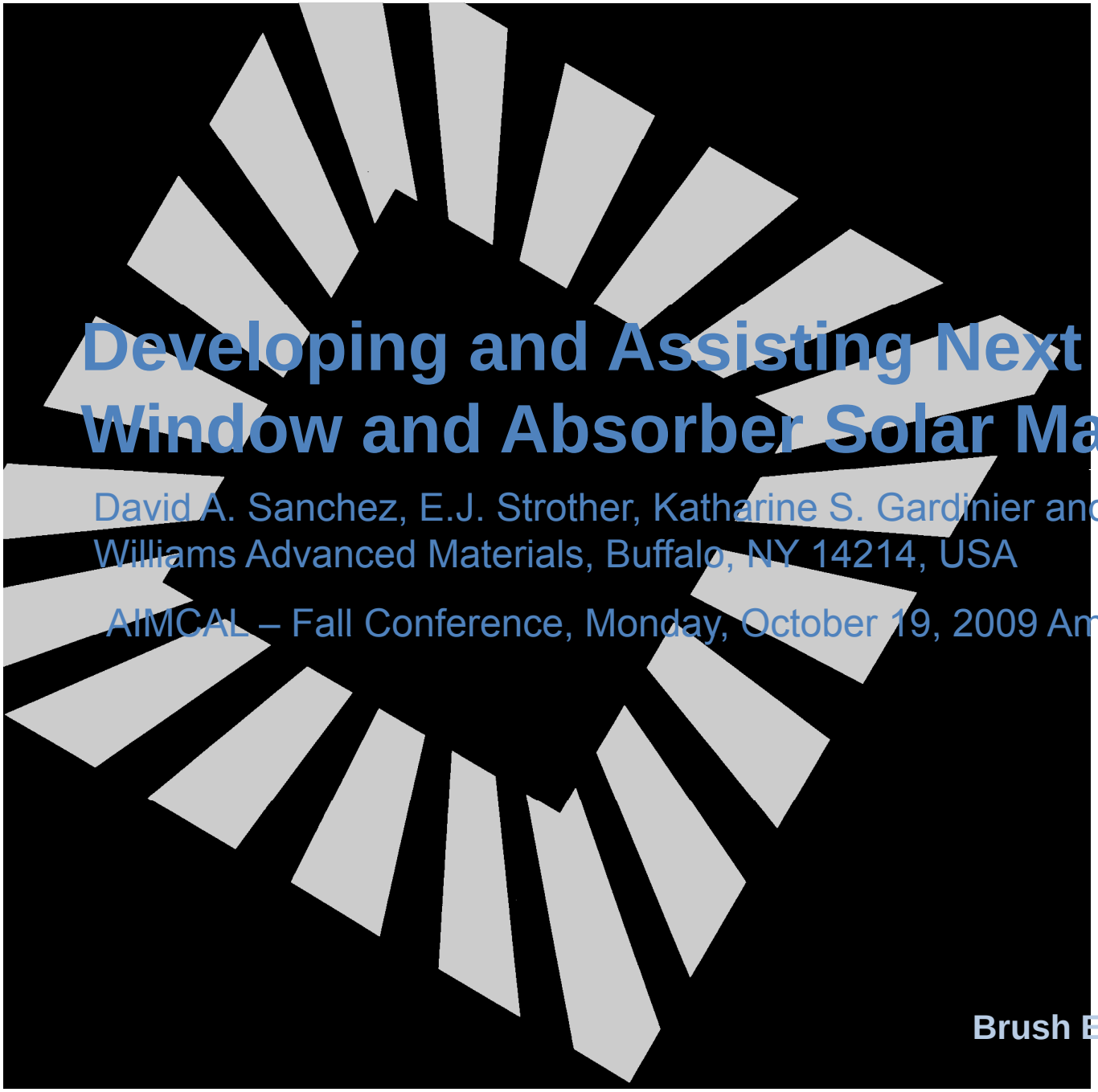

Developing and Assisting Next Generation Window and Absorber Solar Materials.

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A Subsidiary of
Brush Engineered Materials

Materials Development

- Cadmium Sulfide
  - Traditional CdS Powders
  - Need for Microcrystalline CdS Powders
- Copper Indium Gallium (di)Selenide
  - Producing Stable, Reacted CIGS Powders
  - Producing Stable, Pressed CIGS Targets
  - Producing Stable, Scalable CuGa Alloys for CIGS

Cadmium Sulfide

- Basis for Powder Production as pigment
  - Heating acidic cadmium salt solutions in hydrogen sulfide gas.
  - Temperature of solution and reaction rate effected structure and color.
- Produced a fine, low density powder.
- Color ranged from classic brilliant yellow to dark red.

Classic Cubic CdS Yellow.

Hexagonal CdS very red.

“Cadmium Yellow” Raw Material

- Early Evaporation Material
  - Large scale reaction and filtering capacity made cheap raw material attractive for testing.
  - Low density powders hot pressed into medium density tiles (60%)
  - Tiles were sized to granules (0.8mm to 1.5mm) for evaporation trials.
  - Cold press and sinter routes not feasible due to contamination and moisture concerns.

Need for New CdS Material

- Evaporation materials did not allow proper n-type film preparation.
  - Loosely bound compound had ambiguous decomposition behavior.
- PVD targets from this material had limited density by any load/press means.
  - Target tiles would crack in-plane or during bonding.
  - Bright yellow appearance was misleading and often behaved like sulfur rich compound.

New Microcrystalline CdS

- New reaction closer to solid state reactions with special attention to formation temperature.
- Specialized sizing and sieving techniques developed for evaporation or PVD standards.
- Produced a fine, high density microcrystalline powder.
- Color consistently dark yellow/orange.

New Microcrystalline CdS

CdS PVD Tiles by Hot Pressing

– Refined loading and hot pressing approaches minimized moisture, increased (>90%) density and improved base tile characteristics.

As Pressed CdS PVD Tile (w/redux)

After Machining, CdS PVD Tile

CdS for Solar Modules

- -325 mesh, -200 mesh and customer powder sizes are available for evaporation or pressing projects.
- Hot pressed, high density PVD tiles are available for n-type CdS deposition.
- Hot pressed PVD tiles are more machinible and lower moisture/oxygen than wet chemical based options.
- CdS remains very sensitive to deposition technique but RF, pDC and evaporation techniques have compared favorably to CBD films.

Copper Indium Gallium (di) Selenide

1) Cu + In + Ga > {Cu: In: Ga Intermetallic} >> H_2Se (or Se) yields $Cu(In,Ga)Se_2$ or,
2) Cu2Se + $(In,Ga)_2Se_3$ yields $Cu(In,Ga)Se_2$ and finally,
3) Cu +In +Ga +Se yields $Cu(In,Ga)Se_2$.

* Dr. Noufi, R. - High Efficiency CdTe and CIGS Thin Film Solar Cells: Highlights of the Technologies Challenges, IEEE 4th World Conference on PV Energy Conversion. Presentation. May 7-12, 2006. Waikoloa, Hawaii.

- It is generally recognized that the above list represents the most common pathways for creating a useful and stable CIGS layer in CIGS based solar modules.
- Until recently, very few options outside of single crystal, Bridgman Grown crystalline powders have been available.
- Similarly, alloys rich in Copper dominate, and the use of Ga or In in the alloys has been slow to develop.

Need for Stable CIGS Powder

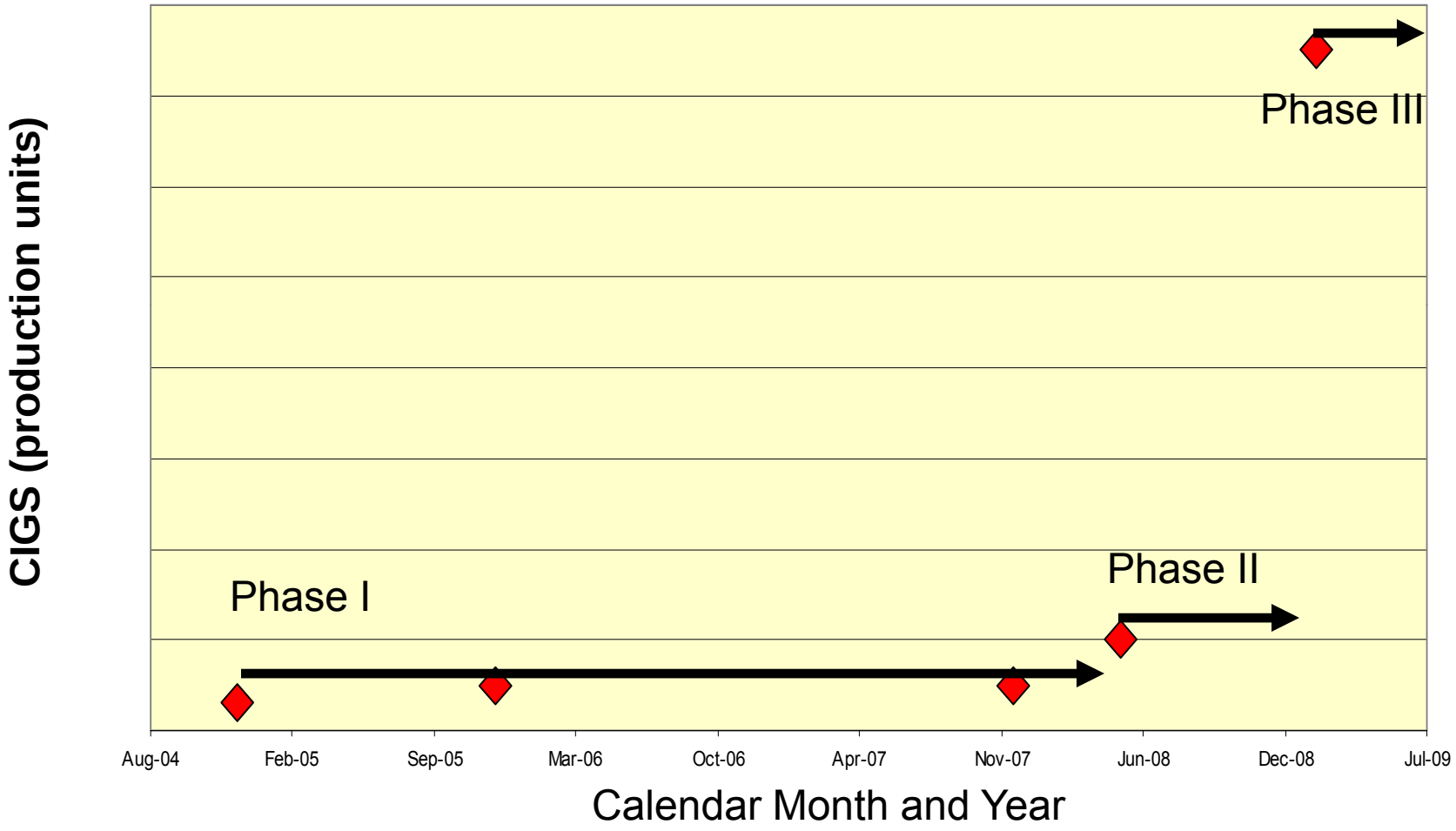
- An evaporation CIGS would have to be stable, homogeneous and non reactive.
- As a PVD target, the powder would have to be dense, stable, hard and free from intergranular fracture in sizing and transport.
- The powder would have to be freely flowing in bulk and dilute phase transport for die filling or feeding.

CIGS Reacted Powder

- Heat of reaction must be maintained to favor primary quaternary selenide.
- Rate of reaction limited to prevent gas generation and vessel interactions.
- Unlike Bridgman Ingots, chemical and material character is homogeneous.

Standard CIGS powder

CIGS Reaction and Scale-up



Composition, Scale and Process

- Phase I. Mostly Catalog and Small Targets
  - Develop reactions, QA techniques and build composition confidence limits.
- Phase II. Scale up finished goods and Test Concepts for Scaling PVD tile raw materials.
  - Requires specific development for die loading and composition variance.
- Phase III. Optimize Reaction and Scale to meet cost and performance criteria.
  - Powders for direct use may differ from PVD tile materials.

Phase I & II Milestones

- XRD, ICP, Spectrograph Standards.

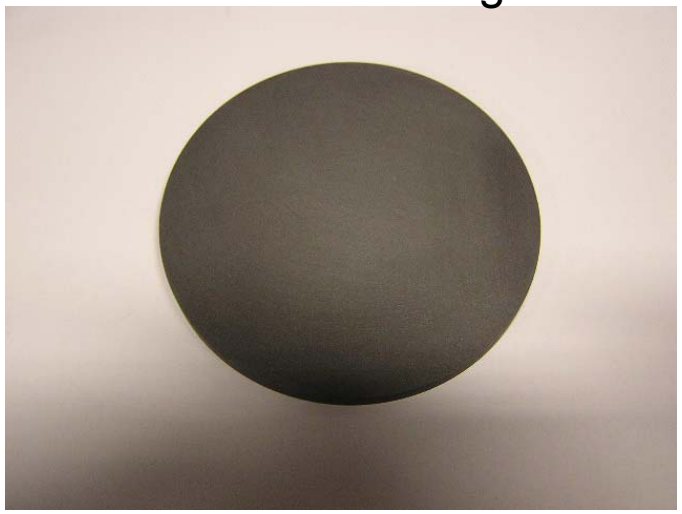
  Average Composition of Stable/Identifiable CIGS at%

  Cu 20 – 25 In 15 – 21

  Ga 6 – 9 Se 50

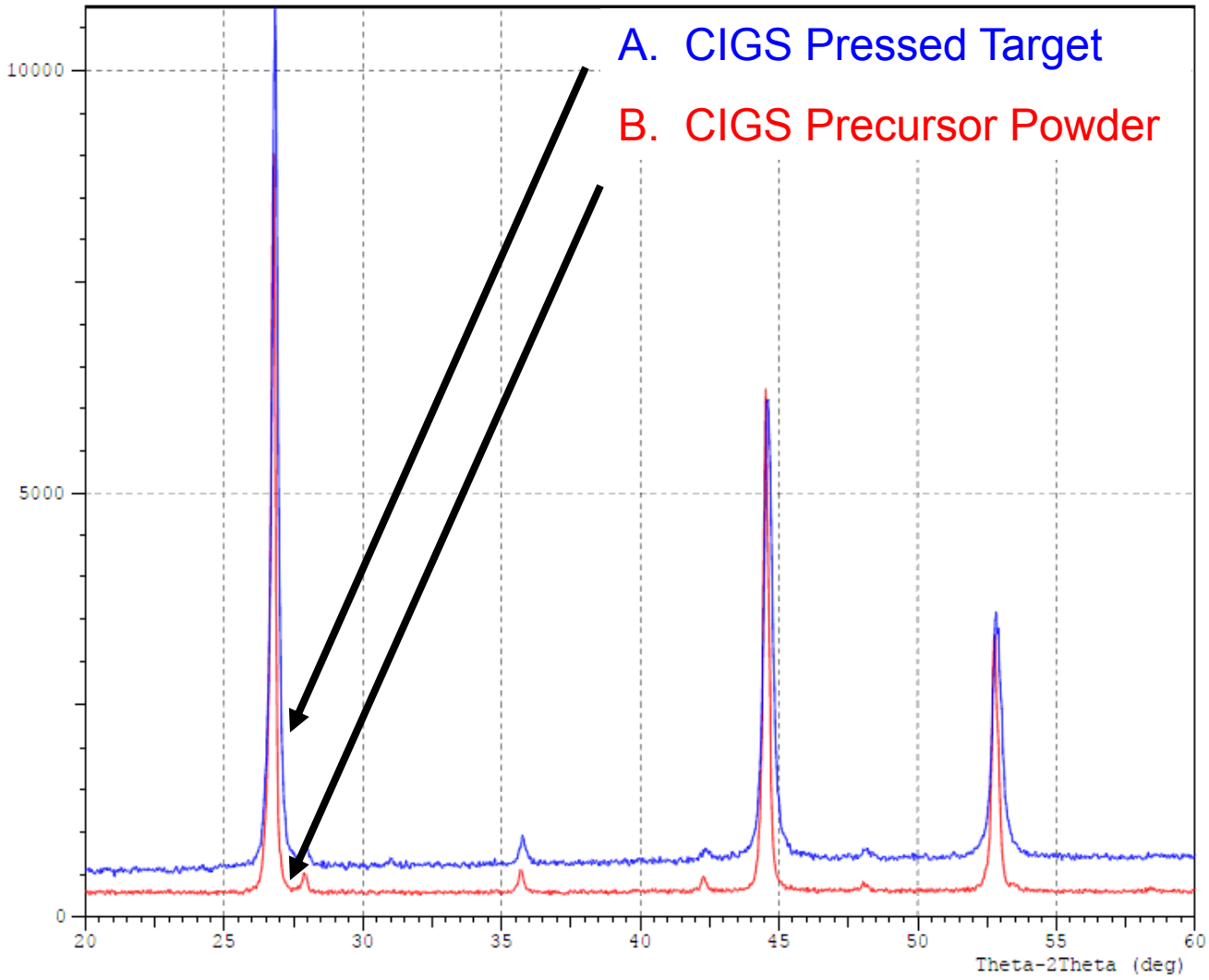
- Powder yield increased from R&D to Production Quantities.
- Pressing and Machining Process Standardized.

As Pressed CIGS Target

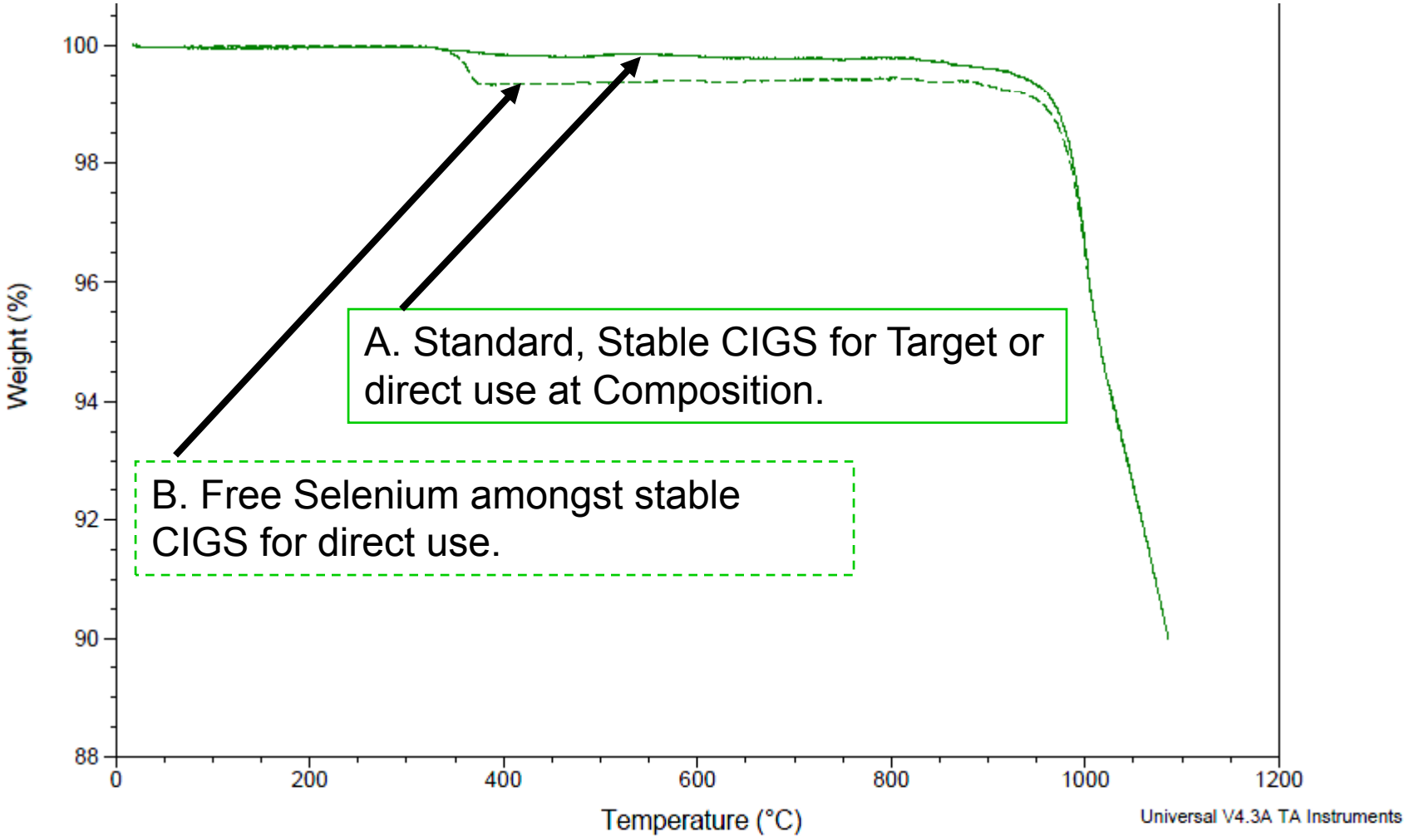


Machined CIGS Target

XRD Overlay, CIGS Powder and Target



Example, Thermogravimetric Analysis of Two CIGS Compositions



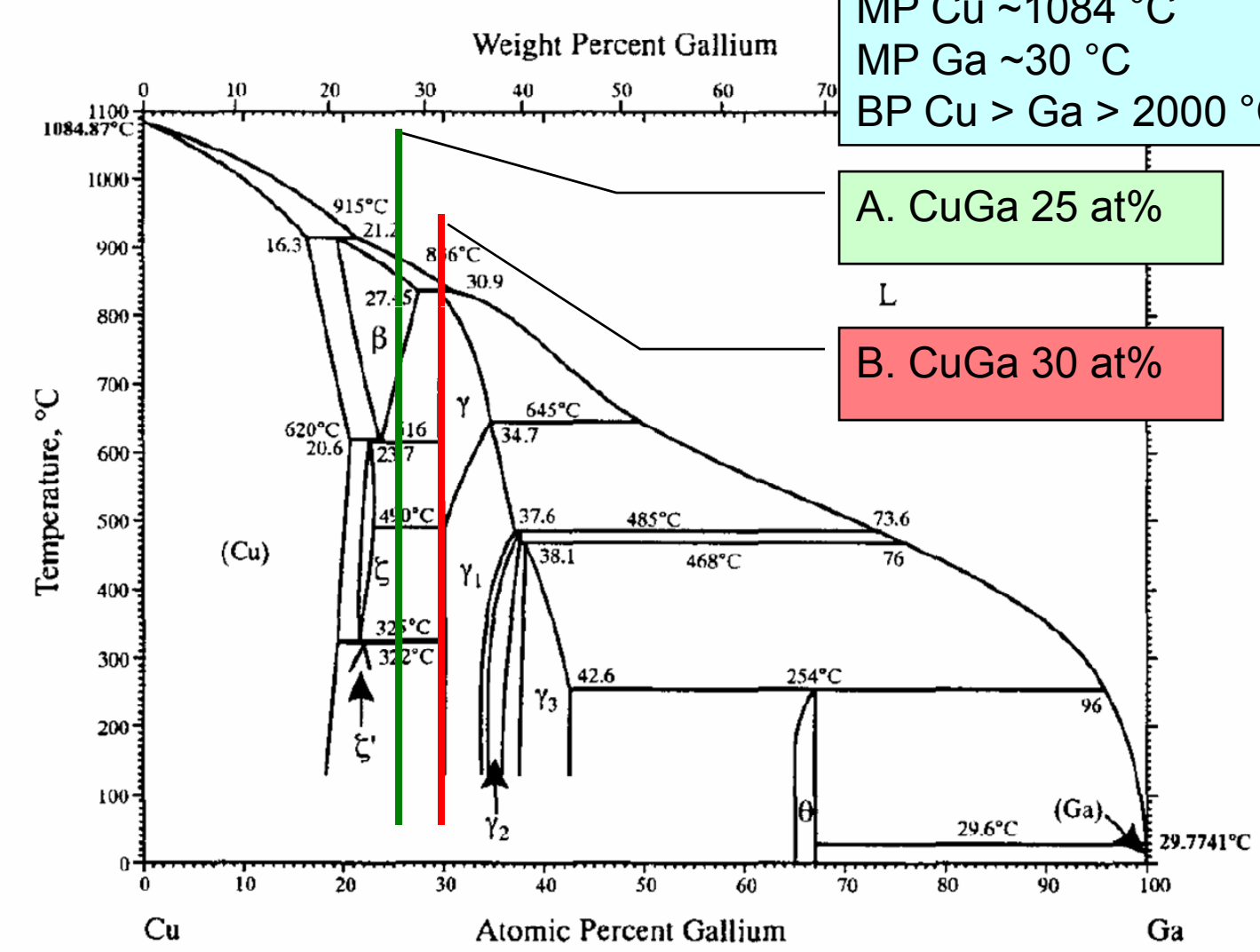
CIGS Compound for Solar Modules

- -325 mesh, -200 mesh and customer powder sizes are available for evaporation or pressing projects.
- Hot pressed, high density PVD tiles are available for p-type CIGS deposition.
- Hot pressed PVD tiles are can be arranged on large backing plates with conventional bonding.
- Standard Compositions have pre and post pressing XRD verification and characterization.
- CIGS remains very sensitive to deposition technique but RF, pDC results show excellent Se incorporation.

Phase III, Powder Capacity and Alloys for Multi-Step CIGS PVD

- Work proceeds further increase production units and lower cost of reacted CIGS.
- Work continues to develop and scale CuGa alloys for large PVD platforms.
- Proprietary and Batch Casting Technology was employed for different target thicknesses and compositions.
- All casting technology must retain desired workability and Gallium content throughout.

Copper –Gallium Phase Diagram



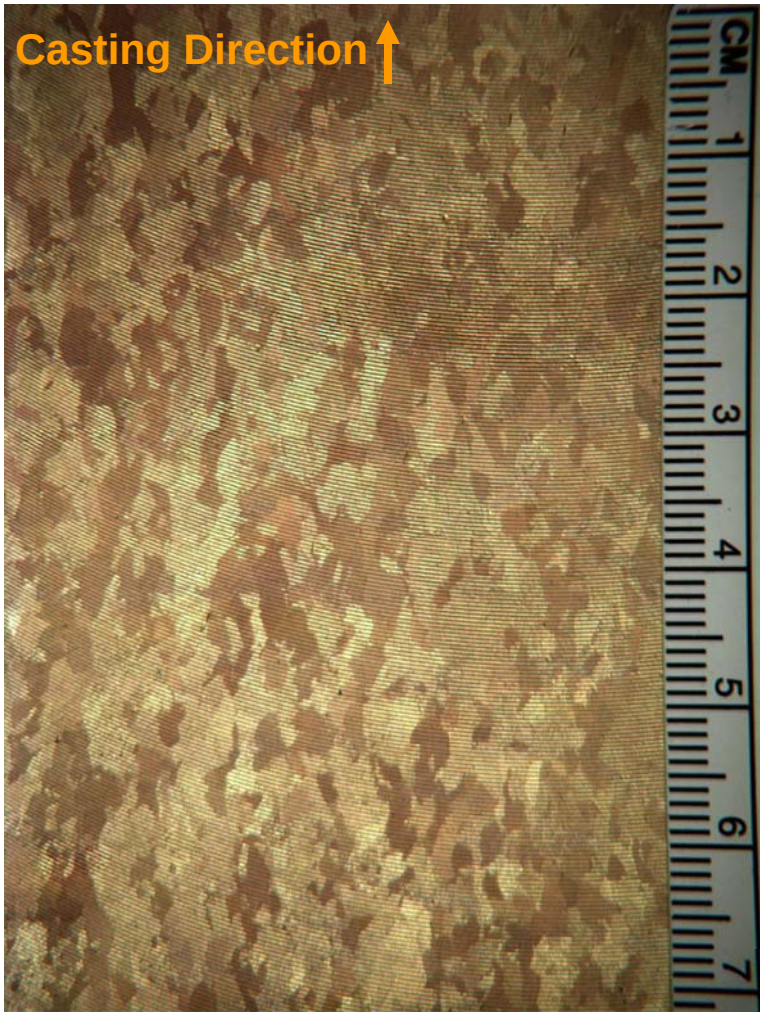
MP Cu ~1084 °C
MP Ga ~30 °C
BP Cu > Ga > 2000 °C

A. CuGa 25 at%

B. CuGa 30 at%

Proprietary Cast CuGa Alloys

- CuGa 25 at% developed at 8mm thick by 200mm wide by “x” long.
- Casting is done in N2 purge.
- Uniform 1-3mm grain orientation & size.
- Fixed cooling rate at Atmosphere.
- Proper Cubic / Hexagonal phase relationship maintains machinability.



Proprietary Cast CuGa 25 at%

Cast and Hot Rolled CuGa Alloys

- CuGa 25 at% developed as VIM cast and hot rolled to up to 24mm tiles.
- Custom cooling profile controls cubic and hexagonal phase concentrations.
- Hot top is easily cut off.
- Hot rolling produces fine 0.5mm uniform grains throughout.
- Machinability is excellent.

Cast CuGa 25 at% @ 25x

CIGS Alloys for Solar Modules

- Proprietary Cast CuGa25 8mm x 200mm x "specified" m @ 1-3mm grain size is available for large PVD tools.
- Cast and rolled CuGa25 16 -24mm @ 0.5mm grain size tiles are available for large PVD tools.
- Novel hybrid technique for the production of CuGa30 8mm polycrystalline tiles is available for large PVD tools.
- Novel technique for at% Gallium 30-50% are under development.
- All CuGa tiles can be conventionally bonded.

Solar Materials Development

- You have seen a novel Cadmium Sulfide Developed from initial chemistry to pressing.
- You have seen how Copper Indium Gallium (di)Selenide powders and Targets have been developed for a series of technologies.
- You have seen traditional casting and metallurgy bring new casting products for multi-step CIGS PVD applications.

Thank you for your Attention!

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