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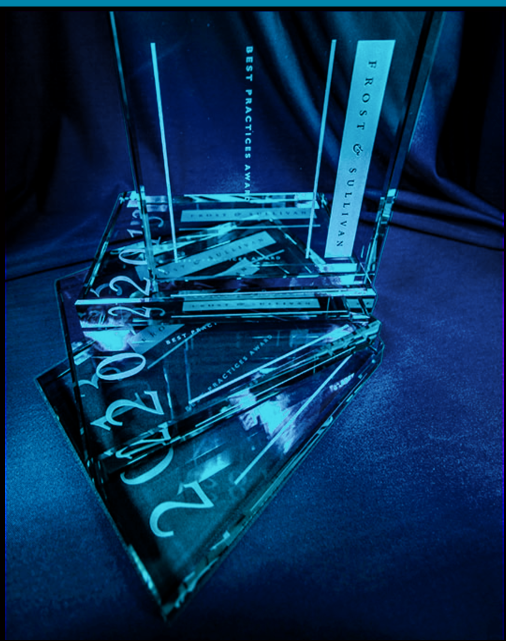
SOLAR-TECTIC

2016 North American Photovoltaic Materials Technology Innovation Award



FROST & SULLIVAN

2016 BEST PRACTICES AWARD

NORTH AMERICAN PHOTOVOLTAIC MATERIALS TECHNOLOGY INNOVATION AWARD

2016 BEST PRACTICES AWARDS

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Background and Company Performance

Industry Challenges

Globally, the photovoltaic (PV) solar power market is booming; pro-solar incentives and national pledges to reduce emissions in the wake of the United Nations' Paris Climate Conference ensure continued strong growth. According to Frost & Sullivan, the market for solar PV expects to reach $179.13 billion in 2020 at a compound annual growth rate of 9.5%.[1] In 2014, cumulative PV capacity increased by 28%—enough to supply 1% of the world's total electricity consumption.[2] Higher efficiency solar cells need fewer panels—translating to major overall cost reduction since requiring less infrastructure, e.g., inverters and cables. Consequently, efficient solar cells are the key to low-cost renewable electricity. Solar cell manufacturers are racing to increase efficiency and output while reducing costs—the market expects to reach $14,022 million by 2022, growing at a CAGR of 20.9% from 2015 to 2022.[3] Nevertheless, high solar cell manufacturing costs and inefficient panel performance impede wide-scale PV commercial adoption.

One method to increase the efficiency of a solar cell is to split the electromagnetic spectrum and use a solar cell optimized to each section of the spectrum. Stacking two solar cells—known as a tandem solar cell—enables more efficient energy harvesting by providing differing bandgaps to collect solar rays. While a premium single-layer polycrystalline solar cell may convert a maximum of 25% of solar energy to electricity, tandem solar cells could increase this figure to beyond 30%.[4] For the lower layer of the tandem solar cell, researchers are exploring different materials to optimize light absorption, including copper-indium-gallium-diselenide (CIGS) cells. Despite its advantages, the sophisticated technology needed for tandem cell fabrication has been confined to the realm of outer space or concentrated photovoltaics due to its high cost. As a result, tandem cells are not attractive for mass production. Recently, an emerging PV technology called perovskite has the potential to overcome these manufacturing challenges. Perovskite processes at just 50 degrees Celsius, requiring little energy, and thereby, significantly decreasing manufacturing costs. As a result, researchers are hopeful they will create a high-efficiency solar cell that is cost-competitive with fossil fuels.

Despite this initial success, there are concerns regarding the material's stability and scalability. As researchers continue to explore perovskite viability for solar cell manufacture, early perovskite commercialization strategies involve depositing the material on the silicon wafer to increase efficiencies. Currently, mono and poly crystalline silicon make up 90% of solar panels—both employ silicon wafers, and typical efficiencies range between 16 and

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[1] See Frost & Sullivan's *Global Solar Power Market—2016 Update: Solar PV Gains Momentum as a Globally Irreversible Mainstream Energy Source* (MBA6-01) May 2016

[2] International Energy Agency http://www.iea-pvps.org/index.php?id=32

[3] See Frost & Sullivan's *Strategic Analysis of the Global Photovoltaic Materials Market: Decreasing Grid Parity of Solar Energy to Spur Demand* (K039-01) March 2016

[4] Fan Fu, Thomas Feurer, Timo Jäger, Enrico Avancini, Benjamin Bissig, Songhak Yoon, Stephan Buecheler, Ayodhya N. Tiwari. *Low-temperature-processed efficient semi-transparent planar perovskite solar cells for bifacial and tandem applications.* Nature Communications, 2015.

25%. Alternatively, thin-film technology eliminates the need for silicon wafers while retaining high efficiencies; it also lowers manufacturing costs due to the need for less material and lower temperature processing which means much less energy consumption.

Solar-Tectic is directly addressing these complex challenges through innovative and proprietary thin-film, tandem-cell technologies targeted toward providing industry-leading efficiencies in both the top and bottom layers. Unlike competitors, the company holds a worldwide patent for a highly crystalline thin-film silicon (or germanium) bottom layer on a tandem structure—providing the market large cost savings through eliminating the need for silicon wafers. This could catalyze a momentous shift from the silicon wafer technology used worldwide, to crystalline thin-film silicon (in tandem with other thin-film materials.) The company is leveraging its materials expertise to develop a number of promising material systems for the top layer. With its proven bottom layer technology, use of industry-validated materials, and superior processes, Solar-Tectic holds the potential to unlock best-in-class solar cell performance and efficiency.

Technology Attributes and Future Business Value

Headquartered in Briarcliff, New York, United States (US), Solar-Tectic is a solar research and development company providing cutting-edge solutions to the PV industry. Based primarily on inventions by the late Dr. Praveen Chaudhari, renowned materials physicist and recipient of a US National Medal of Technology and Innovation, Solar-Tectic leverages its wide portfolio of intellectual property (IP) to harness the inherent efficiencies of both thin-film technology and superconducting materials. In 2016, Solar-Tectic presented a paper at the Fifth International Symposium on Energy Challenges and Mechanics in Inverness, Scotland, making its unique technique for growing the perovskite layer on the silicon public for the first time in a journal publication which followed. This was the first paper ever published on the topic of perovskite/crystalline silicon thin-film tandem solar cells. And unlike competing technologies that use lead in the perovskite layer, Solar-Tectic employs non-toxic tin, allowing for low-temperature crystalline thin-film silicon deposition and tin perovskite film formation simultaneously on soda-lime glass.

While perovskite/crystalline silicon tandem solar cells have been the object of much research, no attention has been paid to perovskite/thin-film crystalline silicon technology. Nevertheless, thin-film modules provide important advantages including shadow-tolerance, greater design flexibility, and lower energy consumption and therefore production cost. When combined with a tandem structure, a thin-film panel can capture both short and long wavelengths of the light spectrum, providing industry-leading performance with theoretical efficiencies up to 45% (when silicon is combined with a higher bandgap (1.8ev) top layer). Specifically, through creating thin-film tandem solar cells incorporating a perovskite layer, Solar-Tectic has the potential to revolutionize the economics of solar cell manufacturing. Unlike competing technologies that apply perovskite to the silicon wafer, the company's IP involves applying the material to thin-film silicon, eliminating the need for the silicon wafer. As a result, the company greatly reduces manufacturing costs while simultaneously matching or exceeding the efficiency of monocrystalline panels. Solar-Tectic holds a patent for a thin-film silicon bottom layer in a tandem structure as well as extensive IP surrounding many other promising thin-film tandem solar cells designs for the top layer. The company's patent pending thin-film semiconducting compounds for the top layer include proven materials such as amorphous silicon (a-Si), III-V materials, CZTS (copper zinc tin sulfide), tin sulfide (SnS), copper oxide (Cu2O) and polymers (P3HT). Finally, unlike competitors using a thin-film technology that employs toxic cadmium telluride, or selenide (in CIGSe), Solar-Tectic's offering is completely benign for the environment.

Moving toward Commercialization

Solar-Tectic has worked with institutions like the National Renewable Energy Laboratory and the State University of New York to develop its technology and achieve proof-of-concept of its patented tandem-cell bottom layer. The company is currently in the proof-of-concept stage for its tandem-cell top layer material systems and is actively seeking funding to conduct laboratory and field studies. Solar-Tectic is open to licensing its patented (and pending) IP, know-how, and proven offerings and is seeking a commercialization partner; according to Solar-Tectic, it is currently speaking with some of the largest solar cell companies in the world. Significant collaborations include a close working relationship with Blue Wave Semiconductors, a Maryland-based company with expertise in thin-film technology production. Solar-Tectic's transformative and scalable technology has the potential to impact the LED display and semiconductor industry, as well. Sapphire glass is an especially exciting application for the company—the company holds patents for depositing thin-film silicon (or germanium) on a substrate coated with aluminum oxide (the chemical constituents of sapphire.) Sapphire is the second-hardest material in existence, second only to diamond. If successfully applied to glass, it can create a shatter-resistant surface—creating a major opportunity in the cell phone market.

Until recently, Solar-Tectic focused on developing comprehensive and global IP; e.g., the patent for silicon (and germanium) use in a tandem cell's bottom layer alone took over five years until issuance at the United States Patent and Trademark Office. The company is now shifting from IP development to publicizing its results through publishing papers and collaborating with universities and research groups (or in-house R&D) for technology demonstrations. At present, full-scale commercialization is dependent on securing funding to prove its top layer material systems; as a result, the company does not have a specific go-to-market timeline. Nevertheless, Solar-Tectic is leveraging its strong reputation in the research community to increase its visibility in the industry at large, as well as employing several marketing strategies to increase its presence online.

Conclusion

High manufacturing costs and inefficient panel performance impede wide-scale adoption of photovoltaic (PV) solar power. Solar-Tectic's patented (and pending) thin-film, tandem solar cell technology employs proven materials that hold the potential to make the cost of PV on par with, or cheaper than, conventional fossil-fuel technologies through catalyzing a momentous shift from the silicon wafer technology used worldwide today in 90% of the panels on the market, to thin-film silicon (in tandem with other thin-film materials). With its technical excellence, strategic execution, and potential to revolutionize the solar cell manufacturing industry, Solar-Tectic is recognized with Frost & Sullivan's 2016 Technology Innovation Award.

Significance of Technology Innovation

Ultimately, growth in any organization depends upon finding new ways to excite the market, and upon maintaining a long-term commitment to innovation. At its core, technology innovation or any other type of innovation can only be sustained with leadership in three key areas: understanding demand, nurturing the brand, and differentiating from the competition.

Understanding Technology Innovation

Technology innovation begins with a spark of creativity that is systematically pursued, developed, and commercialized. That spark can result from a successful partnership, a productive in-house innovation group, or the mind of a singular individual. Regardless of the source, the success of any new technology is ultimately determined by its innovativeness and its impact on the business as a whole.

Key Benchmarking Criteria

For the Technology Innovation Award, Frost & Sullivan analysts independently evaluated two key factors—Technology Attributes and Future Business Value—according to the criteria identified below.

Technology Attributes

Criterion 1: Industry Impact
Criterion 2: Product Impact
Criterion 3: Scalability
Criterion 4: Visionary Innovation
Criterion 5: Application Diversity

Future Business Value

Criterion 1: Financial Performance
Criterion 2: Customer Acquisition
Criterion 3: Technology Licensing
Criterion 4: Brand Loyalty
Criterion 5: Human Capital

The Intersection between 360-Degree Research and Best Practices Awards

Research Methodology

Frost & Sullivan's 360-degree research methodology represents the analytical rigor of our research process. It offers a 360-degree-view of industry challenges, trends, and issues by integrating all 7 of Frost & Sullivan's research methodologies. Too often, companies make important growth decisions based on a narrow understanding of their environment, leading to errors of both omission and commission. Successful growth strategies are founded on a thorough understanding of market, technical, economic, financial, customer, best practices, and demographic analyses. The integration of these research disciplines into the 360-degree research methodology provides an evaluation platform for benchmarking industry players and for identifying those performing at best-in-class levels.

360-DEGREE RESEARCH: SEEING ORDER IN THE CHAOS

Best Practices Recognition: 10 Steps to Researching, Identifying, and Recognizing Best Practices

Frost & Sullivan Awards follow a 10-step process to evaluate award candidates and assess their fit with select best practice criteria. The reputation and integrity of the Awards are based on close adherence to this process.

	STEP	OBJECTIVE	KEY ACTIVITIES	OUTPUT
1	**Monitor, target, and screen**	Identify award recipient candidates from around the globe	• Conduct in-depth industry research • Identify emerging sectors • Scan multiple geographies	Pipeline of candidates who potentially meet all best-practice criteria
2	**Perform 360-degree research**	Perform comprehensive, 360-degree research on all candidates in the pipeline	• Interview thought leaders and industry practitioners • Assess candidates' fit with best-practice criteria • Rank all candidates	Matrix positioning all candidates' performance relative to one another
3	**Invite thought leadership in best practices**	Perform in-depth examination of all candidates	• Confirm best-practice criteria • Examine eligibility of all candidates • Identify any information gaps	Detailed profiles of all ranked candidates
4	**Initiate research director review**	Conduct an unbiased evaluation of all candidate profiles	• Brainstorm ranking options • Invite multiple perspectives on candidates' performance • Update candidate profiles	Final prioritization of all eligible candidates and companion best-practice positioning paper
5	**Assemble panel of industry experts**	Present findings to an expert panel of industry thought leaders	• Share findings • Strengthen cases for candidate eligibility • Prioritize candidates	Refined list of prioritized award candidates
6	**Conduct global industry review**	Build consensus on award candidates' eligibility	• Hold global team meeting to review all candidates • Pressure-test fit with criteria • Confirm inclusion of all eligible candidates	Final list of eligible award candidates, representing success stories worldwide
7	**Perform quality check**	Develop official award consideration materials	• Perform final performance benchmarking activities • Write nominations • Perform quality review	High-quality, accurate, and creative presentation of nominees' successes
8	**Reconnect with panel of industry experts**	Finalize the selection of the best-practice award recipient	• Review analysis with panel • Build consensus • Select winner	Decision on which company performs best against all best-practice criteria
9	**Communicate recognition**	Inform award recipient of award recognition	• Present award to the CEO • Inspire the organization for continued success • Celebrate the recipient's performance	Announcement of award and plan for how recipient can use the award to enhance the brand
10	**Take strategic action**	Upon licensing, company may share Award publically	• Coordinate media outreach • Design a marketing plan • Assess award's role in future strategic planning	Widespread awareness of recipient's award status among investors, media personnel, and employees

About Frost & Sullivan

Frost & Sullivan, the Growth Partnership Company, enables clients to accelerate growth and achieve best in class positions in growth, innovation and leadership. The company's Growth Partnership Service provides the CEO and the CEO's Growth Team with disciplined research and best practice models to drive the generation, evaluation and implementation of powerful growth strategies. Frost & Sullivan leverages over50 years of experience in partnering with Global 1000 companies, emerging businesses and the investment community from 45 offices on six continents. To join our Growth Partnership, please visit http://www.frost.com.