Plasmait

Heat & Surface Treatment

CabWire World Conference 2011

Dusseldorf, 7th – 8th of Nov 2011

Production of PV Ribbon for Photovoltaic Solar Panels:

Overview of Product Specifications and Comparison of Production Processes

Authors:

Igor Rogelj, Commercial Director, Plasmait GmbH (Presenter)

Peter Ziger, Technical Director, Plasmait GmbH

Primoz Eiselt, MD, Plasmait GmbH

Plasmait

Heat & Surface Treatment

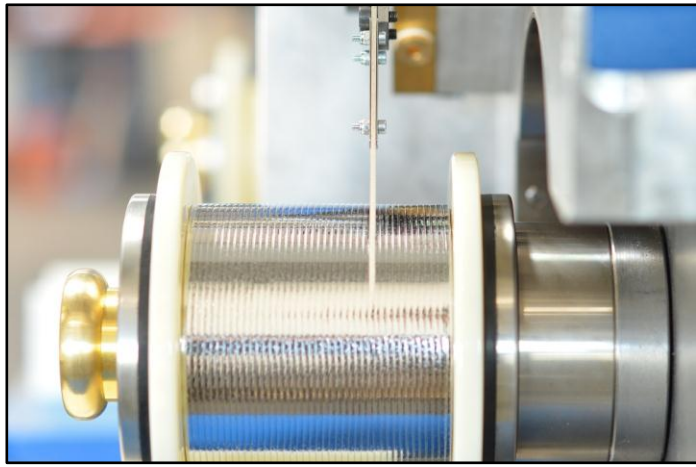
Agenda

- Introduction: What is PV Ribbon?
- PV Ribbon Market and Market Dynamics
- PV Ribbon Specifications & Requirements
- Alternative PV Ribbon Production Processes
  - Annealing
  - Tinning
- PlasmaPREPLATE Tinning vs. Traditional Process

What is PV Ribbon?

- **Interconnect/Tabbing Ribbon**

Interconnect ribbon is a hot dip tinned copper conductor installed in photovoltaic/solar panels. The interconnect ribbon is soldered directly onto silicon crystal to interconnect solar cells in a solar panel. The interconnect ribbon carries the current generated in solar cells to the PV bus bar.



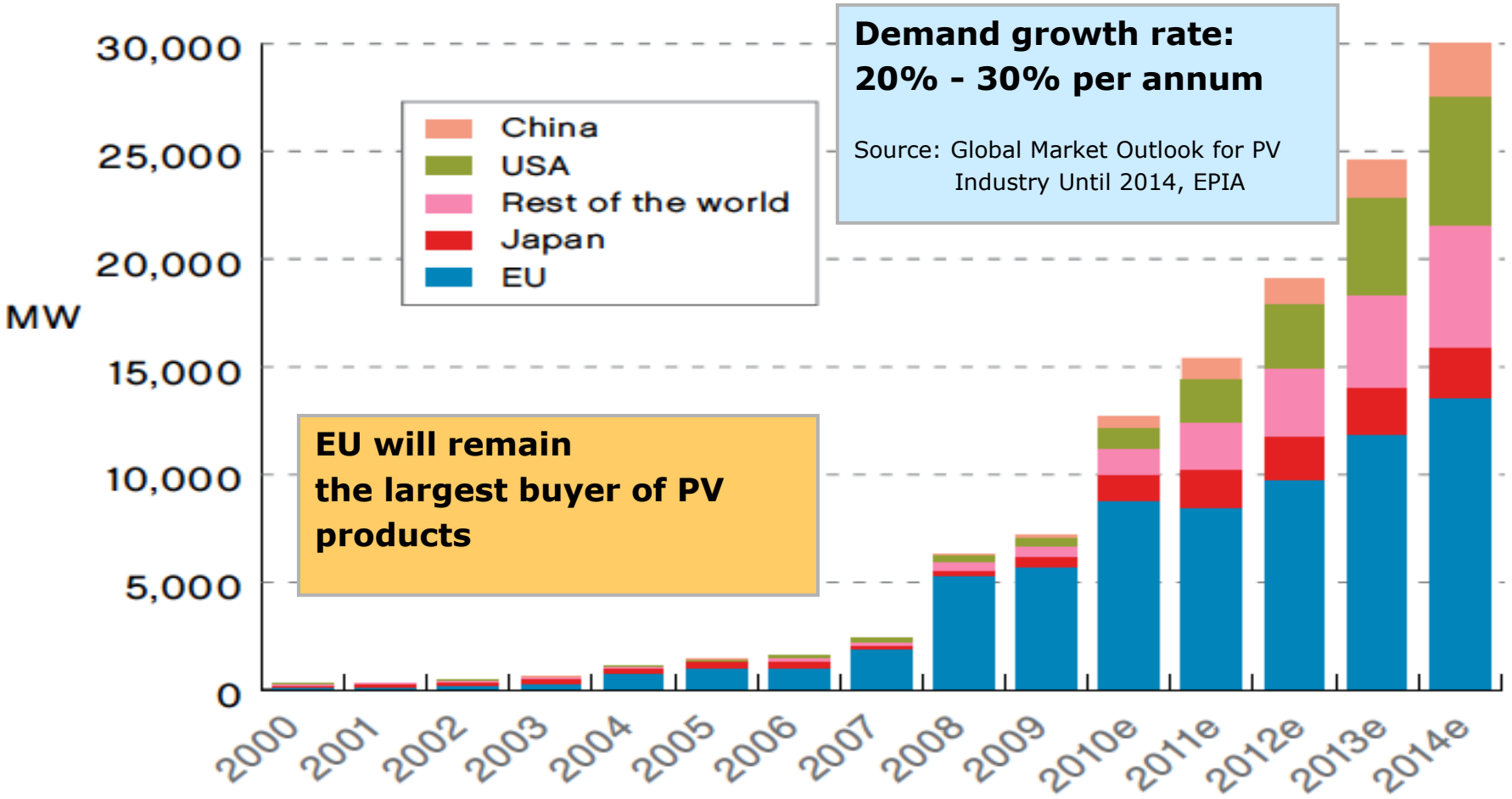
- **PV Bus Bar**

PV bus bar is a hot dip tinned copper conductor installed in solar panels. PV bus bar carries electric current from interconnect ribbons to the junction box.

Plasmait

Heat & Surface Treatment

Industry Outlook: PV Market Demand



Plasmait

Heat & Surface Treatment

PV Ribbon Industry Dynamics

SOLAR PANEL MARKET PLACE & PV RIBBON REQUIREMENTS:

- Over **300 manufacturers** of solar panel worldwide
- Solar Panel market is **fragmented market place in consolidation**
- **Electronics & semiconductor companies** are moving into solar market
- **Fast growing industry** with average annual growth rates of 30%+
- Many different types of panels & cells => **many different types of PV ribbons**
- Innovation & new cell & panel design => **changing PV ribbon specifications**
- Constant price pressure on solar panel => **pressure on PV ribbon pricing**
- Ever more demanding PV ribbon specifications:
  - **Ever thinner cells => ever softer wire, particularly Yield Strength**
  - **3 ribbons per cell instead of 2 => smaller ribbons & larger output required**
  - **More automated panel production & soldering => ever smaller PV ribbon tolerances**

Plasmait

Heat & Surface Treatment

Market Drivers for a PV Ribbon Supplier

- **Changing product specifications** with new PV ribbon products
- Speed of **product development** and **flexible specification range** is key
- PV ribbon is a key component to ensure panel **efficiency and durability**
- Quality PV ribbon reduces **stringer downtime and scrap rate on stringer**
- Cost of PV ribbon is **2% - 4% of total cost** of solar panel
- Panel manufacturer is prepared to **pay for quality** ribbon

=> premium price for quality ribbon

=> quality of PV ribbon & tolerances are getting ever more important

- **First standards for PV ribbon** have just been introduced in Aug11
- PV ribbon production & soldering **processes have not matured yet**

Plasmait

Heat & Surface Treatment

PV Ribbon Product Range

- PV Ribbon size range:
  - PV Bus Bar: width [3mm – 6mm] x thickness [0.2mm – 0.5mm]
  - Interconnect Ribbon: width [1mm – 3mm] x thickness [0.08mm – 0.2mm]
  - **No standardisation yet on ribbon dimensions**
- Spool on types on tinning line payoff / rolling mill takeup:
  - Various spools sizes: 50kg – 600kg
  - Typical spool types: K355, DWF500, DM630
- Packing options:
  - Various spools sizes: 1kg – 22kg
  - Typical spool types: Europe: DIN K125, K160, K200, K250 / Asia: P4, P10
  - **No standardisation yet on packing options**

Plasmait

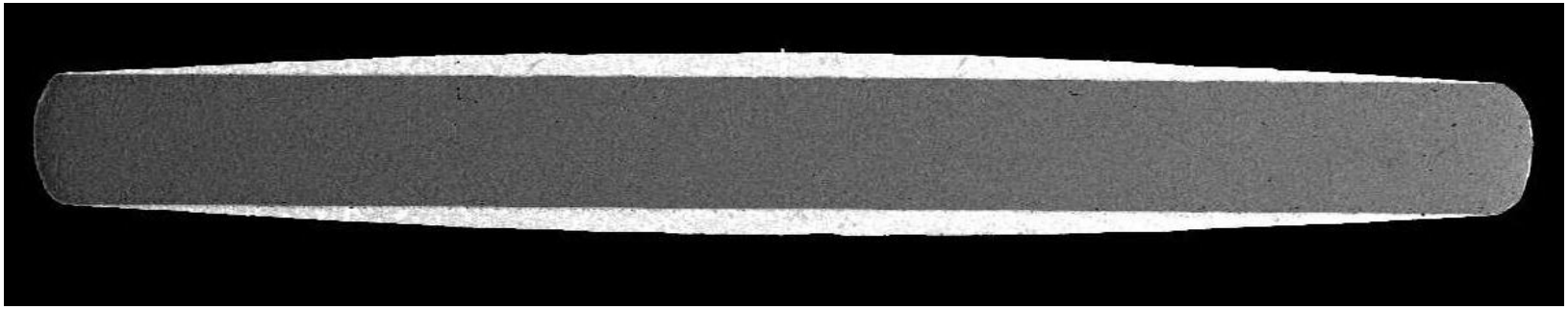
Heat & Surface Treatment

Copper and Solder Specifications

- **Conductor material**: ETP, DIP Form, or OFC (CD-110, CD-101, CD-102)
- **Lead free solder**: Sn 100
- **Lead containing solder**: SnPb 60/40
- **Silver containing solder**: SnAg 96.5/3.5; SnAgCu 96.5/3.0/0.5
- **Lead & silver containing solder**: SnPbAg 62/36/2
- **Low Temperature solder**: BiSn 57/43; BiSnAg 57.7/42/0.3
- **No standardization yet on copper and solder specifications**

Solder Coating Specifications

- Solder coat thickness range: 10 – 40micron +/- 10% - 30%
- Typical solder coat thickness: 20 micron +/- 4micron
- Thickness measuring devices:
  - **X-Ray**: offline one-side thickness measurement
  - **Micrometer:** offline two-side thickness measurement
  - **Laser:** inline two-side thickness measurement
- **No standardization yet on solder coating specifications**



Mechanical Properties of PV Ribbon

- Tensile Strength: < 250N/mm^2
- Elongation: > 20%
- Camber: < 0.5% [5mm on 1m length]
- Yield Strength (Rp0.2%):
  - Hard / semi hard > 120MPa
  - Soft < 80MPa
  - Super soft < 65MPa

Plasmait

Heat & Surface Treatment

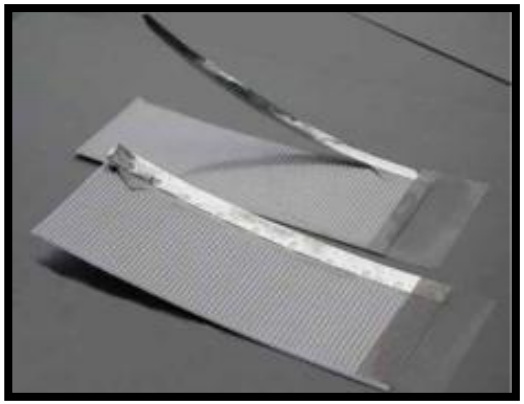
CRITICAL PARAMETER: YIELD STRENGTH

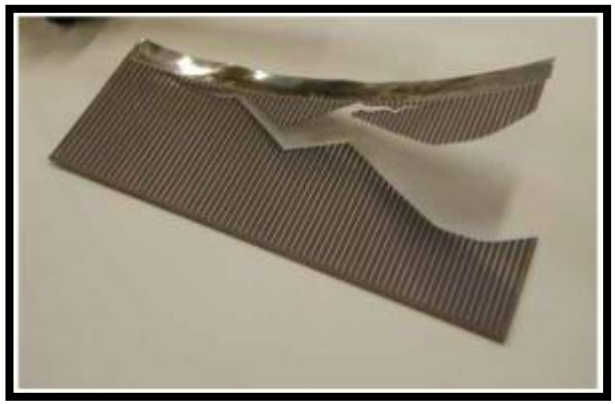
WARPAGE is a result of cooling of solar cell after soldering/stringing

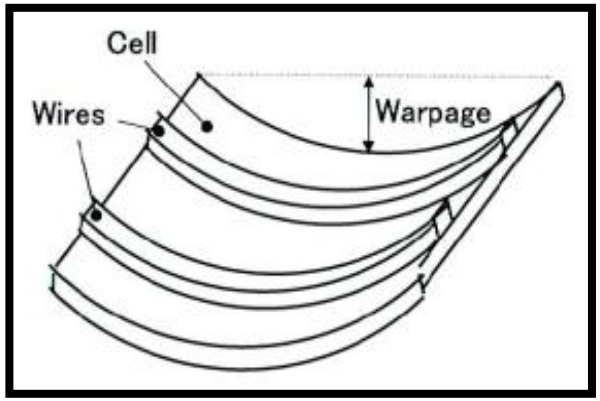
Ever thinner solar cells require ever lower YS (Rp0.2%)

- **5 year ago**: 300µm thick Si solar cell => YS < 130MPa
- **Today**: 160-180µm thick Si solar cell => YS < 80MPa
- **Tomorrow**: trend to thinner Si solar cell => YS < 65MPa

Bare copper ribbon thickness should be used for YS Rp0.2% measurement!



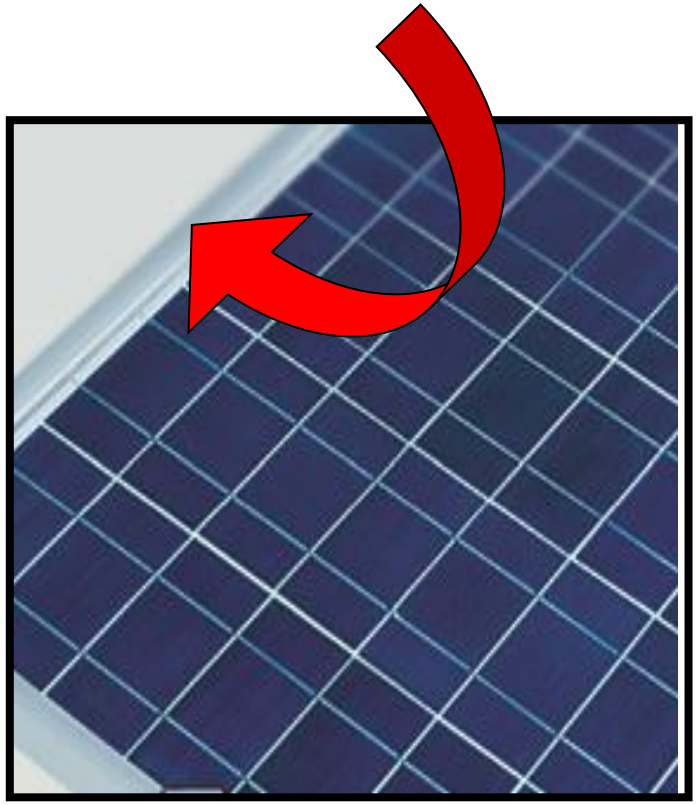




CRITICAL PARAMETER: ELONGATION

Elongation: > 20% (as high as possible)

- Continuous temperature fluctuations during the lifetime of solar panel put solder joints to the test for the duration of the panel lifespan (average 25 years)
- PV ribbon breakages may occur due to stretching/tension along the ribbons
- Sufficient elongation allows ribbon stretching to minimise joint breakages between the interconnect ribbon and bus bar on the edge of the solar panel.



CRITICAL PARAMETER: CAMBER

- Production of solar panels has become fully-automated with increasing stringing speeds
- High-output fully-automated stringers require low camber to minimise down-time and scrap

TODAY: Target Camber < 5mm in 1m

TOMORROW: Target Camber < 3mm in 1m

Plasmait

Heat & Surface Treatment

Annealing Techniques four PV Ribbon Production

- **Resistive annealing**
  - √ Low cost high output annealing for in-line operation with rolling
  - **X** Mechanical properties cannot be achieved (e.g. Yield Strength)
  - **X** Surface damaged by sparks and rolling lubricant deposits get burned onto the ribbon
- **Bell annealing**
  - √ High output but long time of annealing-cooling cycles
  - √ YS can be as low as 50MPa but with low elongation
  - **X** High investment cost – controlled atmosphere bell annealer
  - **X** Spots on surface due to rolling lubricant deposits – if no pre-cleaning
  - **X** Sticking of ribbon on spool due to high temperature/long annealing time
- **Strand (tube) furnace annealing**
  - √ Softness is achievable
  - **X** Too slow to run inline with rolling => multi-line setup & expensive material manipulation
  - **X** multi-line system = multiple takeups & payoffs
  - **X** High production and maintenance costs

Plasmait

Heat & Surface Treatment

Annealing Techniques four PV Ribbon Production

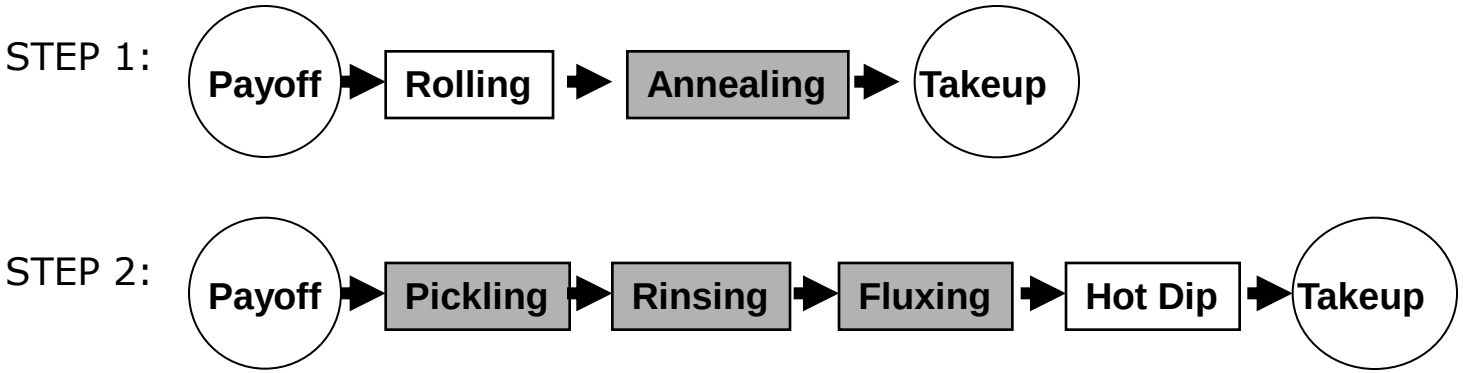
- **Inductive annealing**
  - ✓ High output solution running inline with rolling
  - **X** Limited control over mechanical properties due to inaccurate load matching (YS tolerance)
  - **X** High softness PV ribbon not possible (Yield Strength)
  - **X** Surface deposits get burned onto the ribbon resulting in compromised surface quality
- **Plasma annealing**
  - ✓ High output solution running inline with rolling mill or in line with tinning
  - ✓ Superior surface cleanliness (annealing + degreasing + de-oxidation + surface activation)
  - ✓ Contact-less process = no contact with ribbon
  - ✓ Superior mechanical properties [YS Rp0.2% min. 50N/mm^2; Elongation max. 40%]
  - ✓ Accurate control of mechanical properties through power control
  - ✓ Contact-less process = virtually no wear parts + low maintenance and process costs
  - **X** High capital investment, but surface cleaning included with annealing

Plasmait

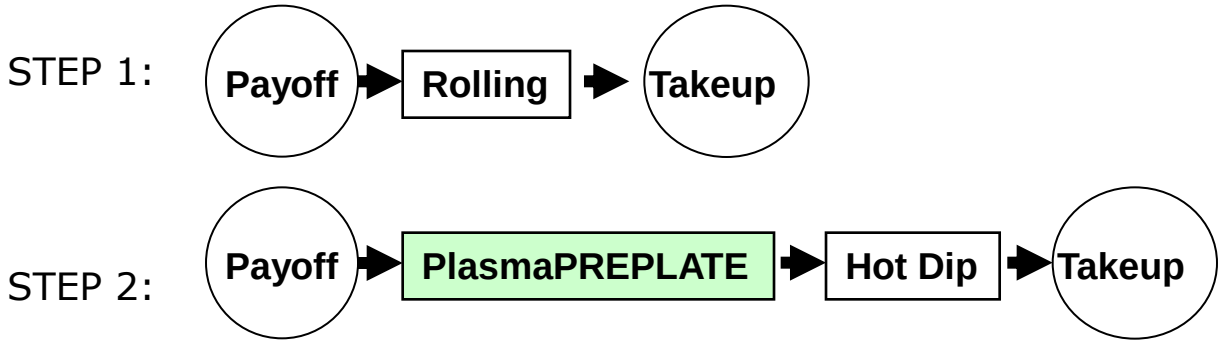
Heat & Surface Treatment

Traditional Process vs. PlasmaPREPLATE Tinning

Traditional Process of Hot Dip Tinning



PlasmaPREPLATE in Hot Dip Tinning Process



Plasmait

Heat & Surface Treatment

Traditional Process for PV Ribbon Production

ROLLING

- High speed rolling, off-line from tinning

TINNING

- Multi-line tinning with chemical pre-cleaning: 2, 3 or 6 lines in parallel
- Tinning speed: 5m/min – 30m/min, subject to product and softness spec.
- Complexity of process control in multi-line process due to interference
- Acid, rinsing, fluxing necessary prior to tinning
- Solder waste due to oxidation and flux contamination in bath
- Scrap rate issues:
  - Wet processes difficult to control inline
  - Mechanical properties are difficult to control due to soft ribbon manipulation
  - Tin coat thickness tolerance difficult to control due to low speed wiping
- Working capital locked on every line (the cost of copper & tin on each line)

Plasmait

Heat & Surface Treatment

PlasmaPREPLATE Process for PV Ribbon

ROLLING

- High speed rolling, off-line from tinning

OR

- Small rolling mill inline with tinning (interconnect ribbon only)

PlasmaPREPLATE TINNING

- Single line tinning without chemical cleaning and no fluxing
- Tinning speed: up to 150m/min, subject to product and softness
- Production utilisation rate of up to 95%
- Finished product packing for full range of spool and disc types
- Acid-free and flux-free, environment-friendly production
- Computer control over production parameters of annealing, tinning, wiping
- Computer based inline quality control
- Small footprint

Plasmait

Heat & Surface Treatment

PlasmaPREPLATE Tinning Line for PV Ribbon Production

Payoff > PlasmaPREPLATE (annealing & surface preparation) > Tinning > Takeup

Heat & Surface Treatment

PV Ribbon Product Quality
Benefits of PlasmaPREPLATE vs. Traditional Process

- Superior and consistent product quality:
  - Super soft wire with YS down to 50MPa & high level of elongation over 30%
  - Smooth consistent and shiny tin coat with lower thickness tolerance
  - Flux & chemical-free tinning allows better process control and finished product quality
- Rapid product development for new products with various specifications => sales
- Computer enabled, inline product quality control
- Computer assisted production know-how management
- Production Recipe Database
- Inline laser coating thickness measurement system
- Alarm system and surface fault record database

Plasmait

Heat & Surface Treatment

Cost of PV ribbon Production
Benefits of PlasmaPREPLATE vs. Traditional Process

- High production speed – **up to 150m/min**
- High production speed, production automation & process control = **less man power**
- Increased production **uptime**
- **Dry surface preparation** (no rinsing, no drying, no waste disposal, no water treatment)
- Considerably **less tin waste** – no flux contamination of tin
- **Quick changeover** between different product ranges & specifications
- Low **operation costs** (lower power, cost of chemicals and their manipulation)
- Low **maintenance costs**
- Small **footprint**
- Computer enabled basic **maintenance alerts**
- **Inline quality control = improved product quality = less scrap and returns**