Precision Process Power and Controls for Photovoltaic Manufacturing

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Better technology. Better results.

NCCAVS 32nd Annual Vacuum Equipment Exhibition-February 23, 2011

Evolution of Power Conversion Platforms

Leader in Power Conversion Across Markets

#1 Worldwide

Thin Film: 41% served share

#1 Solaron + PV Powered

Solar Inverter: 24% of Americas

**Thin film market share based on VLSI Research CSS May 2010 Report; includes AE served markets in RF and DC*
***Solar inverter market share based on IMS Research June 2010 inverter report for the first 6 months of 2010*

AE's Unique Perspectives on Solar PV

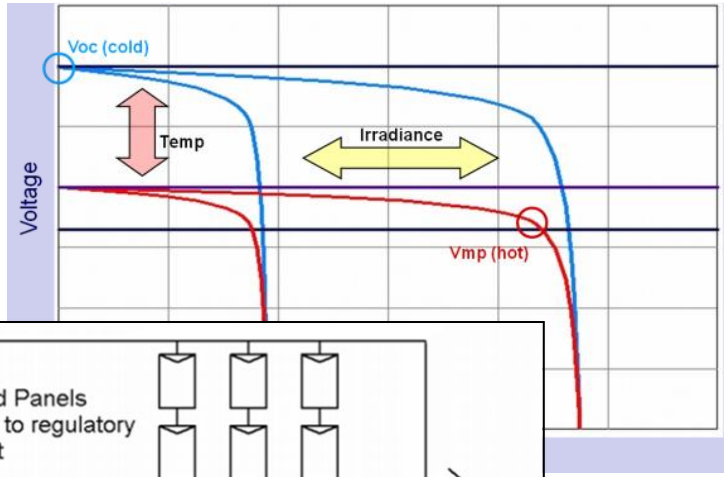
- Solar PV is a very important part of AE's growth strategy
- AE has a unique perspective on panel technology
  - as an enabler to many solar module processes
  - as an user of these same modules along with the remaining BoS components in a solar PV plant

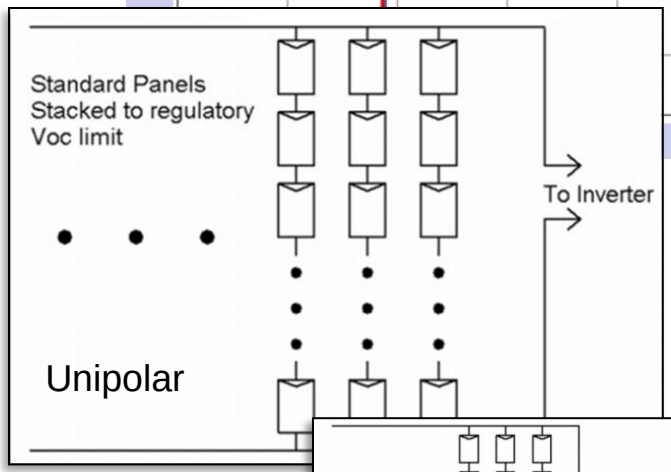
Agenda

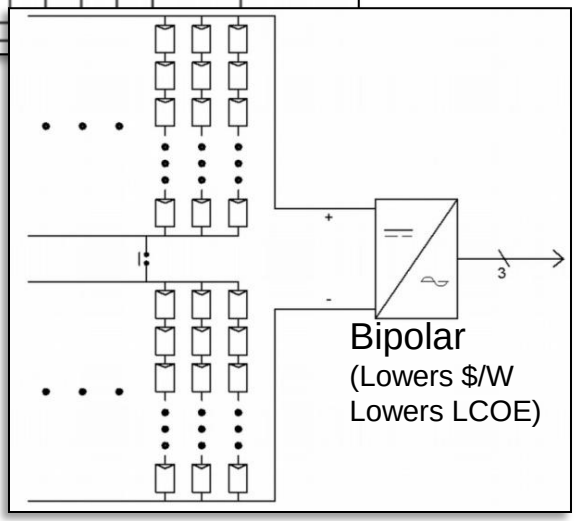
- Introduction to AE Markets/Technologies
- Powering the Grid
  - Optimizing operating voltages
- Powering Plasma Processes
  - Metallization and ITO
  - Active Layers in Thin Film PV
  - Antireflective coatings
- Summary

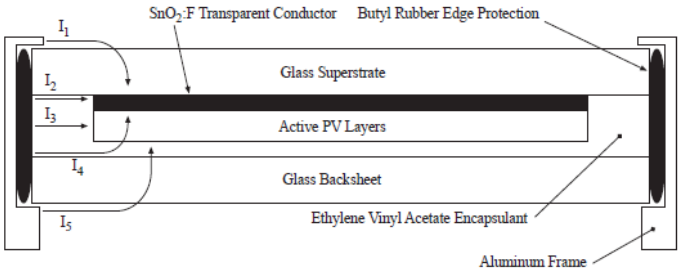
Powering the Grid

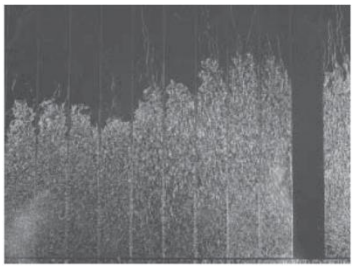
- Challenges for many thin film modules
  - High voltage modules often underutilize Vmax
    - Easier with lower voltage panels
  - Total BoS costs may exceed benefit of lower $/W modules
    - More strings, more combiner boxes
    - Longer home-run wiring
  - Electrochemical erosion of TCO layer at negative voltages force systems to be configured unipolar (higher $ BoS)











Osterwald, C. R., T. J. McMahon, and J. A. Del Cueto. "Electrochemical Corrosion of SnO2:F Transparent Conducting Layers in Thin Film." National Renewable Energy Laboratory. U.S. Department of Energy. Web. 21 Feb. 2011. <www.nrel.gov/pv/thin_film/docs/sno_paper.pdf>.

Powering Plasma Processes

3 Anti-Reflective Coating (ARC)
- PDX® Mid-Frequency Power Supplies
- PEII Low-Frequency Power Supplies
- Crystal® Mid-Frequency Power Supplies

1b Front Contact
- Pinnacle® DC Power Supplies
- Pinnacle® Plus+ DC/Pulsed-DC Power Supplies
- Pulsar™ DC Pulsing Accessory

N Layer

2 P Layer
- Cesar® RF Power Supplies
- VarioMatch™ Automatic Matching Networks
- Apex® RF Power-Delivery Systems
- Ovation™ VHF Power-Delivery Systems
- Navigator® Digital Matching Networks
- Z'Scan® RF Impedance Sensors

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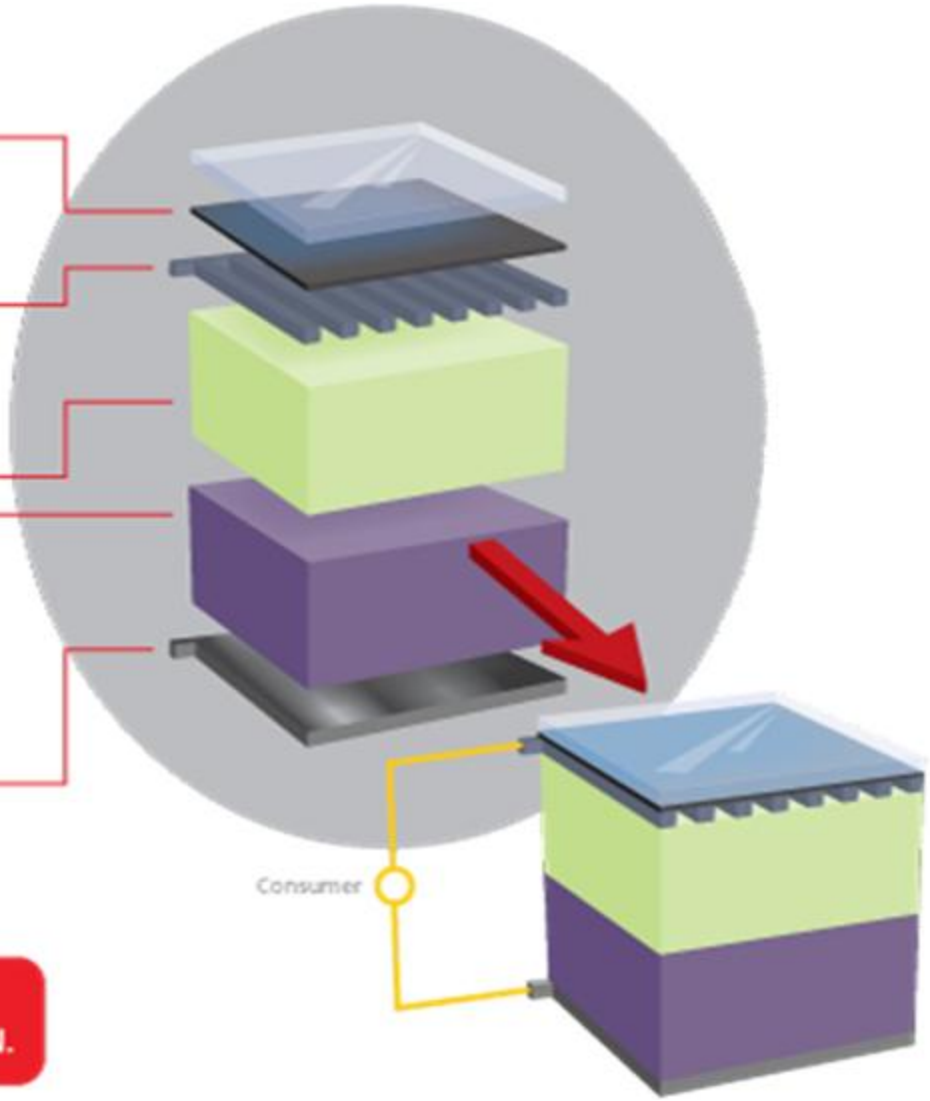
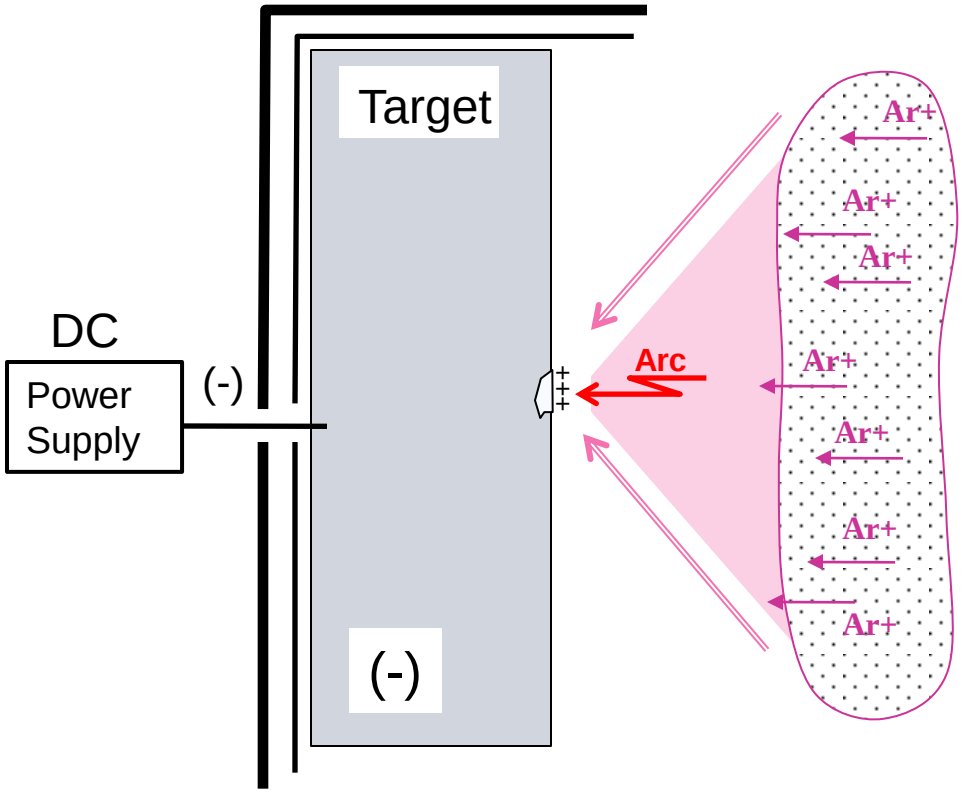


AE® OFFERS EFFECTIVE SOLUTIONS FOR EVERY PHASE OF PHOTOVOLTAIC PRODUCTION.

Arcing in Metallic and ITO PVD Sputtering

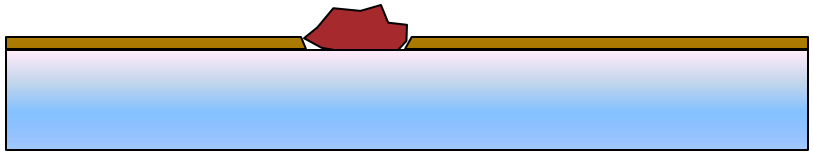
- Arcing in PVD sputtering is a common source of film/process quality issues
- Arcs form due to local charging of defects, flakes, debris, etc.
- Plasma collapses at site of arc concentrating high power density in tiny region
- Energy released into an arc can generate large quantities of macro-particles
- High arc repetition rate can disrupt deposition process



Uniform plasma collapses to arc spot ~ microns in size[1]

Macro-particles are ejected due to concentration of energy in spot[2]

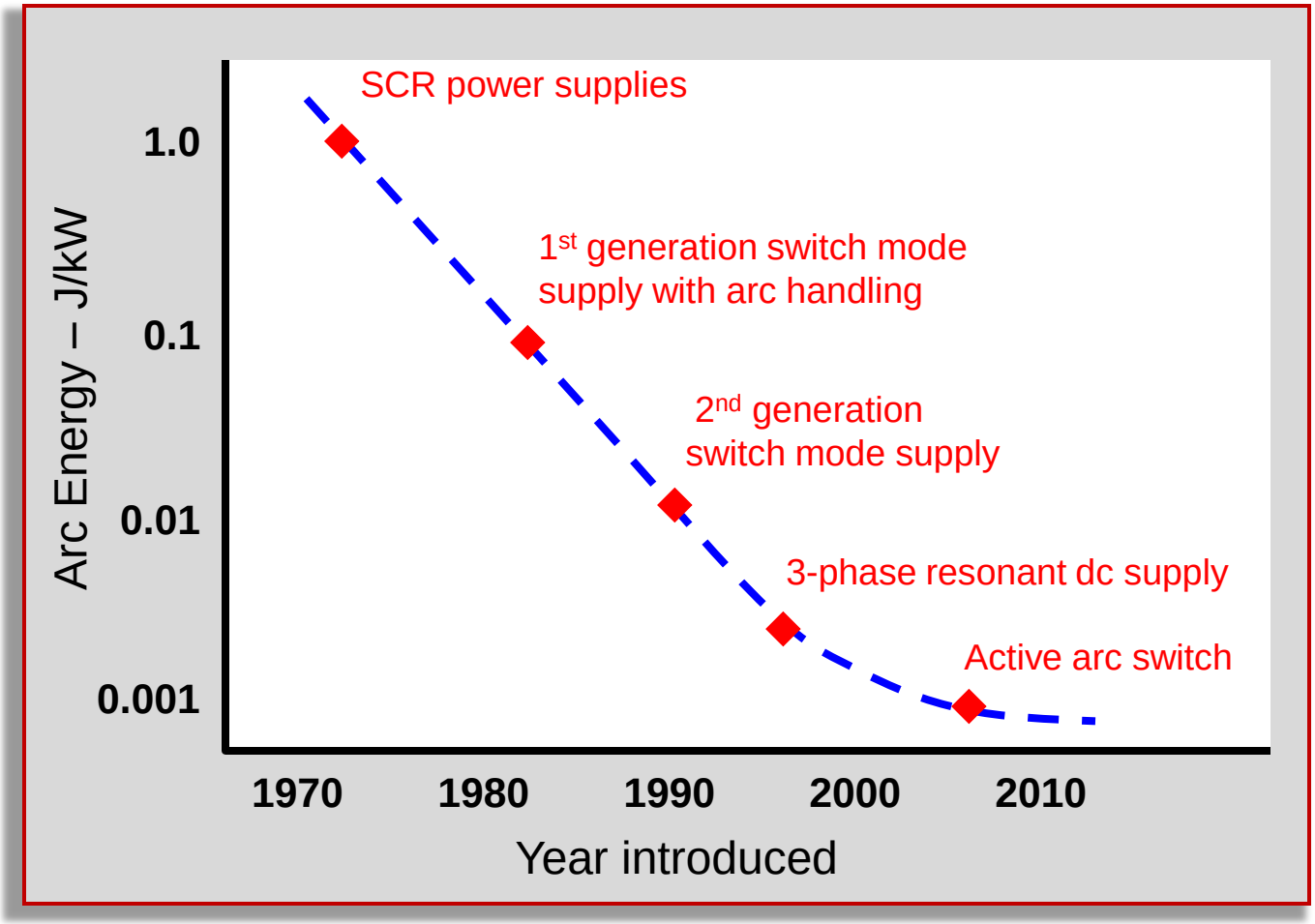
Macro-particles can be ten's of microns in size[3]



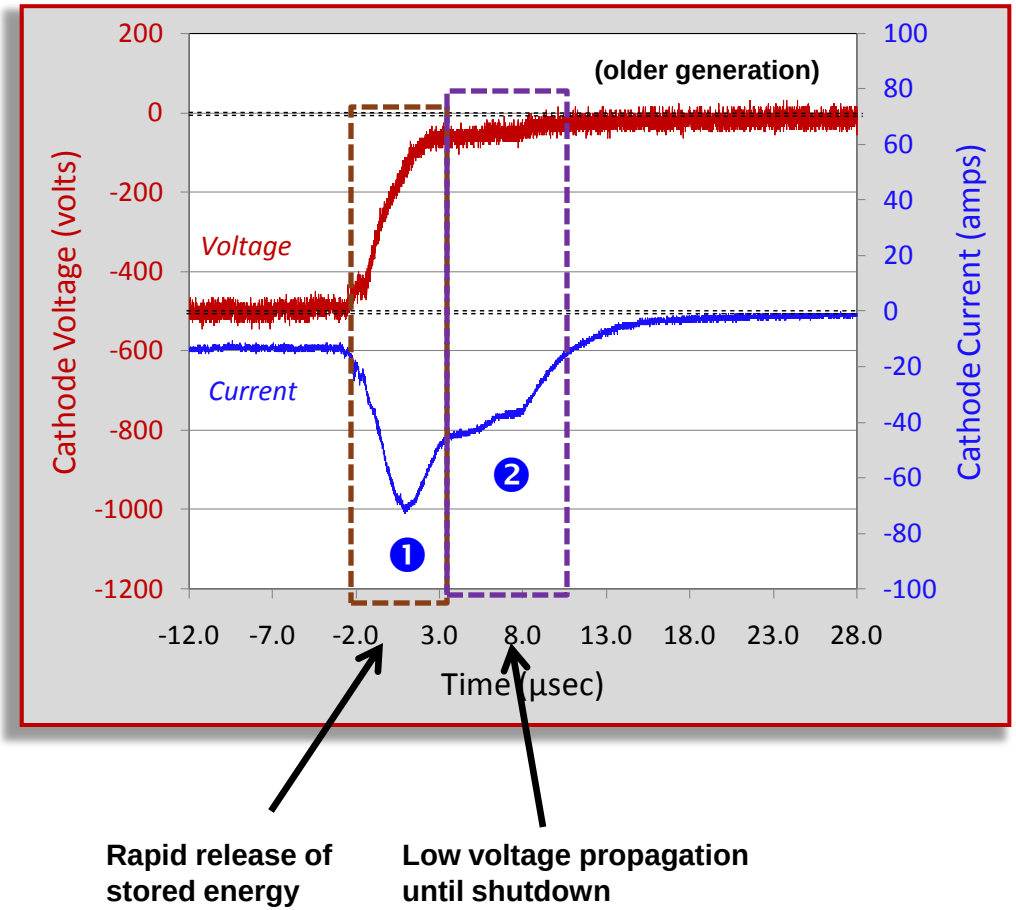
1. Juttner, J. Phys., D, Appl. Phys. 34 (2001).
2. Wickersham, et.al., JVST A 19(6), 2741 (2001).
3. Wickersham, et.al., JVST A 19(6), 2767 (2001).

Sputtering power supply evolution

- Reduction in stored energy + faster response = lower arc energy; fewer particles; less process disruption



Primary stages of arc propagation

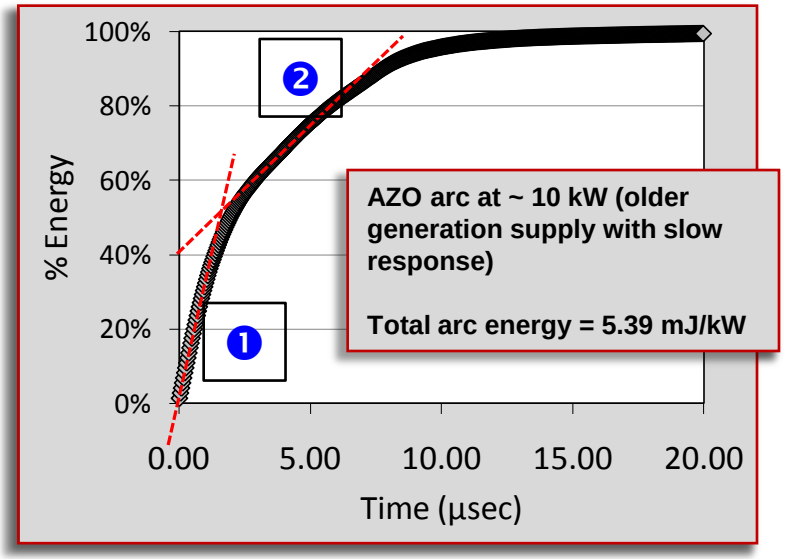


Rapid release of stored energy

Low voltage propagation until shutdown

❶ Stored energy is released rapidly at the onset of the arc

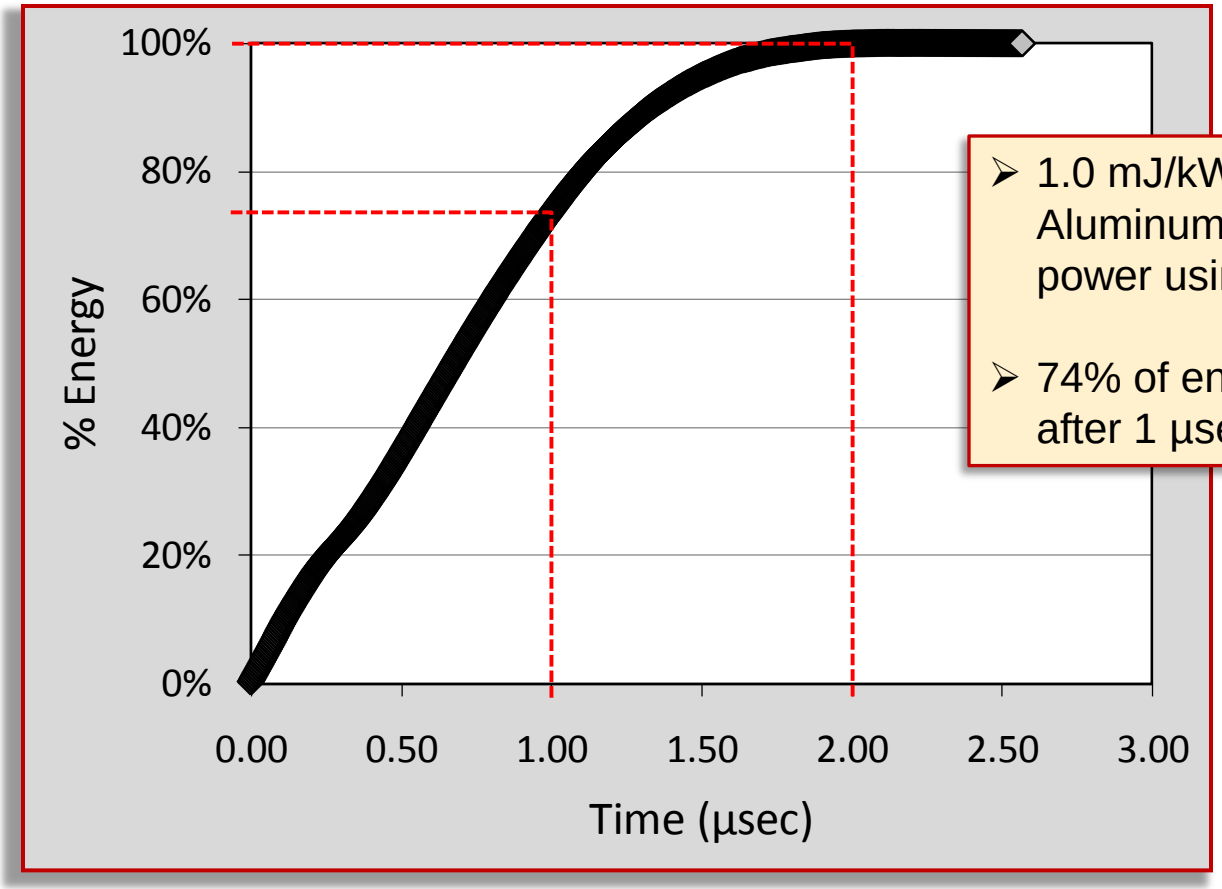
❷ Additional energy is deposited at low voltage as the arc propagates until current flow is cut off through power system shutdown*



Detect and response of new generation supplies is adequately fast to largely minimize energy in stage “2” above

How fast?

- Fast evolving arcs require extremely fast detect and response
- A large fraction of total arc energy is released in less than 1 µsec
- Some materials may be more demanding than others for achieving lower arc energies

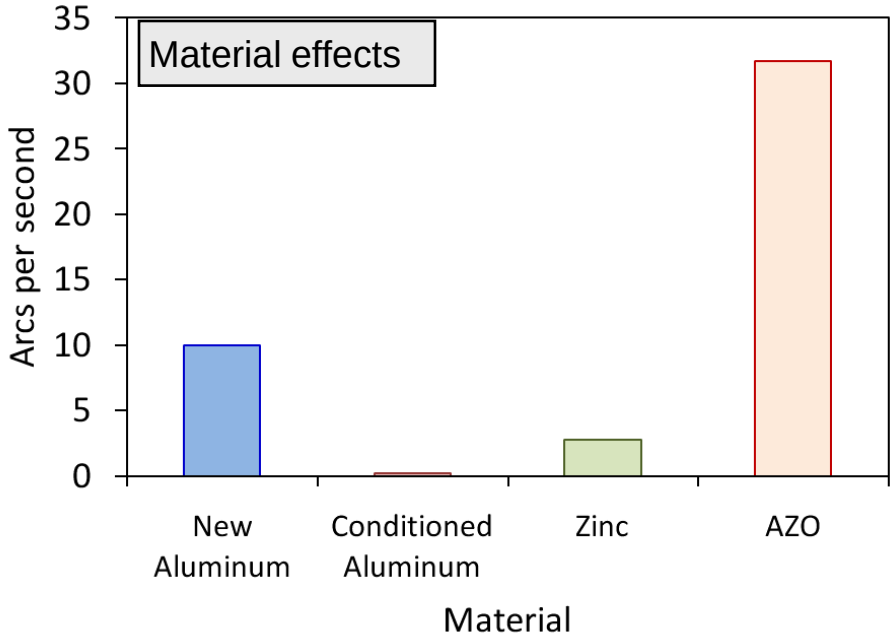


- 1.0 mJ/kW arc on Aluminum @ 20 kW power using low L cable
- 74% of energy released after 1 µsec

Arc rates

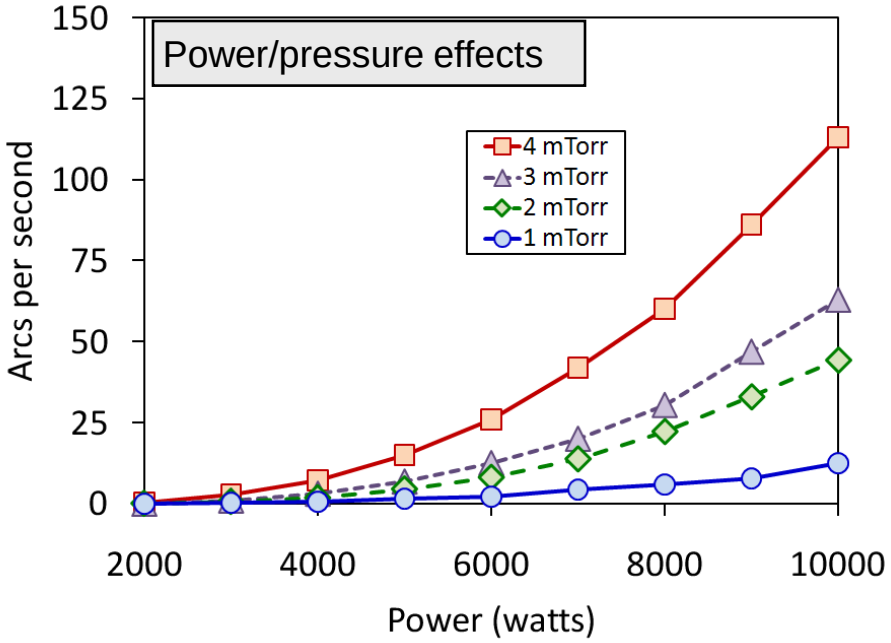
- Arc rates can be influenced by a number of factors
- Different materials often arc at different rates
  - Target history is also a factor
- Sputtering conditions also impact arc rates

Arc rates for different materials sputtered at 10 kW



Material and material history influences arc rates

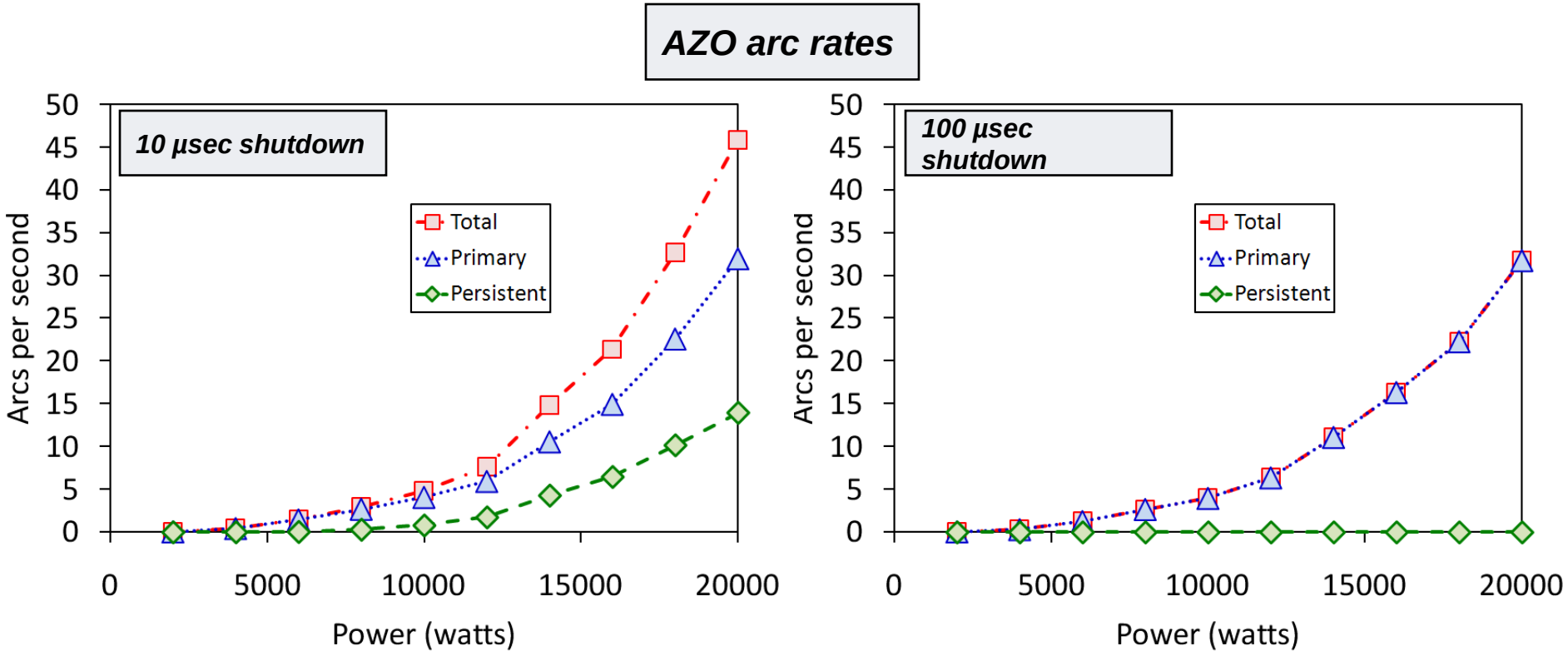
AZO arc rates at increasing pressure and power



Increasing power and pressure both tend to increase arc activity

Arc persistence

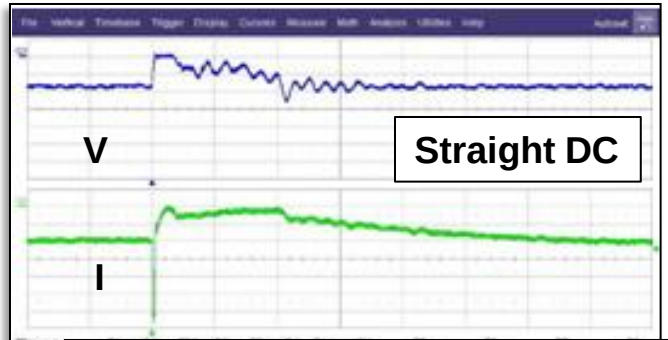
- Arcs occurring immediately after an initial (primary) arc response are considered persistent arcs (often called “hard arcs”)
- Persistent arcs are seen to form when shutdown time is too short
- Persistence and relationship to shutdown seen at all power levels on AZO

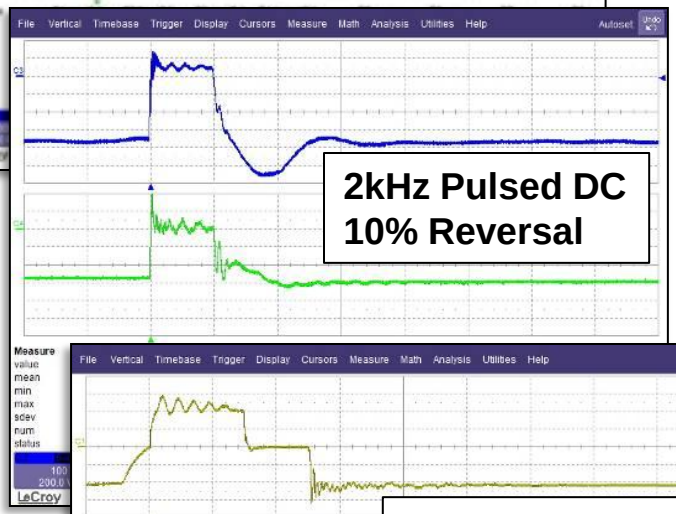


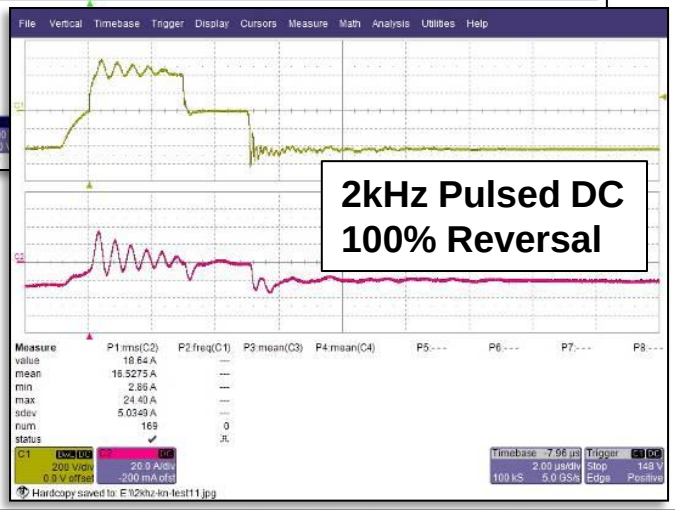
When shutdown time is adequate, total arc rates decrease as persistent arcs are eliminated

DC and Pulsed DC with AZO

- AZO can be operated with DC if arc management is sufficient (course target).
- Fine-grain target material decreases arc rate, but there is no significant reduction in nodule formation
- For AZO, pulsed DC can stabilize the process over the target lifetime by reducing arc rate and nodule growth.
- 100% voltage reversal during pulsing may reduce nodules completely.



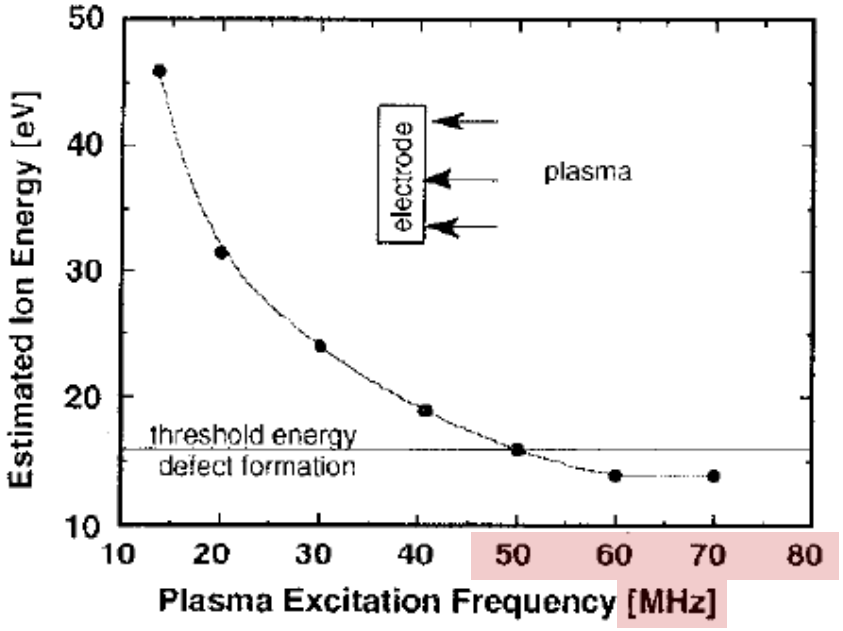




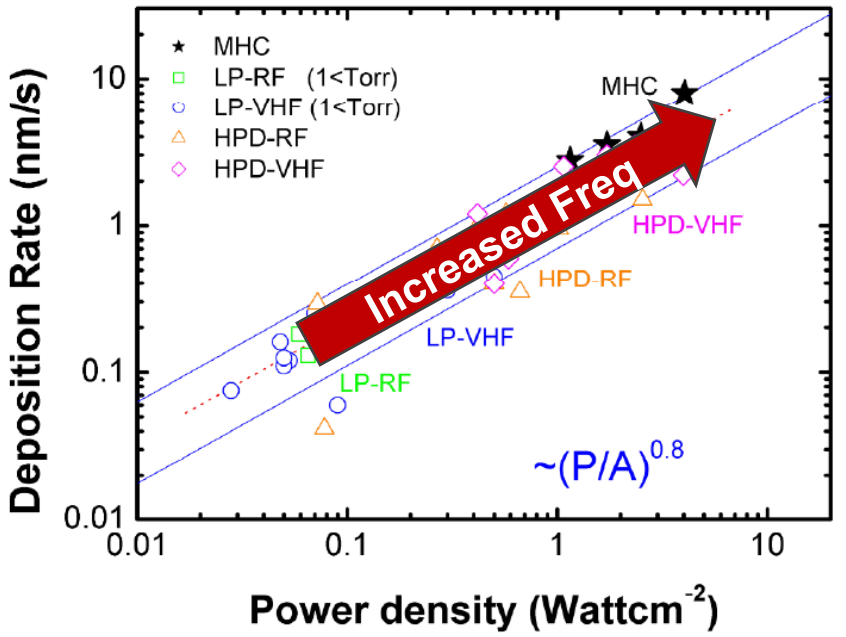
The Effect of Voltage Reversal on Nodule Formation During Sputtering of Aluminum-Doped Zinc Oxide, Ken Naumen, ICCG 2010

PECVD a-Si Based Technologies

- VHF has largely been recognized as providing high relative deposition rates and power densities, while maintaining low peak ion energies below the critical threshold energy for defect formation.



Estimated peak ion energies in function of the frequency for SiH4 plasmas.



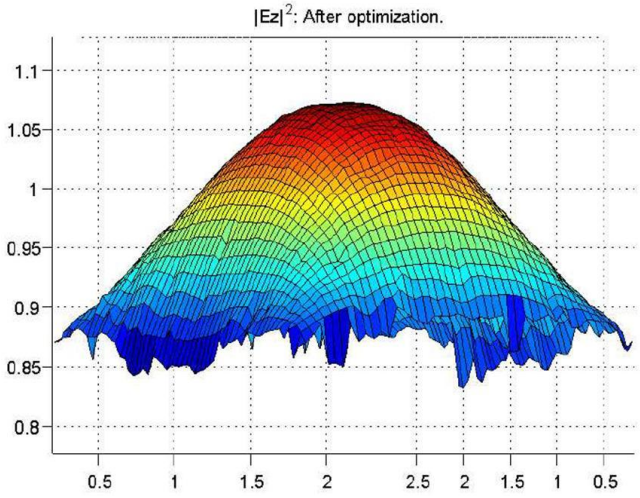
The deposition rate of optimized PECVD conditions over the past 10 years plotted as a function of power density.

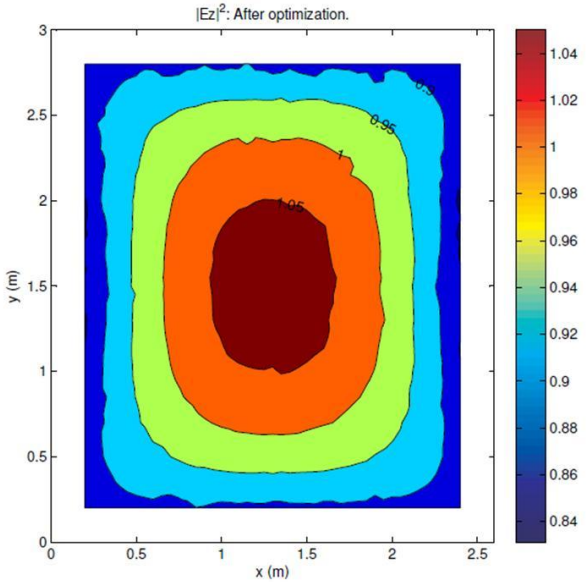
H. Keppner, U. Kroll, P. Torres, J. Meier, D. Fischer, M. Goetz, R. Tscharner, A. Shah, 25th PVSC.pp 669-672.

A. Smets, T. Matsui, M. Kondo, 10.1109/WCPEC.2006.279790, pp 1592-1595.

Uniformity with VHF for Large Area Process

- The relatively short wavelength of VHF produces standing waves across the length of a large area substrate (single point feed), producing unacceptable film uniformity

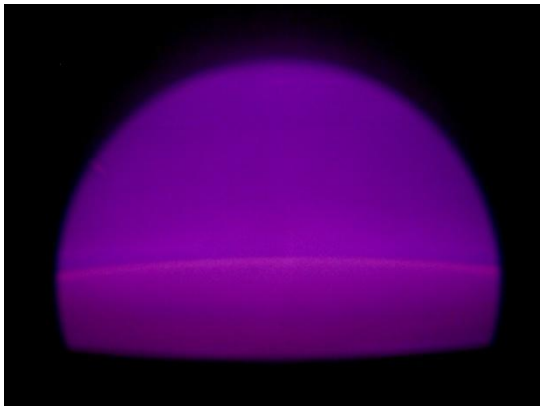


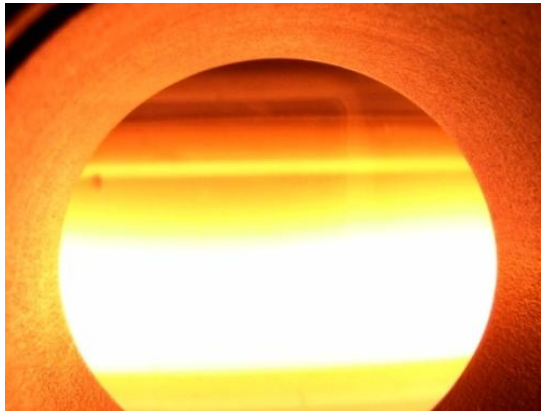


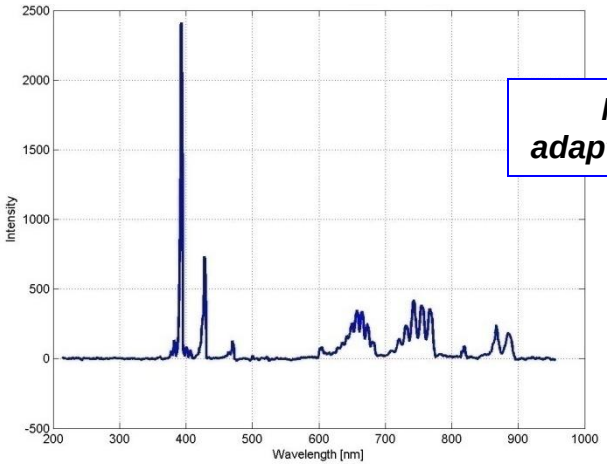
Creating the Optimum Process Solution

- Power application can be key factor in the type of plasma produced

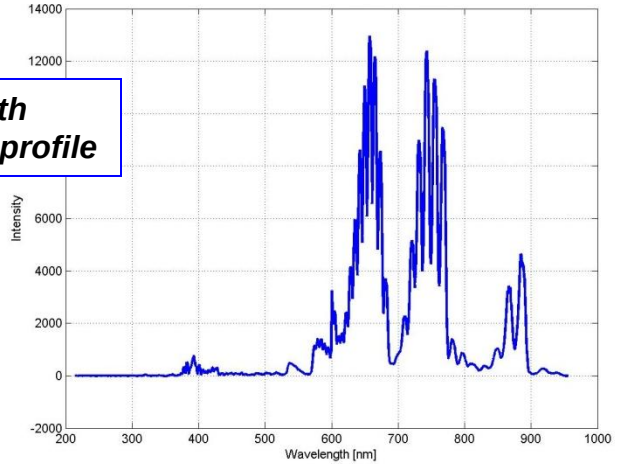
Produced in the same chamber and at the same power, flow rate, and operating pressure







Nitrogen spectrum with adaptable power delivery profile

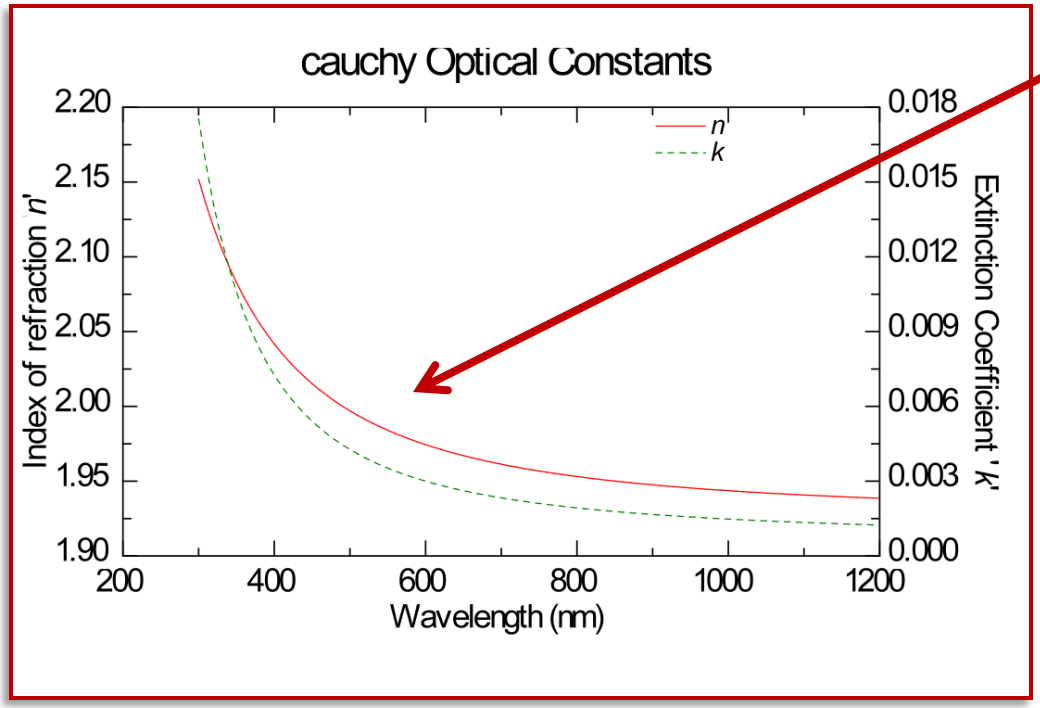


Combining Sources with Multiple Frequencies

- AE has worked with rf technology and combined plasma sources for decades
- At a laboratory level the combining of rf can produce very different plasmas
- This combination can be used to produce different volumetric film properties

SiN_x Passivation
Controlling optical properties

- Plasma enhanced SiN_x CVD
- Optimizing source design along with power delivery leads to unique capabilities for tailoring optical properties of deposited thin films



Tight control of n combined with very low k across full spectral range

Summary

- Precision process power plays a major role in the quality and performance of solar PV films
- New and challenging materials require unique responses of the power supply to maintain good films
- Process power mix can be used to produce unique volumetric film properties
- In PV, you still need energy to create energy. So we will continue to innovate as we raise the bar on performance and efficiency.

Thank you for your attention!

NasdaqGM: AEIS

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