Outlook for consumables used in crystalline silicon cell and module manufacturing for 2010

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ABSTRACT

With growth in 2009 suffering from recession and an ongoing credit crunch, this paper presents a review of the key trends in cell and module manufacture for the crystalline silicon (c-Si) PV module market. The c-Si segment remains the largest segment, and is competing effectively with less mature thin-film technologies. PV is still a largely uneconomic way to generate power, and requires subsidy to maintain sales volume and growth. While subsidies exist, the industry treads the narrow path of growing at a healthy clip, developing robust technology and business models, and mapping paths to profitable business without subsidies once PV installations become economically viable.

Introduction

In 2010 the dynamics of the solar industry will remain at the whim of the political landscape that supports industry subsidies. Drivers to reduce carbon emissions, decrease reliance on foreign fuel supplies, or to create jobs will put support for alternative energy on the menu of policy alternatives around the world. As national governments see local advantage in promoting PV-related industry, whether through tax credit incentives or various feed-in-tariffs, carefully designed incentive schemes will be introduced. However, governments need to be sensitive to the fine line of over-subsidizing PV projects: poorly designed programs run the risk of putting money in the pockets of the project financiers as happened in Spain in 2008, or overestimating the falls in module pricing, reducing incentives, and under-stimulating the PV food chain and the subsequent installation of new projects.

Importantly, this balancing act needs to be dynamic. As silicon went into oversupply in 2008, followed closely by the global financial crisis, spot and contract pricing for polycrystalline silicon crashed from historic highs; wafer manufacturers not tied to supply contracts were able to cut prices, which flowed through the supply chain reducing module prices dramatically. As these prices fell, governments in large module-consuming countries (especially Germany) scrambled to review and adjust incentive levels in line with cheaper supplies. This balancing act will continue over the next year as western economies struggle to get out of recession.

The solar industry has built its very existence on the promise of recovering free energy from sunlight at an economic cost. What exactly the economic cost is depends on many factors, most beyond the scope of this article, but the absolute requirement to reduce the cost of the final module has been a driving force behind PV cell development for 30 years or more, and will likely continue for five years or more. This relentless push to reduce cost for a given functionality may look like Moore's law, but is subtly different. Without incentive and subsidy programs, the PV industry would be starved of the volume demand that fuels innovation and cost improvement necessary to achieve an economically sustainable cost of power generation, and would lose momentum.

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Materials trends in the near future

With a few notable exceptions, c-Si cells (both mono- and multicrystalline) are manufactured with H-bar grids on the front and back of p-type wafers with an n-type junction on the front side, and an aluminium back surface field. This process is a compromise between low cost of manufacture, and cell efficiency. The challenge for the future is to redesign this cell architecture not only to improve efficiency, but to achieve an overall reduction in cost. In fact, this points the way to the first dictum for the introduction of new materials: do not add cost, and provide a viable roadmap for future cost reduction.

So what might a c-Si cell look like in one to three years as the industry works to achieve the point where solar power generation competes directly with other technologies? These cells might look reminiscent of cells that are produced in 2010, but there will be differences in the detailed architecture, and process flows in manufacturing.

Linx-AEI c-Si roadmap

The intrinsic cost of high-purity silicon will drive its reduced use for any cell design. Wafer thicknesses will decrease the point where either the efficiency of the cell is sub-optimal, or the physical yield of processing is low enough to impact the economic value. The Linx-AEI roadmap which captures c-Si process trends in the near and medium term is shown in Fig. 1.

	Current Leading Edge	Medium Term 2012	Future
Wafer	Multi c-Si 180 μm Mono c-Si 145 μm Predominantly p-type Wire sawn	Multi c-Si 140-160 μm Mono c-Si 120 μm Mainly p-type Diamond Wire sawn	Multi c-Si <120 μm Mono c-Si <100 μm n- and p-type Thin film on carrier substrate Cleaved
Texturization	Multi c-Si Acid based Mono c-Si Alkali based	Multi c-Si acids / alkali Mono c-Si acids / alkali Formulated texturizers	Acids / alkali Laser Dry etch
Junction Engineering	Single diffusion	Selective Emitter Deposited passivation	Backside selective emitter Boron BSF Emitter wrap and metal wrap
Anti Reflection	PECVD	PECVD PVD Coat	PECVD PVD Coat
Contact	Printed Paste	Plated Front grid Back contact Non-contact paste deposition	Silicide Point contact + Al Interdigitated back grid Interconnect on Backsheet

Figure 1. The Linx-AEI c-Si Technology Roadmap.

Areas in yellow are the most important areas of technical interest.

In the following sections we review some of the material developments that may be introduced in the next few years.

Key material trends to watch in 2010

Texturization and cleaning

Wet processes are important determinants of cell efficiency. By forming a surface that entraps light for conversion, and determining the quality of the silicon surfaces, wet processes can be a large influence in the final cell efficiency. Ultraclean processes, aggressive chemicals, and automated handling are all common in semiconductor processing, but carry costs for the pure chemistry, safety precautions, and eventual disposal of the used etchants.

In texturization, wet chemistry has shown that it is a viable and cost-effective approach to producing high quality texturization in both mono- and multicrystalline wafers. However, some of the etch conditions used are problematic. Many etchants are temperature dependent, and temperature uniformity in a cooled bath is difficult to maintain. Surfactants also present a challenge for in-line filtration, since concentrations can vary with filtration time, and high surfactant concentrations can even block filters. Several commercial suppliers have introduced formulated caustic and acidic etchants for texturization which are gaining market traction.

In subsequent processing carrier lifetimes, recombination at defect sites and passivation quality are all impacted by cleaning efficiency. The line between cleaning and etching is blurring, and in cell processing removal of a thin layer at the silicon surface both removes defectivity, and undercuts particles and contamination, helping removal. A side benefit is also the reduction of very high surface dopant concentrations that results in a more consistent resulting doping profile, and higher cell yield. Again, multiple wet chemistry suppliers are introducing formulated cleans which are seeing adoption in leading edge cell makers.

Metallization

Printed paste, despite the cost of the base metal powders used, represents a remarkably cheap and efficient way of putting metal where it is needed. As cells develop limits of the screen-printing technology (edge acuity, aspect ratio, etc.), these become the gating factors on the process. Various techniques have been introduced aimed at increasing aspect ratio and line acuity, and improved pastes formulations are continuously being evaluated to improve conductivity, and formation of ohmic contacts to various doping levels and types of silicon.

For example, work is progressing on double print techniques that increase the aspect ratio. Increases in printer alignment accuracy are important to enable double printing and collaboration between equipment makers and materials suppliers is necessary to develop viable processes.

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Some cell designs are replacing much of the Ag front paste with plated Ni/Cu/Sn stacks, which offer high conductivity and solderability with significant reductions in Ag use. These techniques still require a seed layer of fritted Ag paste to make contact to the emitter, so the plating is performed in an incremental process step. We expect lines using this technology to move into production this year, but problems of plated defects on SiN pinholes and defects still are a concern.

In the longer term, and especially on high efficiency cells, we expect emitters to migrate to the back of the wafer, and interdigitated metal lines to collect current. This technique requires laser-ablated point contact through a rear-side passivation, and alternate metal deposition processes. Subtractive techniques may offer better quality, but it remains to be seen if this approach can be more cost-effective in standard cell designs. Our work suggests that some novel subtractive lithographic contact grids offer cost advantages over standard lithography, while improving line quality, and offering efficiency improvements of printed lines.

Selective emitters

In the drive to squeeze more efficiency out of the cell, the search to reduce the resistance at the metal/silicon contact while maintaining the optimum doping profile in the photocell has received considerable attention. For many semiconductor professionals this is best achieved with multiple masking steps and diffusion processes. However, in the relentless push to avoid additional cost, multiple routes to reduce processing steps and achieve the same result have been developed, mainly by turnkey production line manufacturers.

Techniques to achieve these selective emitters include the following approaches, among others:

- Etching back highly-doped silicon from open areas while leaving the grid line areas untouched.
- Laser doping the emitter areas, and using the paste firing to drive in a light diffusion from spray-deposited phosphoric acid.
- Differential doping through laser patterned oxide masks prior to standard processing.
- Printing dopant pastes over emitter areas that dope n^{++} emitter regions.
- Using etchant screen print pastes to open windows in an oxide before standard deposition.

All of these techniques increase efficiency with modest increases to capital and process costs; however, the reported benefits in absolute efficiency (from 1% to 1.5%) increase the power output of a panel by as much as 10%, or significantly reducing the cost per kWh and LCOE of an installation, offsetting the higher manufacturing cost. Broad introduction of SE processes started in 2009, and will continue apace in 2010 onwards.

A further development of selective emitter technology is leading the emitter contact through the wafer and making metal contact at the rear side. This can either be done by doping the walls of a laser drilled hole at the same time as emitter diffusion (emitter wrap through – EWT), or lining the through hole with metal leading to a rear-side grid (metal wrap through – MWT). While some companies have developed viable MWT and EWT processes, few are currently in volume production. We expect these technologies to become more common in two to five years.

While these processes are elegant, the laser drilled holes can weaken thin wafers, reducing mechanical yields. Some wrapped processes do not add novel materials, but some processes use conductive pastes to make contact at the back contact point. Additionally, techniques for depositing metal through the laser via will need to be implemented, possibly with plating technology.

Encapsulant

For many years, standard c-Si modules have followed a very consistent moduling approach using glass frontsheets, thermally crosslinked encapsulant, and a laminated backsheet. Well-designed cells with high-quality materials continue to perform well, and recent studies have proposed extending standard module lifetimes to 30 years or more. However, in the spirit of continued cost reduction, elimination of high-cost materials and processes are constantly being evaluated.

Thermoplastic encapsulants offer reduced laminator process times since the materials do not need a hold time at temperature to crosslink of the common encapsulants, predominantly ethylvinylacetate (EVA). This reduced processing time improves throughput, and potentially offers capital cost savings due to the reduced number of laminators required. Critical to the introduction of thermoplastic encapsulants are the properties of the materials, and their ability to meet performance characteristics used by EVA. Novel encapsulants using PVB, olefins, urethanes and silicones have all been announced and multiple manufacturers have products in development. Certifications are underway with international test organizations, and these materials will compete in both thin-film and c-Si modules.

Backsheets

Japan was one of the first countries to promote PV installations with subsidies, and a strong domestic industry developed in the 1980s. C-Si modules used a laminated PET backsheet that offered good insulation, but that was degraded with exposure to UV light and harsh environments. As a consequence, module lifetimes were guaranteed at only 10 years. In contrast, most modules for commercial and residential use in Europe and North America are expected to last significantly longer, and the use of fluoropolymer cladding materials – mainly PVF – became common. Time supply constraints and the consequent search for alternative materials have brought in PVDF and other fluoropolymer alternatives. Simultaneously, backsheet laminators and module makers have experimented with other materials that may still satisfy the longer lifetime guarantees without failing. Additionally, the incorporation of materials with high IR reflection or good UV and visible reflectance can increase module efficiency, and reduce the environmental stresses on the PET insulation layers.

The highly customizable nature of backsheets is leading to a large number of module maker-specific products that incorporate different materials. Key for material acceptance is not only certification by UL, TÜV or IEC, but the ability to supply the very large film volumes that are needed if materials are adopted by leading module makers.

Frontsheets

For both thin-film and c-Si modules a key material is the frontsheet. While glass is a cheap, plentiful material, glass frontsheets are technically complex, with moulded surfaces to aid light capture, aesthetics, and module durability, and narrow composition specifications to meet transparency needs.

Improvements to glass for c-Si modules have focused on tuning surface morphology, while adding anti-reflective coatings to ensure more light is captured. These ARC layers can couple up to 4% more light into the cells, but their cost must be lower than the benefits of increased efficiency. Several suppliers are now offering coating materials based on xerogels, or solgels that can be applied to frontsheet glass to in-couple more light, some together with application equipment, and others in collaboration with glass suppliers. It is critical that these materials demonstrate high durability for acceptance since they will be on the outside of modules. A small percentage of c-Si modules use ARC today, but as costs are better understood, we expect the proportion to increase.

While some thin-film modules use polymeric ETFE front coatings, the high durability of these materials, combined with better transmittance, has lead some c-Si makers to offer polymer frontsheets instead of glass. Acceptance of these materials is still limited, but weight savings may open access to roof mount markets that cannot carry large additional weight.

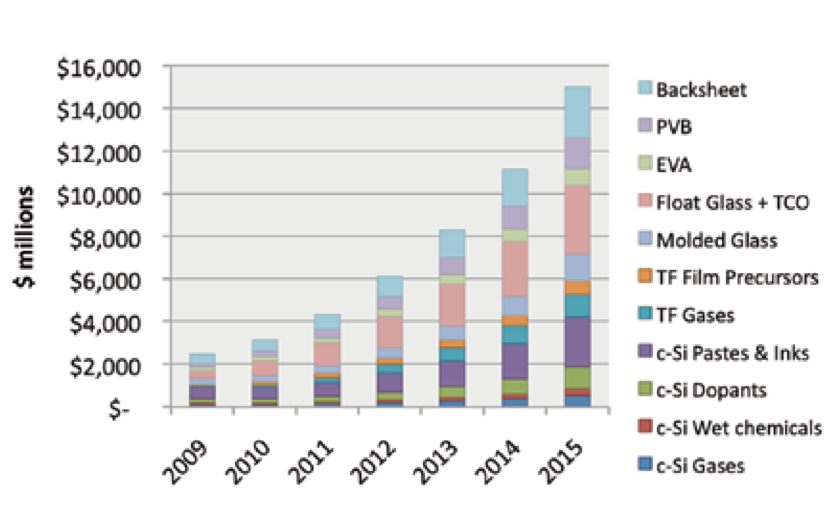

Figure 2. Materials demand forecast for PV cells and modules.

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Summary

Despite a significant slowdown in 2009, the outlook for the PV materials supply industry will see a slow year in 2010 with high growth in some segments. Revenues in the areas of c-Si wafer processing material in 2009 were US$916 million, with only US$134 million worth of gases and materials used in all thin-film manufacturing. The largest material segment was the moduling materials, which for the purposes of our segmentation included all glass, and finished 2009 at an estimated US$1,405 million.

Growth in 2010 will rely on the progress made in efficiency and manufacturing for Si-based thin film and CI(G)S modules. If these module types meet their efficiency and cost targets it is likely they will gain market share. In our baseline scenario thin-film manufacturing materials demand will double in 2010, while the c-Si materials demand will not grow in 2010. Moduling materials demand is forecast to grow 39% in 2010. Our belief is that any shortfalls in market growth for thin-film modules will be easily met with c-Si modules.

Fig. 1 shows our forecast for materials market growth to 2015. The overall market will grow from $2,455 million in 2009 to $8,275 million in 2013. The market growth forecast is reliant on a 'business as usual' subsidy environment. Alternative scenarios are presented in the Linx AEI Consulting report "Advanced Chemicals and Materials for PV cells and modules" published in January 2010.

The growth opportunities identified here are all important contributors to the effort to make the PV industry commercially viable without subsidy, and once successful, self-sustaining. If materials suppliers can collaborate with equipment makers and process developers to bring these innovative processes to market, the point where PV competes with utility supplied power will only come sooner.

About the Author

Mark Thirsk is Managing Partner of Linx Consulting. Mark has over 20 years' experience spanning many materials and processes in wafer fabrication. He has served on the SEMI Chemicals and Gases Manufacturers Group (CGMG) since 1999, acting as Chairman between 2001 and 2003.

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