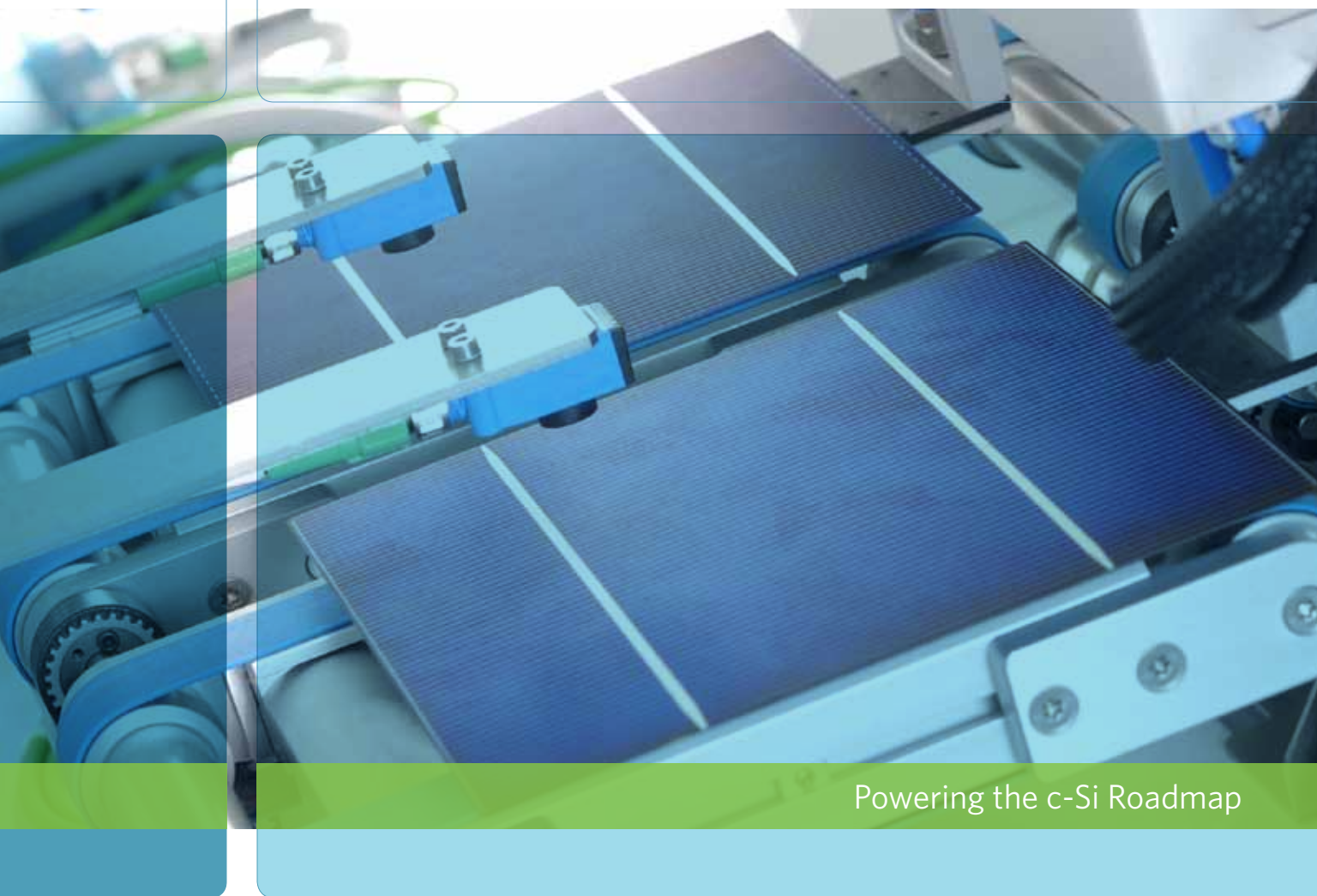
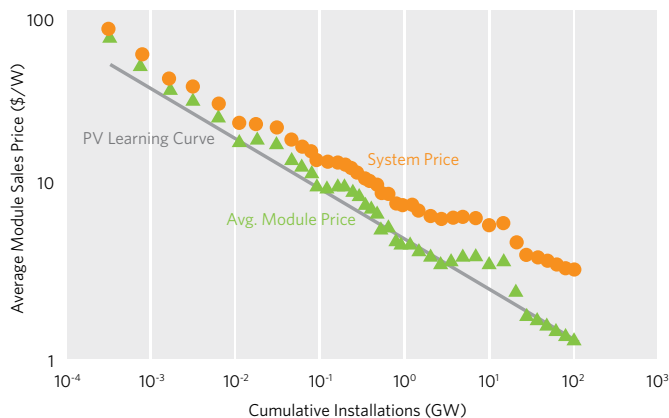




Powering the c-Si Roadmap

APPLIED BACCINI[®] CELL SYSTEMS

POWER SHIFT: ACCELERATING SOLAR PV TO GRID PARITY

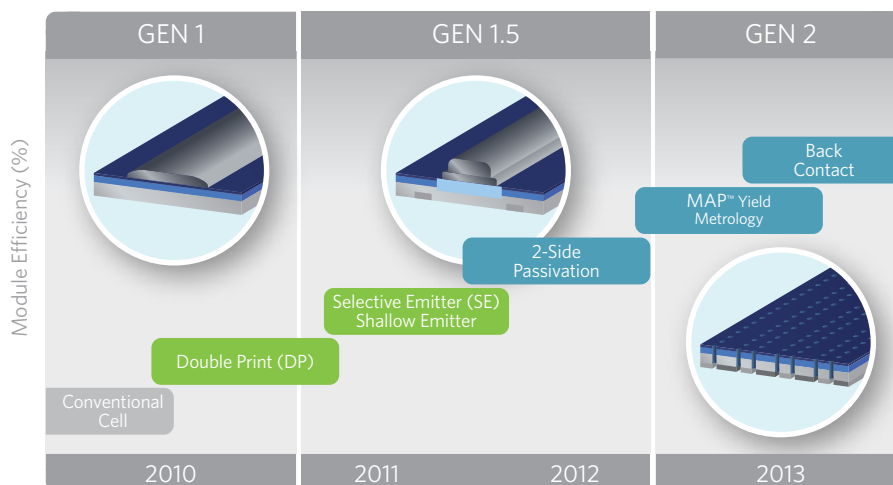


Source: Navigant Consulting

To reach grid parity and expand solar PV world wide, the industry must continue to drive down module cost per watt. In the past, these learning curve improvements have come from optimization of conventional processes, and increasing scale. We are at a major inflection point where future cost reduction must come from delivering higher efficiency cell structures at high yield, and at very high factory outputs.

ADVANCING SCALE AND TECHNOLOGY SIMULTANEOUSLY

CRYSTALLINE SILICON CELL EVOLUTION



1% EFFICIENCY = 10¢/WATT

Increasing cell efficiency is the biggest lever for reducing the cost of solar PV. Every percentage point increase in cell efficiency translates directly into a 10 cent reduction in cost per watt. The higher cell efficiency also reduces the panel area required to generate a given solar output, lowering balance-of-system cost.

To achieve these efficiency advances, the industry will undergo a series of major technology transitions in cell design over the next several years. Producing these new cell technologies at high yield can only be accomplished with a fundamental and dramatic shift in manufacturing capabilities.

ATTACKING COST PER WATT

Increasing Cell Efficiency

Scaling new cell processes, such as double printing and selective emitter, will demand major advances in the quality, accuracy and precision of screen printing, and greater levels of process control automation. Next generation cell designs will utilize entirely new process technologies, requiring cell manufacturing platforms that are extendible with reduced capital outlay. Applied Baccini is enabling these new technologies with integrated platform and process solutions that deliver high yield and throughput in volume manufacturing.

Reducing Material Cost

Bulk silicon represents 30% of the cost of a solar cell - its most expensive component. To minimize cost, the industry must reduce wafer breakage, while moving to ever thinner silicon wafers. Applied Baccini has a history of innovation in soft wafer handling, which greatly reduces wafer breakage at high manufacturing throughputs. In addition, silver paste consumption represents nearly 50% of cell metallization cost. By enabling double printing processes, Applied Baccini is helping to reduce paste costs by up to 30%.

Scaling Throughput

Increasing factory megawatt output has a major impact on reducing cost per watt. This requires processing cells at very high net throughputs, without sacrificing yield. Advances in hardware architecture and factory automation will be needed to maximize throughputs at high yield.

Applied Baccini is driving innovations in print head design, platform architecture, wafer handling and factory automation software in order to increase net throughput that will enable lowest overall cost for cell manufacturers.

EXTENDING THE POSSIBILITIES

SCREEN PRINTING TECHNOLOGY, CONTINUOUSLY RE-DEFINED

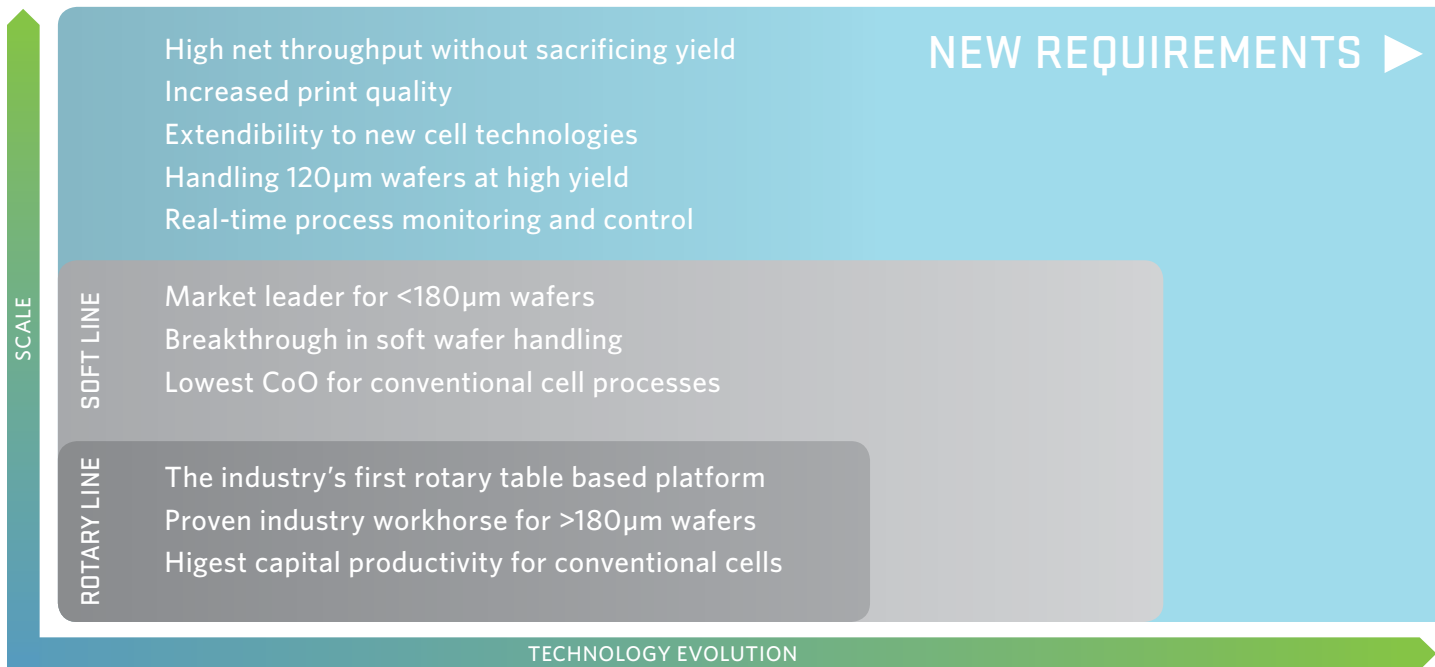


Screen printing is the method of choice for crystalline silicon (c-Si) cell manufacturing, refined over decades and proven to deliver the world's most efficient, cost effective cells. From the industry's infancy, Applied Baccini Cell Systems has pioneered a continuous stream of advances in screen printing technology and process automation. Our innovation has catalyzed major increases in factory scale and cell efficiency, and has significantly driven down cost per watt.

But today, as solar energy is poised to leap from "boutique" to "mainstream" status, further large scale cost per watt reductions require fundamental changes in the way solar cell capacity is created.

By extending a 40-year legacy of screen printing innovation into new areas, we are providing a full range of cell manufacturing platforms to meet every market need.

A RANGE OF PRODUCTION PROVEN PLATFORMS



Esatto Technology™ Enabling Advanced Cell Structures

Applied Baccini platforms are complemented by Esatto integrated process solutions, a suite of capabilities optimized to reduce cost and risk, and speed time-to-market. Esatto facilitates the creation of overlapped patterns on c-Si wafers with very high levels of precision in a manufacturing environment. Such high precision is instrumental in implementing advanced cell structures such as double printing and selective emitter.

From our position as the industry leader, Applied Baccini is uniquely empowered to convene an ecosystem of partners to meet

customer specific applications. We have a 40-year legacy of know-how and relationships that helps manufacturers extend the lifecycle and capabilities of existing systems. Esatto delivers:

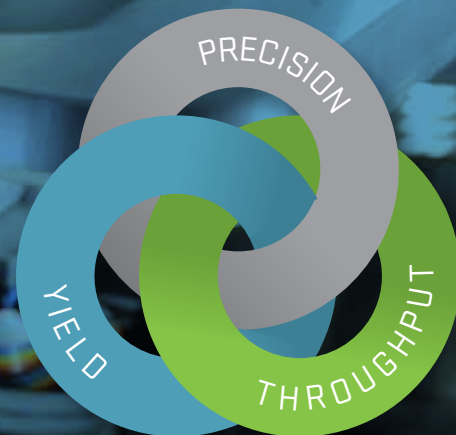
- Advanced vision systems
- Proprietary software algorithms for high precision print alignment
- Optimized consumables ideally suited for specific processes, and qualified on Applied Baccini equipment
- Process consulting



INTRODUCING
APPLIED BACCINI®

PEGASO™

An enabling platform technology
that accelerates the industry
efficiency and cost roadmaps.



A benchmark in yield and print precision at more than twice the throughput.

ALIGNMENT ACCURACY

$<8\mu\text{m}$

NAMEPLATE THROUGHPUT

$>2900\text{wph}$

NET THROUGHPUT

$>2700\text{wph}^*$

WAFER THICKNESS

$120\mu\text{m}$

WAFER BREAKAGE

$<0.15\%$ FOR ENTIRE LINE

* Effective throughput under ideal working conditions factoring in material yield and system uptime.

APPLIED BACCINI PEGASO PLATFORM

The industry's first truly modular manufacturing platform.

The solar industry's next leap forward requires simultaneous manufacturing advances that deliver high precision, accuracy and yield, at very high net throughputs. The Applied Baccini Pegaso platform provides a clear pathway to realizing all these benefits, enabling the volume production of conventional and new high-efficiency cell designs, at the lowest cost.

PATHWAY TO 100MW/YR



DUAL INDEPENDENT LANES AND PRINT HEADS

>2X the throughput in the same footprint.

System sustains 50% throughput if one lane is taken offline for maintenance.

PATH 1

PATH 2



Print

Dry



Print



THE POWER OF MODULARITY

Cutting the time, cost and risk of introducing new technologies in manufacturing.

Enables customer configurability for lowest cost.



MODULAR PRECISION

To meet precision requirements at optimal cost, new print modules can be added. Coming soon: a dual head print module based on proven Soft Line technology.

Design innovations fuel performance

NEAR ZERO WAFER BREAKAGE



Unique soft wafer handling with no edge contact. Low accel/decel optimized movement. Patented Bernoulli flipper and sort gripper.

HIGH AVAILABILITY



Dual sided maintenance access and offline module repair reduce mean time to repair (MTTR). Rapid process recipe optimization.

ADVANCED PROCESS CONTROL



Extensive collection of data parameters on every wafer processed. Connectivity to E3™ software for data logging, fault detection, run-to-run control and closed loop control of print process.

REMOTE MONITORING AND CONTROL



Single wire connectivity to front end server enables complete line control from any module along the line, in addition to facilitating remote system operation and process monitoring.



MODULAR CONFIGURABILITY

Line configuration can be optimized for performance and cost. Process or metrology modules can be added to meet customer unique applications at the lowest cost.



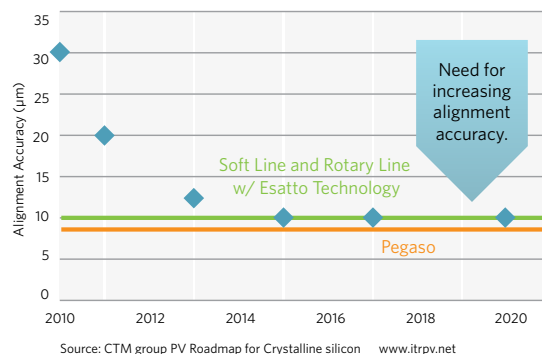
MODULAR EXTENSIBILITY

New cell designs can be manufactured by integrating entirely new technology modules into an existing line.

APPLIED BACCINI PEGASO-XP PRINTER

A game-changing breakthrough in printer technology.

To enable large-scale production of the most advanced double printing, selective emitter and other cell processes, the Applied Baccini Pegaso platform incorporates a revolutionary new dual print head technology, Pegaso-XP. This technology sets a new benchmark in print quality, accuracy and precision at high throughput, allowing cell manufacturers to achieve a tighter distribution of wafer performance – and higher revenues.

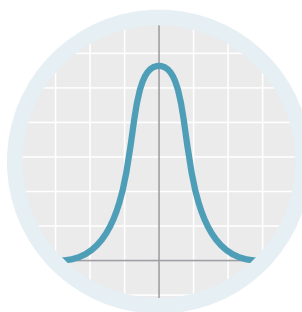


Tighter process distribution by design.

<8 μ m ACCURACY

$\pm$ 10 μ m PRECISION

<0.10% WAFER BREAKAGE



Tighter process control

Planar motor design provides full drift control. z and theta print head control, and the ability to manipulate squeegee angle and pressure, enable greater process regulation.



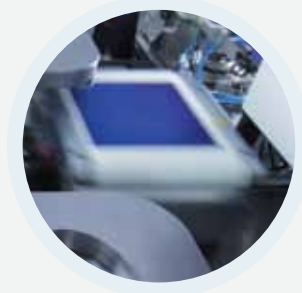
Reduced print variability

Embedded high resolution optical pre-print and post-print inspection systems enable full area alignment with closed loop control.



Greater availability

Automated wafer inspection and rejection prior to printing, and quick screen change (<40 seconds), increase system uptime.



Enhanced print quality

Fully independent shuttles ensure precise wafer placement under print head.



PRODUCTION-PROVEN PLATFORMS

A HISTORY OF RELIABLE PERFORMANCE

The Baccini Rotary Line and Soft Line platforms are the cornerstone of almost every solar factory in the world today, well-known for their productivity, reliability and yield in demanding production environments. Both platforms bear testimony to Baccini's role as the true industry pioneer and technology leader. And the platforms' well entrenched position in the market for over several years validates their superior technological capabilities and cost of ownership. Baccini continues to further innovation on these platforms to help customers stay competitive in the marketplace.

Screen Printer



Loader

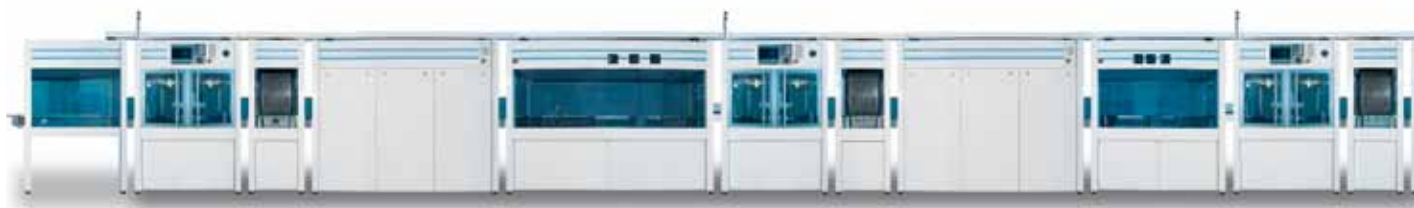
Applied Baccini Soft Line

Advanced platform for
handling thin wafers at the
lowest CoO.

- Market leader for <180µm cells
- Net throughput >1,250 wafers per hour, 45MW/YR
- <0.2% breakage rate for full line
- Lowest CoO for conventional cells

<180µm Cell Production

Automated Optical
Inspection System



Screen Printer

Dryer

Dryer

Applied Baccini Rotary Line

Proven production platform
with the highest
capital productivity.

- Market/installed base leader for conventional cells
- Net throughput >1,200 wafers per hour, 40MW/YR
- <0.5% wafer breakage for full line
- Highest capital productivity for conventional cells

>180 μ m Cell Production

Automated Optical
Inspection System

Laser Edge
Isolation System



Dryer

Tester

Cartesian Sorter

TECHNOLOGY LEADERSHIP



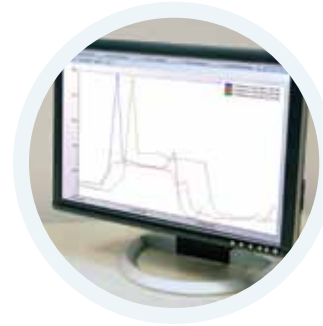
High Uptime

- Automatic inspection (rejection/recovery capabilities)
- Automatic paste refilling and screen cleaning device
- Automatic paper roll refresh and easily replaceable print nest cartridges



Soft Handling

- Highly controlled wafer handling and transportation
- Use of paper on print nest
- Print head adjustment and positioning for set-up eliminates the need for pick-and-place relocation of the wafer



E3 Diagnostics Software

- Monitors equipment
- Detects and classifies faults
- Tracks performance
- Controls process run to run
- Analyzes data and reports statistics

Laser Edge
Isolation System



Tester

Super Sorter

DOUBLE PRINTING

To maximize efficiency, cell designs need to minimize shadowing of the active surface while also reducing resistive losses. An advanced printing technique, double printing, places a second, narrow layer of silver paste on top of a conventional contact line, achieving a narrow profile that reduces line resistance without increasing width. Double printing drives down cost per watt by increasing cell efficiency as well as by reducing paste consumption.

Double printing is one of the first cell enhancements to benefit from Esatto Technology. Esatto Technology uniquely delivers this capability through a combination of hardware and software that ensures alignment accuracy — a critical factor for double printing and other multi-printing applications. In addition, an integrated approach to optimize paste, screen, and process ensures repeatable results in manufacturing.

Double printing using Esatto Technology is in volume production at a number of leading customer locations — and is generating several additional megawatts with only one extra printer and drying oven.

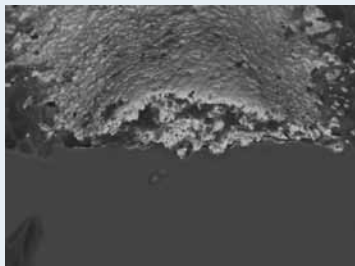
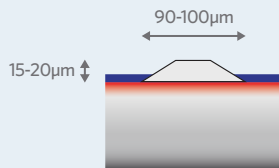
SILVER IS **50%**
OF METALLIZATION COST



ENABLED BY ESATTO
TECHNOLOGY

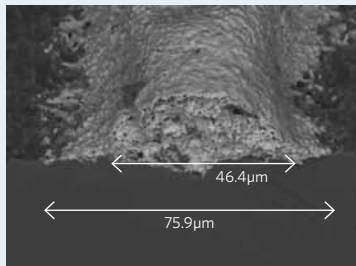
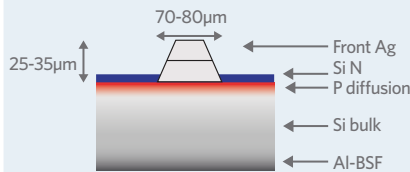


SINGLE PRINTING



Single Print 90µm x 18µm

DOUBLE PRINTING



Double Print 76µm x 25µm



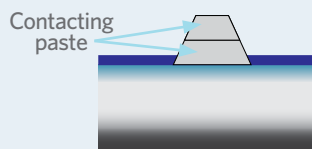
0.12% EFFICIENCY GAIN

28% PASTE REDUCTION

Paste optimization

In double printing Gen 1, the finger patterns are screen printed twice, with the same silver paste. In double printing Gen 2, two different pastes are used for the top and bottom layers, further improving performance with reduced paste consumption.

DOUBLE PRINTING 1

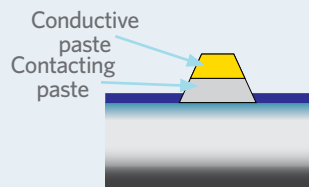


First layout



Second layout

DOUBLE PRINTING 2



First layout



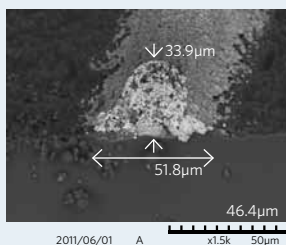
Second layout

Fine line printing

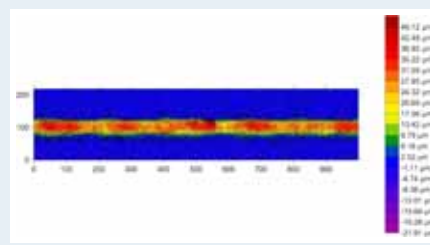
Through the Esatto Technology initiative, Applied Baccini is collaborating with major paste manufacturers to improve and bring to market fine line double printing. Fine line double printing Gen 2 has been proven to increase cell efficiency by 0.12% and decrease paste consumption by 28%.

	Width [μm]	Height [μm]	A/R	Weight [mg]	Voc [mV]	Isc [A]	FF [%]	Rs [mOhm]	Rsh [Ohm]	Eff [%]
SP	98	25	0.25	185	622	8.18	78	3.38	24.7	16.33
DPII fineline	62	28	0.45	134	627	8.31	76.7	5.11	23.6	16.45

Table 1 Morphological and electrical data for SP and fine line double printing



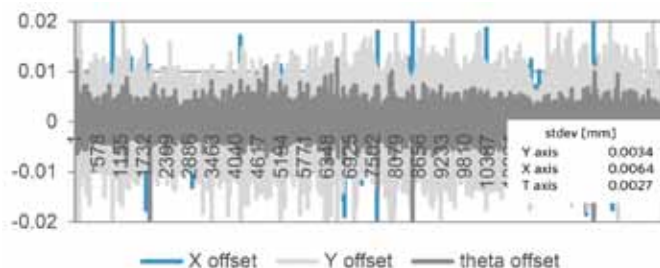
SEM Photo of fine line
DPII 52μm x 34μm



3D laser scan of fine line finger with roughness
Rz of 11μm and finger width 62μm

Closed loop control

To achieve constant production monitoring, the Applied Baccini Pegaso platform delivers closed loop control for double printing with a pre- and post-print optical inspection system that monitors process parameters and provides real-time feedback to operators.



Offset control during DPII production

SELECTIVE EMITTER

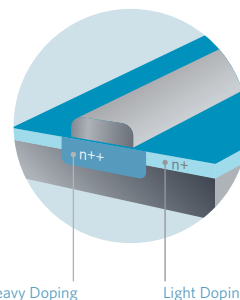
Selective emitters (SE) on high performance cells increase efficiency by improving panel voltage and current (Voc and Isc) values and minimizing recombination and resistive losses. It is extremely critical to align the metal lines precisely on top of the selective emitters, so that the highly doped regions lie directly below the contact fingers. If the metal lines are not printed precisely the cell can fail due to a shunt. Correct and robust alignment also enlarges all downstream and upstream process windows.

Esatto Technology metallization solutions offer the ideal solution independent of wafer type and SE formation methods with

upgradable high-precision kits. Esatto's high-precision camera kits, illumination systems and advanced software enable precise alignment of metal critical for SE structure formation.

Esatto Technology supports all aspects of the selective emitter process, including the selection and printing of the high-dose doping paste, etching paste and contact paste, in addition to providing innovative screen technology.

Double printing over selective emitter structures using Esatto Technology further boosts cell efficiency and also reduces consumption of silver paste.



- Heavily doped region is limited to the emitter contact area
- Metal needs to be aligned on top of emitter for best efficiency
- Reduced width of the heavily doped region limits recombination

>0.5% EFFICIENCY GAIN

SE Methods - Paths to Selective Emitter

There are several different known SE formation methods. Applied Materials' screen printing platforms and Esatto Technology provide all the elements required for tightly aligning and printing the front metal grid over the SE pattern.

Advanced vision, alignment, and print solutions detect difficult to see SE patterns to accurately print over the SE region.

Esatto Technology Alignment Capability



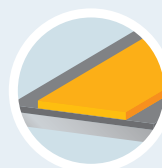
Difficult to "see" SE



Esatto Technology

1 PRINTED DOPANTS

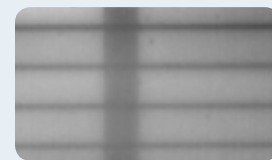
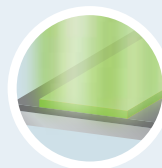
- Single print and dry step
- Easy integration
- Low cost



Dopant Paste / Mono c-Si

2 LASER DOPING

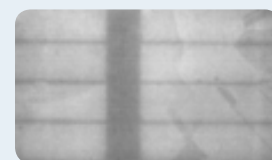
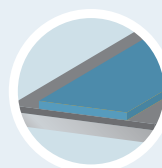
- Additional 1-2 steps
- Sharp junctions
- Cell reliability issues



Laser Doping / Mono c-Si

3 ETCH BACK

- Multiple additional processing steps
- Narrow process window



Etch Back / Multi c-Si

4 ION IMPLANTATION

- Profile control
- Implant followed by high temperature annealing
- High capital cost



Ion Implant / Mono c-Si

Applied Baccini Selective Emitter Formation Solution

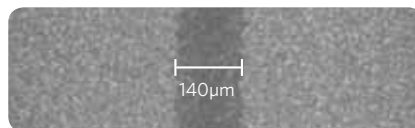
Leveraging Esatto Technology, Applied Baccini offers a selective emitter formation solution that provides customers with a rapid, low-risk route to fabricate SE structures.

The Applied Baccini solution involves a simple direct dopant process using standard Baccini equipment for screen printing the dopant; qualified paste; high lifetime, non-metal screens and dedicated process support. It is easily integrated into the cell manufacturing process immediately before the conventional emitter diffusion and subsequent phosphorous gas (PSG) removal processes. Precise alignment of front metal contact is enabled by Esatto Technology. Applied Baccini's selective emitter formation solution has been proven to raise absolute cell efficiencies by more than 0.5%.

Selective Emitter Development Structures



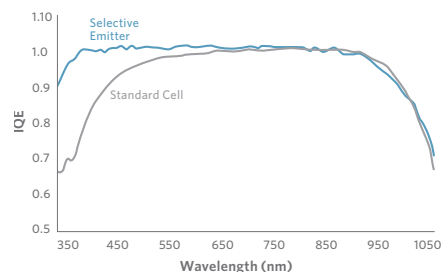
As printed



After diffusion/drive-in

Dopants screen printed utilizing Esatto Technology show excellent placement accuracy and line edge control.

Selective Emitter Efficiency Gains Internal Quantum Efficiency



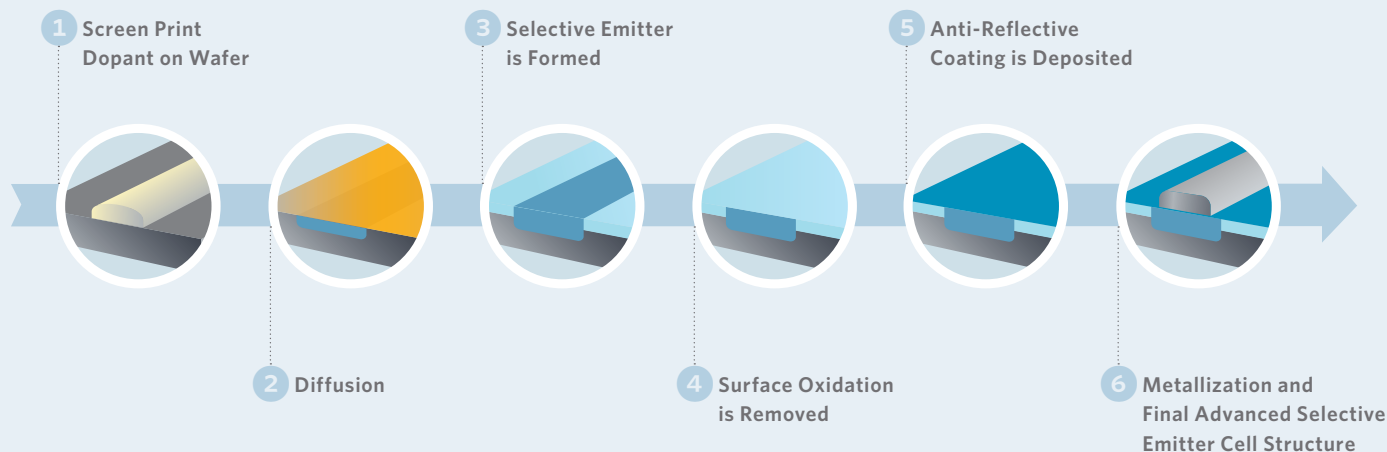
Short wavelength light response improvement with PDP SE and optimized POCl diffusion.

0.5% efficiency enhancement achieved for mono c-Si.

SE Process Flow

Add just one Baccini printer and dryer to your cell manufacturing line.
Optimized process recipes and qualified consumables deliver proven results.

- Simple direct dopant process
- Standard equipment
- Easy integration
- Qualified consumables
- Proven screen printing technology



STATE OF THE ART R&D AND SERVICE TECHNOLOGY CAPABILITY

APPLIED R&D CAPABILITY REDUCING THE TIME, COST AND RISK FOR CUSTOMERS

- Advanced cell manufacturing development
- Process research and optimization
- Advanced screen printing technology development and performance validation
- Performance validation on full cell line
- Application development for customer specific solutions



Wafering Apps and Cell Manufacturing Lab Xi'an China

Process validation on
wider data sets

Hardware reliability testing

Performance validation on cell line

Customer demos and training



Manufacturing Center of Excellence Treviso, Italy

New product and process
development

Development and demonstration
of advanced cell metallization

Customer demos and training

APPLIED GLOBAL SERVICES PRODUCTIVITY SOLUTIONS FOR SUSTAINABLE HIGH TECH MANUFACTURING

Applied Global Services has the solar industry's largest team of highly trained support experts and provides spare parts, parts refurbishment and system upgrades, all designed to help you get the most out of your tools.



E3™ Automation

The Applied Materials E3 equipment diagnostics platform connects to any solar tool, providing pre-integrated MES connectivity specifically designed for c-Si manufacturing. For example, the E3 SPC component automatically detects product quality variations, providing control charts, automatic notification and a corrective action plan to factory operators.



SmartFactory™

SmartFactory is a scalable, affordable factory automation solution that improves tool utilization and increases throughput. By tracking work-in-progress (WIP) within a factory, SmartFactory assures high factory productivity.

MARKET AND TECHNOLOGY LEADERSHIP



OVER 40 YEARS OF TECHNOLOGY LEADERSHIP

First fully integrated cell metallization line for c-Si solar cells

First twin-table and rotary-table screen printer technology

First planar motor positioning for print accuracy control

First to enable alignment on invisible patterns for selective emitter

First to enable double printing in high volume manufacturing

First to deploy automatic testing and sorting of solar cells

First to enable in line metrology

First fully modular platform with dual independent lanes for integrated cell manufacturing

Over **7** billion cells processed worldwide at more than **120** customers

>40GW of installed capacity of screen printing tools in the field

Market **leader** for screen printing and integrated metallization systems

Technology leader in **advanced** cell manufacturing processes and ultra-thin wafer handling

Track **record** of system reliability and manufacturing productivity

Backed by the **global service**, supply chain, process expertise and factory automation capability of Applied Materials

From the **#1 producer** of solar and semiconductor processing equipment



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