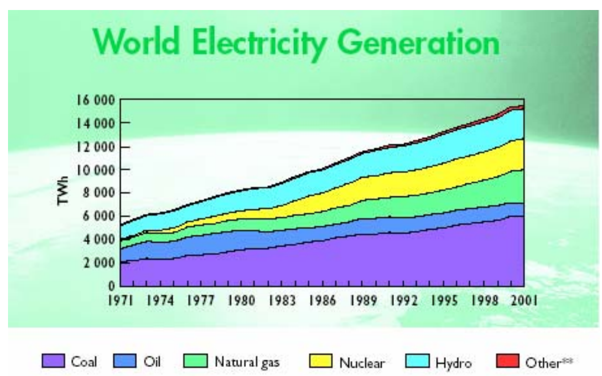
Solar cells are becoming a highly promising alternative energy source for various markets. In the last five years or so a tremendous amount of research effort has been put into increasing the efficiency of solar cell technology and reducing its manufacturing cost. It is believed that success in both of these areas will further propel its use in various markets. The two major structures commercially pursued for solar cell manufacturing are crystalline Silicon-based structure and thin film-based structure. Thin film technology includes amorphous silicon or cadmium telluride, CdTe, or copper indium diselenide, CIS or copper indium gallium diselenide, CIGS structures. From the manufacturing perspective thin film technology has a tremendous potential for achieving cost reduction by leveraging flat panel display (FPD) manufacturing infrastructure. Laser technology plays a key role in manufacturing of thin film solar cells by scribing the pattern at each of the three layers of the cell structure. At Spectra-Physics, we have developed laser-scribing process for each of the amorphous silicon thin film solar cell layers and have investigated ways to achieve maximum possible scribing speed. Laser scribing is a key enabling technology in reducing the cost of manufacturing of thin film solar cells.

Introduction

The world energy demand is increasing at a rapid pace due to economic boom in developing countries and increasing needs of developed countries. Data from International Energy Agency (IEA) (Figure 1(a)) predicts a continued steady increase in the world's energy demand[1]. 90% of the energy demand is fulfilled by use of fossil fuels such as coal, oil, and natural gas. The energy required for power (primarily electricity) generation accounts for ~ 35 to 40% of the total demand. Historical data over the past 30 years shows (Figure 1(b)) that world electricity generation has increased steadily and 60-70% of electricity is generated using fossil fuels. The increased use of fossil fuels is emitting high levels of CO_2 gas in atmosphere



(a)



(b)

Figure 1. (a) World energy demand in future and (b) past 30 years of world electricity generation data.

(Figure 2) and threatening to create severe environmental issues such as global warming. Also the prices of these natural energy resources have increased significantly in recent years because of its demand. The environmental issues and high cost of our natural energy resources have spurred researchers around the world to work on developing alternative energy resources. The leading candidates among the "green" or "clean" cost effective alternative energy solutions that might alleviate current problems include wind, bio-fuels, and solar power. Among these potential

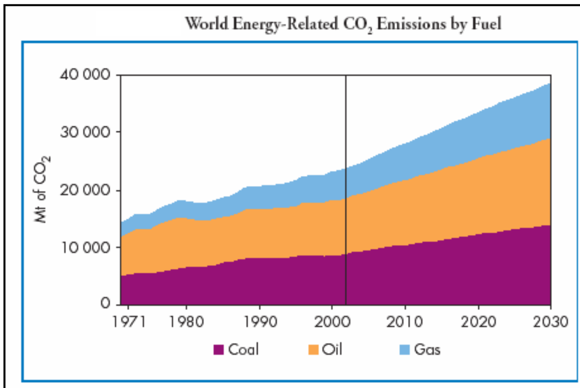


Figure 2. Worldwide energy-related CO_2 emissions by fuel type.

solutions, solar power technology (also commonly referred to as a Photovoltaic technology) seems to have captured the attention of many around the globe as a best solution for generating electrical power. It has gathered tremendous momentum in past few years in its implementation at industrial and commercial levels and even down to residential level.

In last five years or so tremendous amount of research effort has been put into increasing the efficiency of solar cells and in reducing its manufacturing cost. It is believed that recent and potential future success achieved in both of these areas will propel its implementation tremendously as shown in Figure 3.

In this paper we will describe how lasers are enabling and helping solar cell technology to achieve the technical and economic targets necessary to potentially replace our "high priced dirty" coal and oil burning energy alternatives of today.

Types of PV Solar Cell

There are three basic types of solar cell technology: multi-junction gallium arsenide (GaAs), crystalline silicon, and various types of thin films on glass or metal substrates.

GaAs cells are fabricated using MOCVD techniques on mono-crystalline wafers and have the highest electrical conversion efficiencies (typically 28-29% but recently as high as 40%). These multi-junction cells are expensive to manufacture and therefore usually limited to applications where cost is not an issue or where only small active areas are needed, such as satellites or solar concentrators.

Crystalline silicon cells are the most widely manufactured and deployed commercially today. They are made from either mono-crystalline or multi-crystalline silicon wafers and have efficiencies typically in the 13-22% range.

Thin film cells are a more recent entrant with slightly lower efficiencies of 8-18%, but also lower production costs.

Figure 4 shows the approximate relationship between cost and cell efficiency of the competing technologies at the present time[2]. This is a constantly changing picture as researchers and innovators involved in each

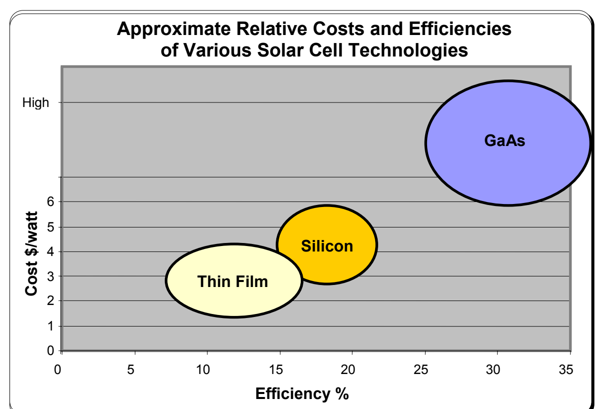
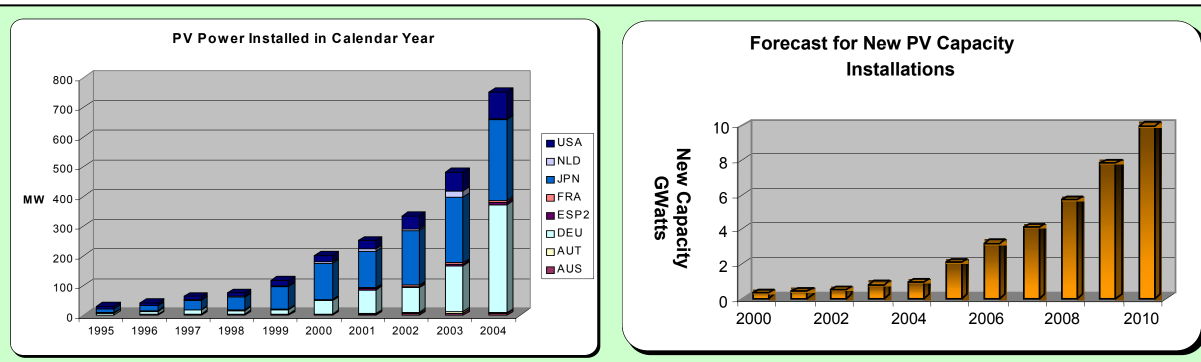


Figure 4. Relative cost and efficiency of various solar cell technologies.



Source: Photon

Figure 3. Forecast for surge in Photovoltaic cell implementation market

respective technology strive to increase the efficiency and lower their manufacturing costs.

The two major structures pursued commercially today for solar cell manufacture are the crystalline Silicon-based and thin film-based structures. Schematics of these structures are shown in Figure 5.

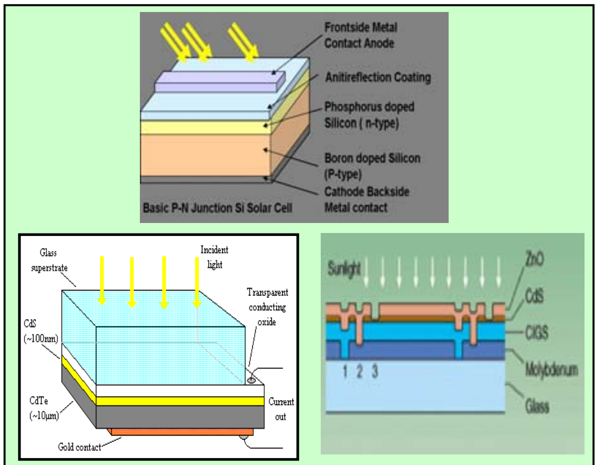


Figure 5. Schematic of various types of solar cells

It is very important to reduce the cost ($/Watt) of solar cells for its successful adoption in large volumes. The two factors that contribute heavily to the overall solar cell cost are its production cost ($\$/m^2$) and its efficiency ($Watt/m^2$). Hence, reduction in production cost and increase in efficiency has to be achieved for reducing solar cell cost. While increasing solar cell efficiency continues to be a focus for the research community and will likely be achieved in the long term, reduction in production cost of the thin film solar cell can be readily achieved by adopting the existing flat panel display industry's scaleable, automated, in-line manufacturing infrastructure. Companies that manufacture the in-line material coating machines for the flat panel display market such as Applied Materials, Oerlikon, Ulvac and Leybold have recognized this opportunity and started to develop turnkey production lines. The theory is exactly the same as in the display market, in that scale-up of the substrate area reduces manufacturing costs as the equipment used to manufacture scales at a different rate. This is illustrated in Figure 6[2]. Laser technology also plays a key role in these in-line production systems.

Crystalline Silicon Shortage

Crystalline silicon cells currently account for more than 93% of the PV market. In 2006, the solar industry actually surpassed the semiconductor industry in its usage of silicon wafers, accounting for 55% of

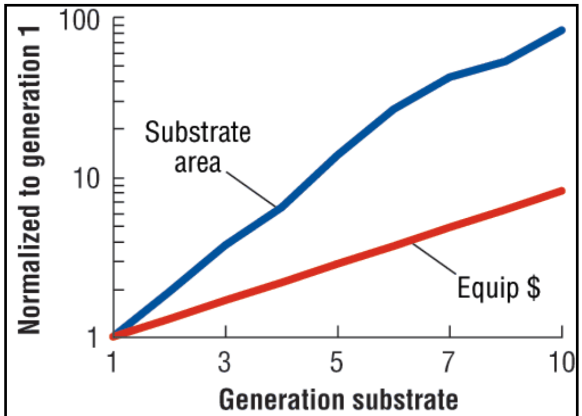


Figure 6. Scaling of FPD substrate area Vs equipment cost.

consumption worldwide (see Figure 7)[2]. The rapid ramp-up in demand for silicon wafers has created a shortage in the feedstock supply and temporarily pushed the price of silicon higher. Hence the future growth and potential for reducing production costs of crystalline silicon cells is becoming questionable. This has motivated the industry to look more seriously at the alternative thin film technologies as they use little or no silicon at all.

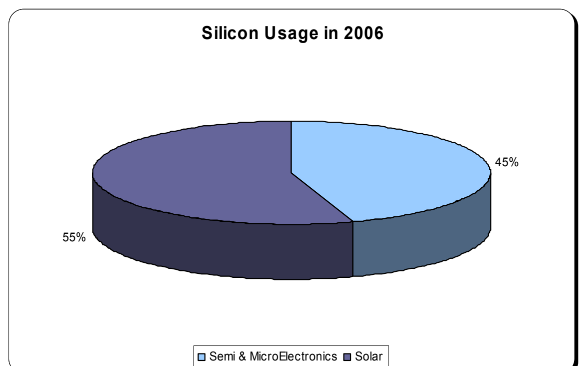


Figure 7. Increased silicon usage by photovoltaic manufacturers in Y2006.

While thin film solar cells have lower efficiencies of about 8-18%, they have a huge potential for achieving lower production costs. Furthermore, active research in thin film solar technology using new materials and structures promises to achieve higher efficiency in future. The tremendous potential for low-cost production of thin film solar cells is due in large part to leveraging off of the flat panel display (FPD) manufacturing infrastructure. The expectation of reduced manufacturing costs follows from the logic that as the glass panels increase in size, the tooling cost will *not* increase proportionately, a benefit that simply cannot be realized with crystalline silicon technology.

Lasers play a key role in manufacturing of thin film solar cells by scribing the necessary patterns in each layer of the cell. Also, higher power laser sources have recently been developed to help achieve the required scribing processes at the speeds necessary to fully leverage FPD infrastructure.

Thus the combination of developments in laser technology and leveraging the existing FPD manufacturing infrastructure provides a viable path for the production of very low cost thin film solar cells.

Laser Structuring of Thin Film Solar Cell

Thin film solar cells consist of multiple layers of different materials coated onto a glass or metal substrate; a couple of typical cell structures are shown in figure 5. The most common absorber (semi-conductor) materials used are amorphous silicon, Cadmium Telluride and CIGS (Copper Indium Gallium Diselenide). Usually transparent conductive oxides such as Indium Tin Oxide or Zinc Oxide, and metals such as Aluminum, Gold, or Molybdenum form the electrodes of the cell.

A typical process sequence for fabrication of a-Si based thin film solar cell is show in Figure 8.

Lasers, typically Diode-Pumped Solid State (DPSS) type, are used to scribe each layer of the cell and also for the edge scribing (isolation) process. Thus, laser technology is key to the overall manufacturing process.

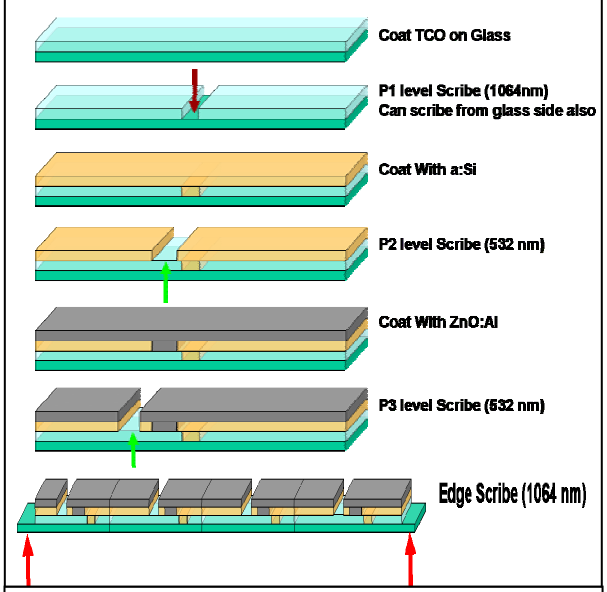


Figure 8. Typical process steps in manufacturing of a-Si based thin film solar cell panel.

P1 level Laser Scribe

As shown in Figure 8, the first step in manufacturing of thin film solar cell is to coat the front electrode onto 2 to 3mm thick glass substrate. This is typically a 1.0 to 1.5µm thick layer of Indium Tin Oxide(ITO), Tin Oxide or Zinc Oxide, commonly known as a transparent conductive oxide (TCO). Second step is to scribe 25-50µm wide P1 electrode pattern, this is usually done using a 1064nm, 15-20watts average power q-switched DPSS Nd-vanadate laser irradiated from the glass side (or from the oxide side). For higher throughput it is necessary to scan the beam rapidly and operate the laser at high repetition rates – ~80-100khz or higher. It is important to choose a laser with a narrow pulse width 15 – 50ns as this ensures that the peak power is well above the material ablation threshold even at these very high repetition rates. Beam quality and pulse-to-pulse stability are also very important for a clean scribe and a reliable, repeatable process. Within the above laser parameter space scribing speed of 1-2m/s can be easily achieved. For even faster scribing speeds, some manufacturers are investigating the use of other wavelengths, multiple laser beam lines, and lasers that can operate at even higher repetition rates. Also, the use of square flat top beam shaping optics helps achieve higher scribing speed by reducing the beam overlap required for scribing.

Figure 9 shows the top view and a 3D profile of 40µm wide P1 level scribe cut at 1.25m/s, using 20watt average power, 1064 nm, q-switched laser Hippo™ H10-106Q, operating at 80kHz.

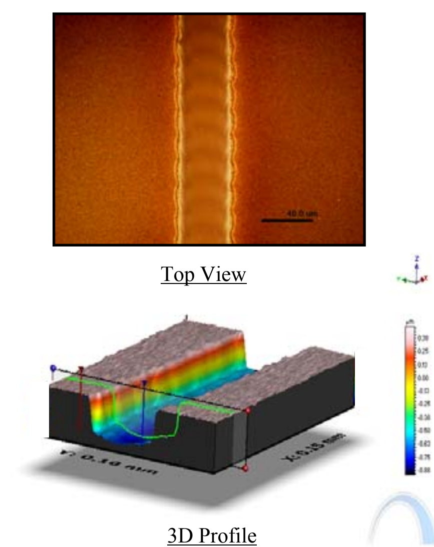
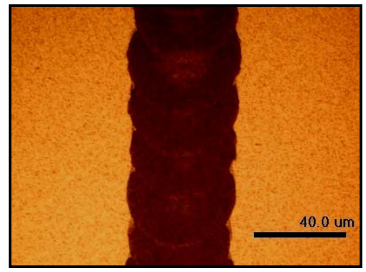


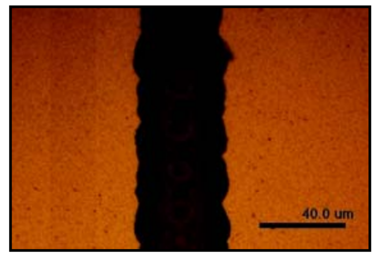
Figure 9. P1 layer ITO scribed using 1064 nm, Hippo™ H10-106Q laser at 1.25 m/s.

P2 and P3 Level Laser Scribes

Once the front electrode layer on the glass is patterned the panel goes back into the CVD machine and is coated with the semiconductor, in this example a thin layer, typically less than 1µm, of amorphous silicon. This P2 layer is then patterned using, in most instances, a green 532nm Nd-vanadate laser irradiated from the glass side. For P2 level also width of the pattern is in the range of 25-50µm. Again high repetition rates are a requirement for higher throughput and a short pulse width of 15-30ns is ideal. Due to lower material ablation threshold for a-Si material the power requirement for P2 scribe is much lower, usually less than 1watt. Either a low average power green laser can be used or the beam from a 4-6watt laser can be split and multiple scribes can be done at the same time. Once the P2 scribes have been completed, the panel is coated with a top contact of typically less than 1µm thick ITO or ZnO and Aluminum, and then laser-scribed with the final 25-50µm wide P3 pattern. This is also done from the backside of the glass with an identical laser used for the P2 process. Beam quality and pulse-to-pulse stability are again very important for a good scribe and to avoid damage to the underlying layers. Also, as mentioned above for P1 layer scribing, further higher scribing speed can be achieved using higher repetition rate laser and/or flat top beam shaping optics.



Top View of P2 level scribe



Top View of P3 level scribe

Figure 10. P2 and P3 level scribed using 532 nm, HippoTM H10-532Q laser at 1.5m/s.

Figure 10 shows top view of 40µm wide P2 and P3 level scribes achieved at scribing speed of 1.5m/s using 532nm HippoTM, H10-532Q laser at 80kHz.

Edge Scribe

In some cases, depending upon manufacturing process used, after the patterning of P3 level is completed there is a need for one more laser scribe or cleaning operation to remove all the material from the edge of the glass substrate. An 8-10mm wide band around the perimeter of the glass substrate needs to be cleared to insure electrical isolation and make room to accommodate subsequent panel packaging. A high average power, 100Watts or more, q-switched 1064nm Nd-Yag laser is well suited for this purpose. Since the area to be cleared is fairly large, some manufacturers are using sand blasting as a cheaper alternative to lasers.

Summary

Solar cells are promising to be a great “clean” source for generation of electricity in future. Thin film solar cell structures, which do not use costly crystalline silicon and can be built on a large glass panel show tremendous promise for manufacturing solar cells at a very low cost. The use of existing FPD manufacturing infrastructure can be leveraged to achieve lower cost for manufacturing of thin film solar cells.

Lasers are used to scribe all three layers of a-si based thin film solar cell structure. DPSS lasers at fundamental wavelengths of 1064nm and at frequency-doubled 532nm make a perfect source for scribing layers at high scribing speeds of 1 to 2m/s. Further throughput improvement can be achieved by using flat top beam shaping optics. In the future, even more throughput is possible by implementing higher repetition rate and average power laser sources combined with multiple beam line system design.

The laser is again playing a key role in bringing to reality a technology that has shown promise for decades. As with the semiconductor and display industries, lasers are helping to cut the cost of production, thereby brightening the future of the thin film solar industry.

References

[1] 30 Key Energy Trends in the IEA and Worldwide, January 4, 2005, www.worldenergyoutlook.org

[2] “Lasers May Brighten the Solar Cell Market,” Photonics Spectra, June 2007, pp 54-57

Meet the authors

Rajesh (Raj) S. Patel has accumulated 21 years of experience in the laser material processing field. He is currently a manager at Spectra Physics, a division of Newport Corporation, and is responsible for managing laser processing applications lab. Prior to working at Spectra Physics he has also worked at IBM, Aradigm, and IMRA America in the past. He received his Ph.D. degree in mechanical engineering from the University of Illinois at Urbana-Champaign in 1989. His professional interests are in the areas of laser development, laser material processing and equipment design, mask technology, optics, and application of lasers in various fields. He has worked with various lasers for developing applications in microelectronics, semi-conductor, bio-medical, and the photonic industry. He is an author of 22 U.S. patents related to laser processing, optics, and the mask technology field and has published and presented more than 45 technical papers.

David Clark is Director of Strategic Marketing at Newport/Spectra-Physics. He gained his BSc in Applied Physics in the UK at Coventry University and has over 18 years of experience in Product Development, Sales and Marketing.

Jim Bovatsek is a laser applications engineer at Newport Corporation's Spectra-Physics Lasers division in Mountain View, CA. He has focused on laser application development with nanosecond, picosecond, and femtosecond pulsed lasers since 2000. He received his Bachelors in Science, Physics degree from the University of California, Santa Barbara in 1997.