GT ADVANCED TECHNOLOGIES

"Plasma CVD passivation; Key to high efficiency silicon solar cells",

David Tanner

Date: May 7, 2015

Summary:

- Remarkable efficiency improvements of silicon solar cells have been realized over the last 25 years.

- The key technical developments are;
  - Improvements in silicon quality for both mono and multi-crystalline type wafers.
  - Development of new silver pastes
  - Development of new fine-line capable SS screens
  - Development of p and n type passivating dielectrics.

- Coupled with new cells designs, the above technologies have allowed for interactive improvements of the solar cell performance

Silicon Solar Cell Efficiency Improvements

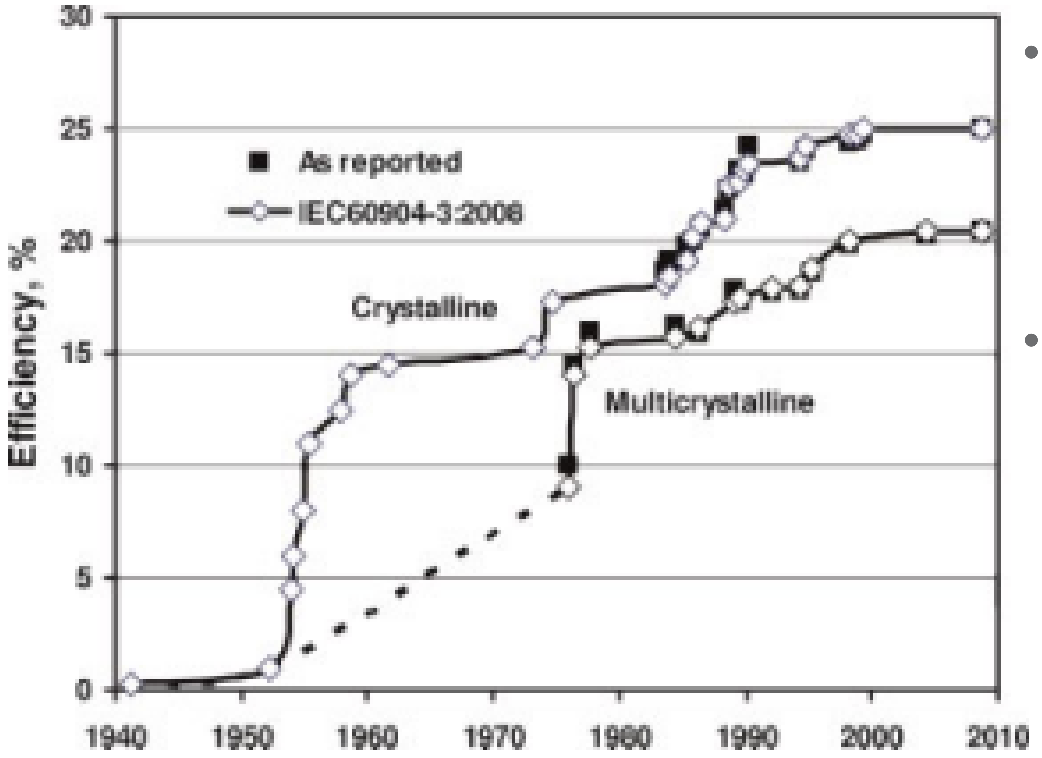

Figure 3. Evolution of crystalline and multicrystalline silicon solar cell efficiency

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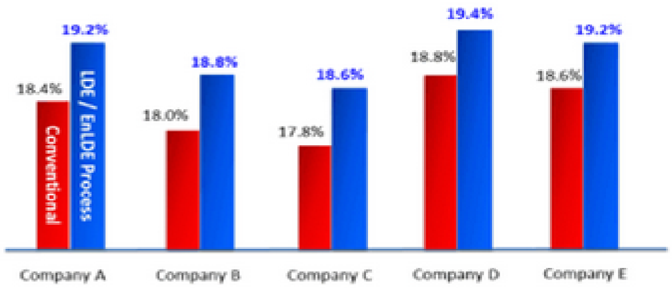
- **There have been large improvements of silicon solar cell commercial efficiencies since 1990.**

- **Surface passivation using plasma deposition of dielectric layers has played a large role in driving and enabling the large efficiency improvements.**

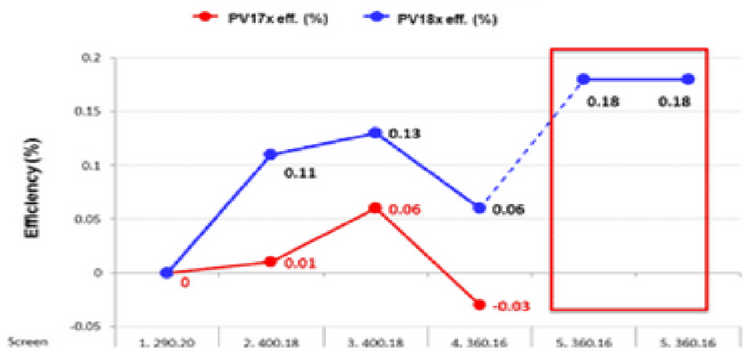
Silver Paste and Diffusion Optimization

DuPont™ Solamet® PV18x
Improved performance through diffusion optimization



DuPont™ Solamet® is the real and authentic LDE enabler achieving >0.5% cell efficiency gain

DuPont™ Solamet® PV18x Boost Efficiency by Screen Optimization on High R_{sheet} Wafers

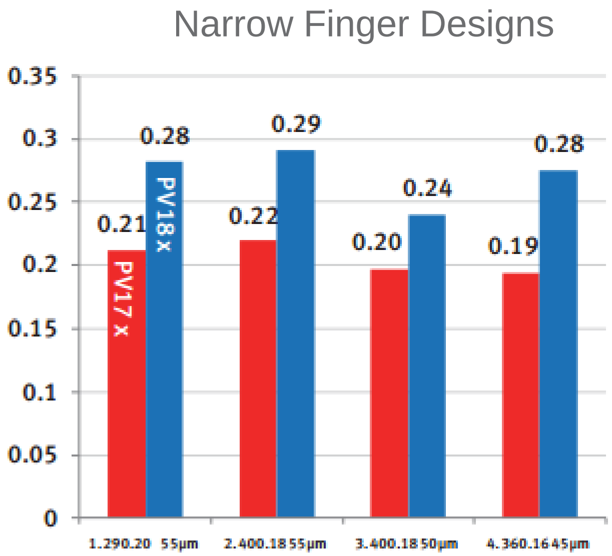


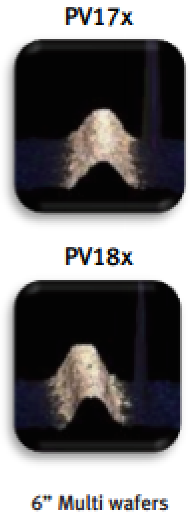
Solamet® PV18x improved performance through diffussion optimization

Solamet® is the real LDE enabler achieving >0.5% cell efficiency gain

- **Improved silver pastes have dropped the typical contact resistance about 4X**
- **This allowed for retuning the POCl3 diffusion process to higher sheet resistance and thinner junctions (better cell voltage and current).**
- **This also allows for the Si3N4 anti-reflection coating passivating coating to be more effective. The surface passivation quality is directly related the surface doping concentration.**

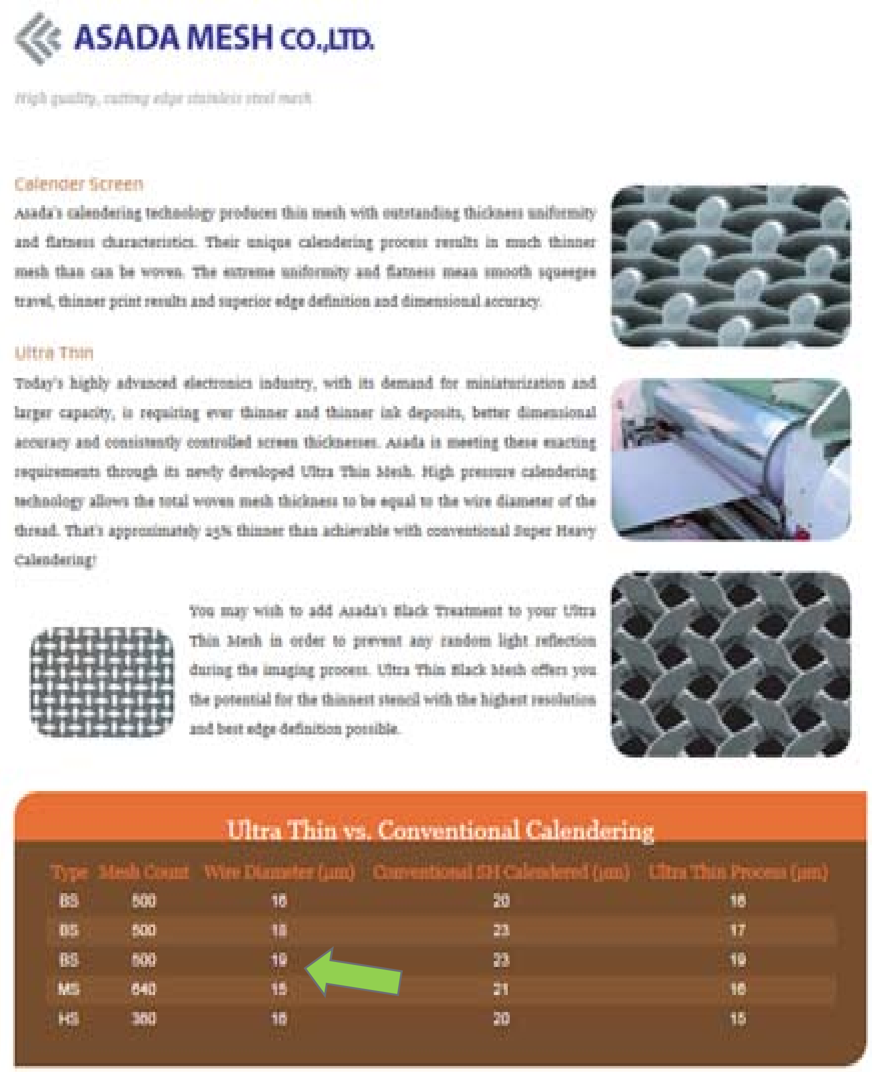
Silver Paste and New Screen Technology





DuPont™ Solamet® PV18x improve aspect ratio with narrow finger line design

- **With new screen technology with small diameter wire with the new silver paste formulation can be printed with 45-55um finger widths.**
- **This reduces the shadowing of the contacts and reduces the area of the contacts making the surface passivation more effective**



ASADA MESH CO.,LTD.

Calender Screen

Asada's calendering technology produces thin mesh with outstanding thickness uniformity and flatness characteristics. Their unique calendering process results in much thinner mesh than can be woven. The extreme uniformity and flatness mean smooth squeegee travel, thinner print results and superior edge definition and dimensional accuracy.

Ultra Thin

Today's highly advanced electronics industry, with its demand for miniaturization and larger capacity, is requiring ever thinner and thinner ink deposits, better dimensional accuracy and consistently controlled screen thicknesses. Asada is meeting these exacting requirements through its newly developed Ultra Thin Mesh. High pressure calendering technology allows the total woven mesh thickness to be equal to the wire diameter of the thread. That's approximately 25% thinner than achievable with conventional Super Heavy Calendering!

You may wish to add Asada's Black Treatment to your Ultra Thin Mesh in order to prevent any random light reflection during the imaging process. Ultra Thin Black Mesh offers you the potential for the thinnest stencil with the highest resolution and best edge definition possible.

Ultra Thin vs. Conventional Calendering

Type	Mesh Count	Wire Diameter (µm)	Conventional SH Calendered (µm)	Ultra Thin Process (µm)
BS	500	16	20	16
BS	500	18	23	17
BS	500	19	23	19
MS	640	15	21	16
HS	360	16	20	15

Anti-Reflective Coatings and Passivation

- These can be used for both the front and back of the cell depending of the bulk silicon dopant type.

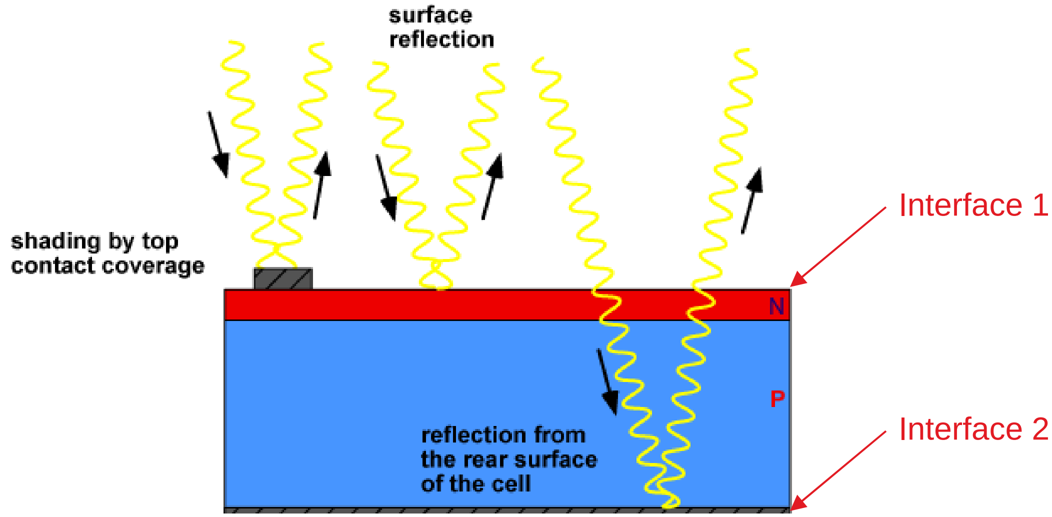
- In reality these two issues have separate functions and have very different requirements.

- In prevalent cell process flows these two steps have been combined for many reasons – highest among them is cost and process simplicity.

- Using suitable dielectrics researcher have found suitable materials that have the correct index of refraction, low light absorption and a fixed charge for surface passivation requirements.

Requirements for a Functional Anti-Refection Layers

- All light incident on a solar cell DOES NOT get converted to carriers do mainly to a small number of loss mechanisms which can be devastating to cell performance



- Anti-Reflective Coatings are employed to minimize the reflective losses which can exceed 30% !! of the incident energy depending on process
- Typically these layers are on the sun side of the cells, but new bifacial cell approaches require ARC tuning on both sides.

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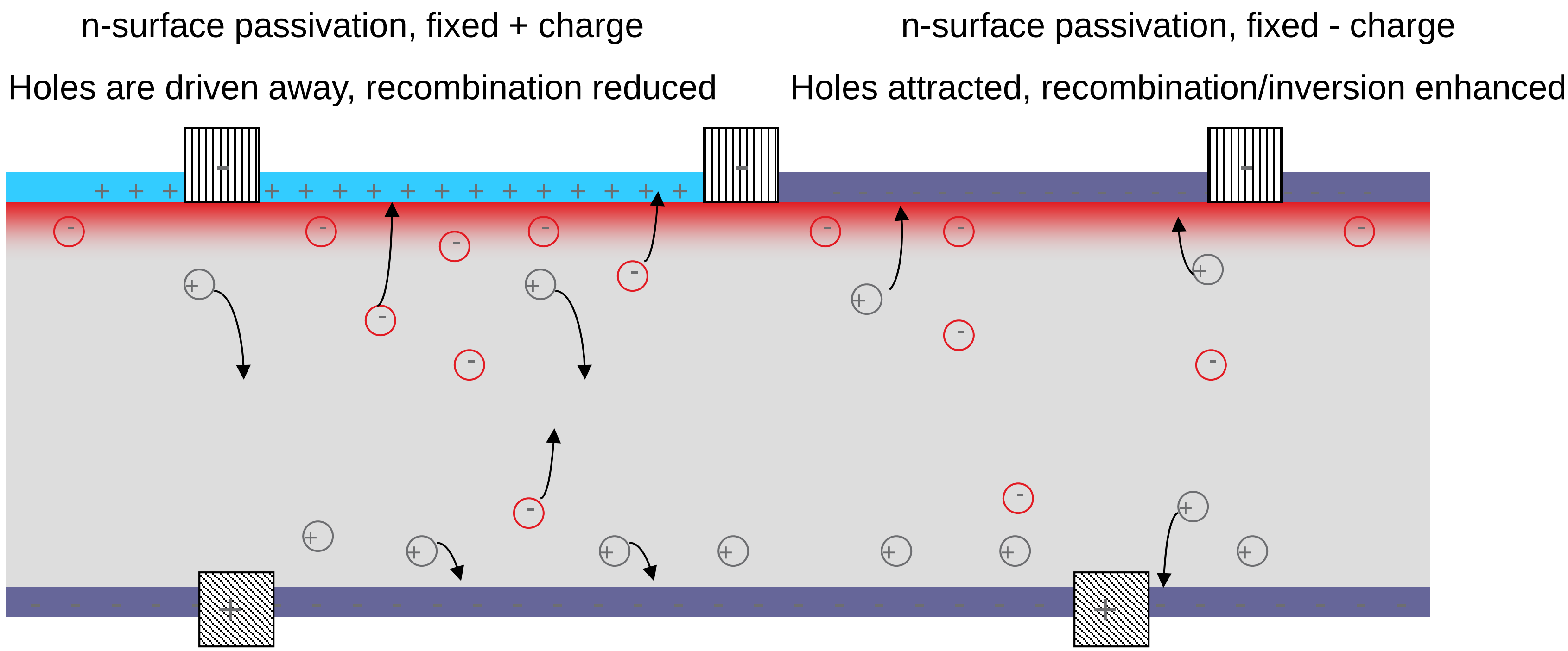
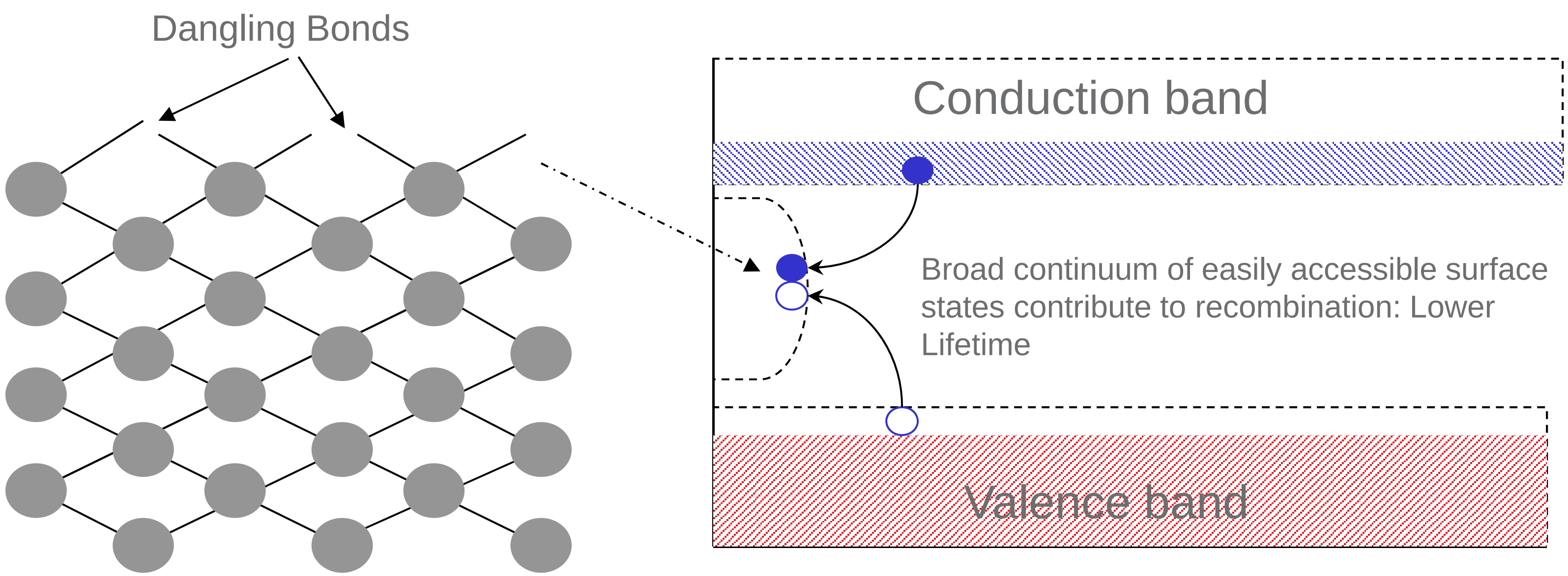
Requirements for Materials for Surface Passivation



On the p-type surface a negative fixed charge is desired in order to drive away electrons and avoid inversion

Surface Passivation and the Effect of Hydrogen

- With high quality material (very low defect single crystal) the lifetimes achievable in a solar cell are often limited by the surface passivation.
- The addition of hydrogen to the films has a tendency to passivate the dangling bonds. These effects have been shown to be stable for most types of defects.



ARC and Passivation: Material Choices

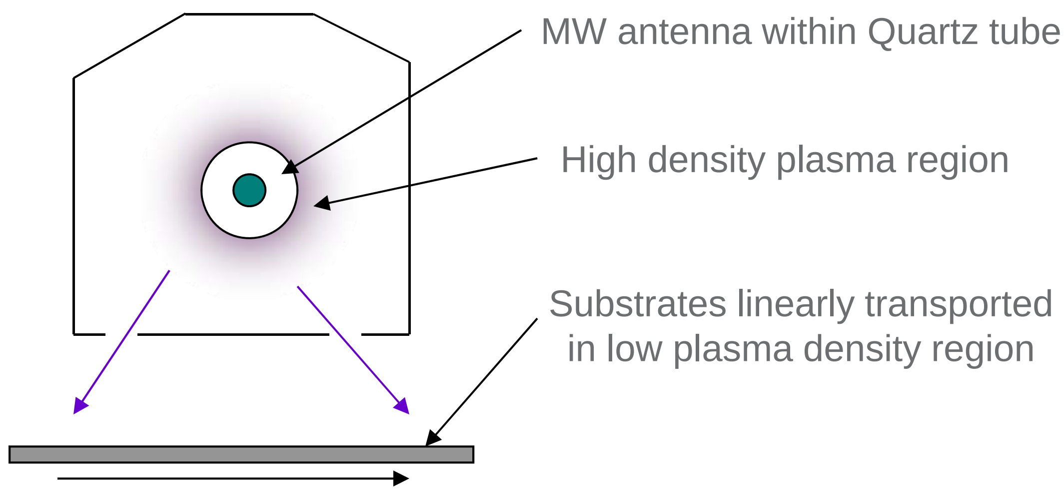
- Several dielectrics fit the requirements;
  - the Index of refraction in the range of 1.7-2.1
  - low absorption of light between 400-1000nm,
  - A substantial fixed charge that is positive or negative
  - Can be deposited by techniques that generate a significant amount of hydrogen that improve surface passivation even more.

- Silicon Nitride (Si_3N_4) is a typical choice for a positively charged dielectric for use on n-type doped silicon (front or back).
  - The index can be easy adjusted to 19.5-2.05 by adjusting the Si/N ratio.
  - Using SiH4/NH3 or a SiH4/N2 gas mic one can obtain films with 2-5% elemental hydrogen.

- Aluminum Oxide (Al_2O) is a typical choice for a negatively charged dielectric for use on p-type doped silicon (front or back).
  - The index can be adjusted to 1.6-1.7 range. Typically a Si_3N_4 cap is used.
  - Using TMA/H20/N2 or TMA, N2O gas mixes can obtain films with 2-5% elemental hydrogen

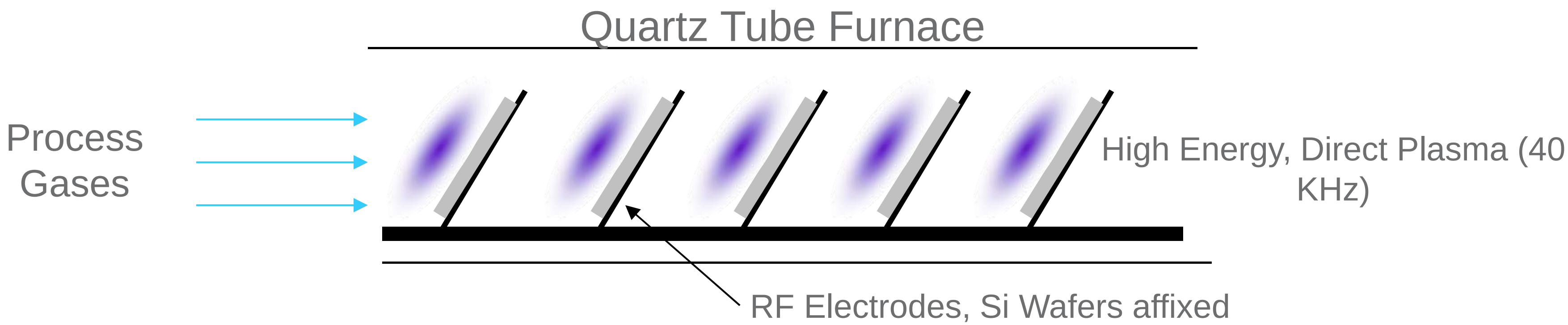
$Si_xN_yH_z$ and $Al_xO_yH_z$ Process tool designs/methodologies

- **Indirect Plasma processes**
  - Tools/Processes designed such that that the arriving reactant species are generated multiple mean free paths away from the substrate (outside of the plasma)
  - Microwave (MW), inductively coupled, remote plasma PECVD (Roth and Rau)
  - Typically SiN films use SiH4 and N2 / AlO films use TMA (or similar) and N20 reactants. PECVD (Roth and Rau)

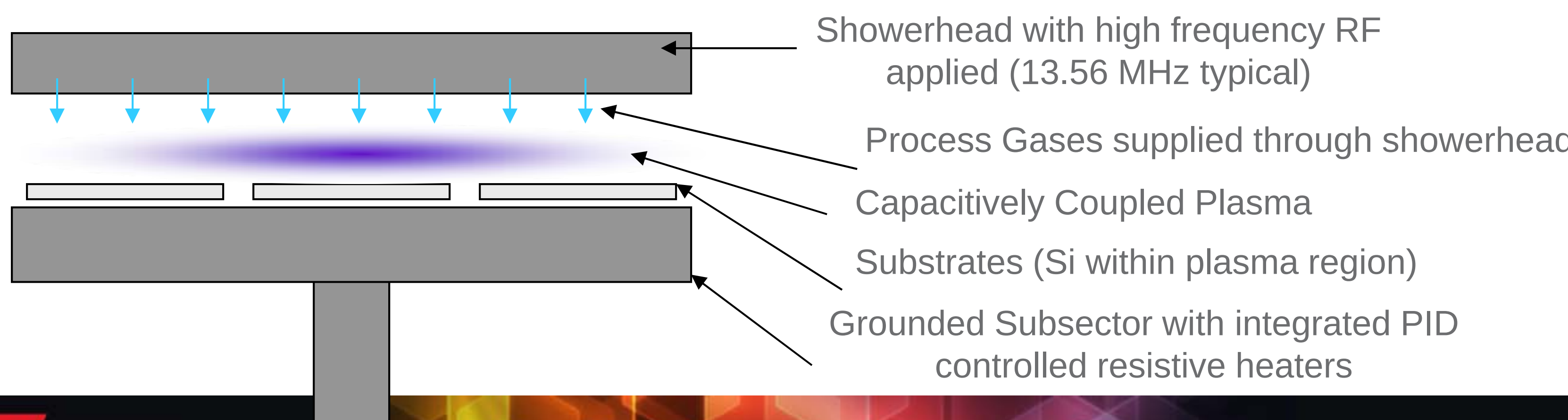


Typical Solar Process tool designs/methodologies

- Direct Plasma processes
  - Low Frequency, parallel plate (capacitively coupled)/tube furnace type direct plasma PECVD reactors (Centrotherm/ 48th Institute)



  - Parallel plate, showerhead/subsector, High Frequency (capacitively coupled), direct plasma (Avanti, Jusung)



Typical Production Scale Passivation Equipment

… Emitter Diffusion → Phosphor Glass (PSG) Etching → **Anti-Reflection Coating, Rear and Front Side Passivation (Al_2O_3 and SiN_x layer with MAiA)** → Annealing → Laser Ablation → Screen Print …

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QUESTIONS?