LOW TEMPERATURE PHOTONIC SINTERING FOR PRINTED ELECTRONICS

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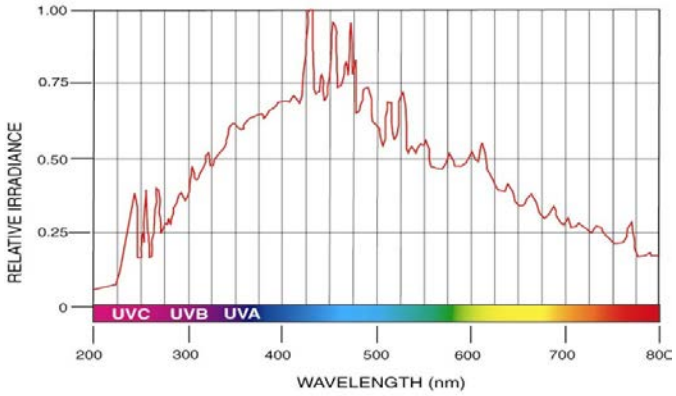
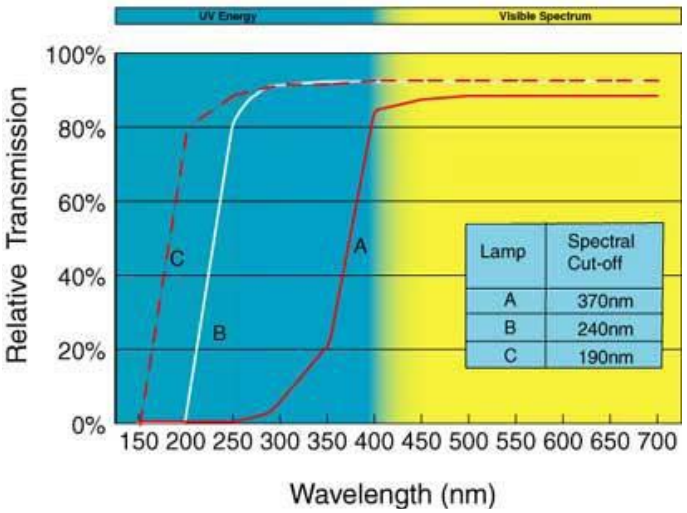
Topics

- Introduction to Pulsed Light
- Photonic sintering for Printed Electronics
- R&D Tools for Ink Development
- Roll to Roll Production Equipment
- Copper Sintering for FC
- Thermal Management Solutions
- Satellite Test Center Facilities
- Concluding Comments

Flash Lamps

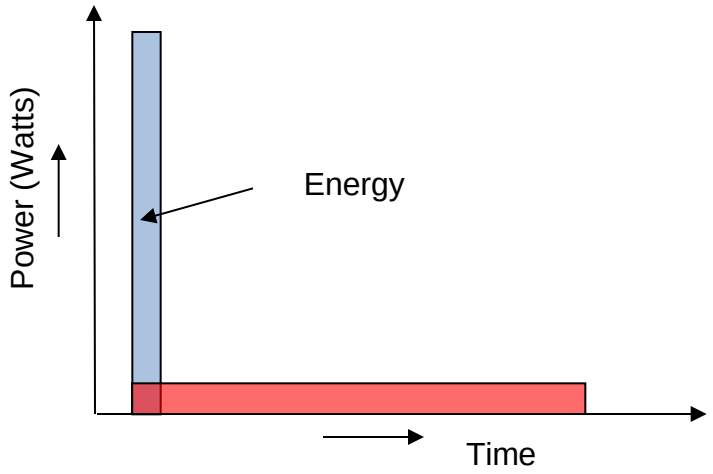
- XENON flash lamps have a broad spectrum of Light from deep UV to IR.
- Typically used for Curing and Sterilization where high photon energy is required
- When XENON gas is broken down due to a high energy field it goes from being an insulator to a conductor
- Excitation and recombination of ions within the arc plasma creates light.
- The envelope material can determine the spectral content of the lamp
- XENON flash lamps are inherently used for low temperature applications.

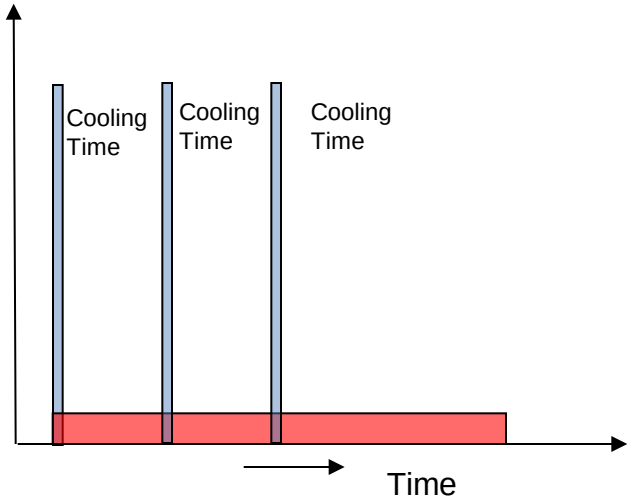




Pulsed vs. Continuous

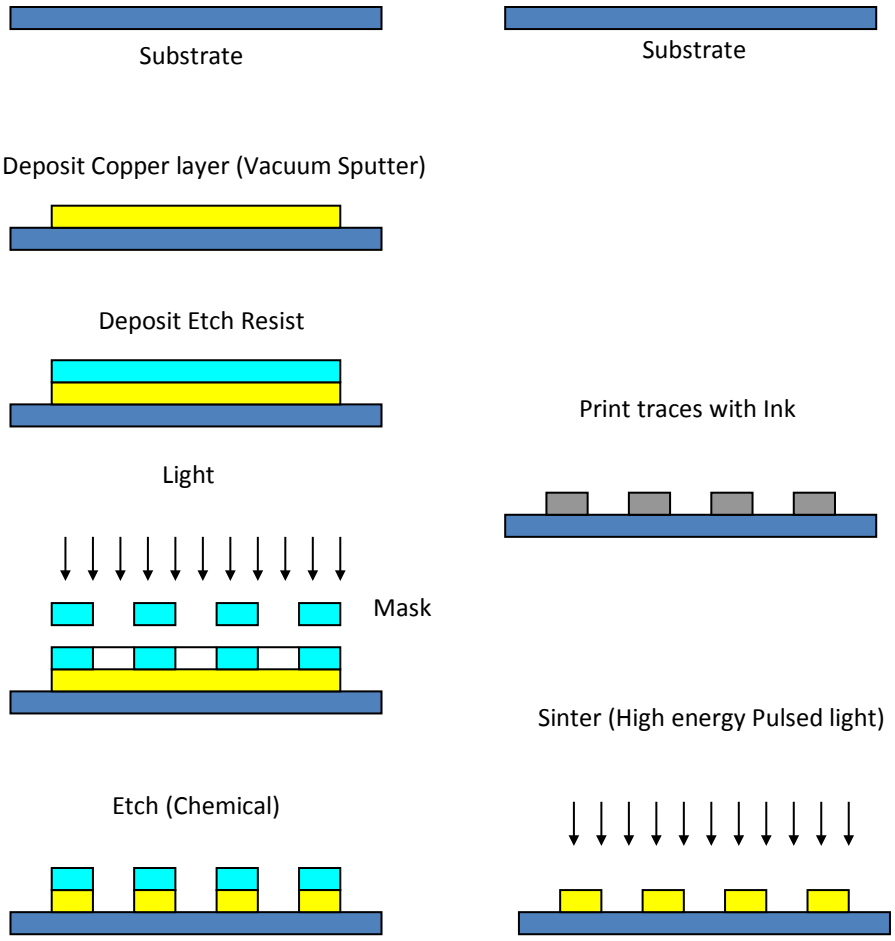
- If we try to expend 100 Joules of energy we can do it in two ways
  - 10 Watt lamp for 10 seconds or
  - 1 Megawatt pulse for 1 micro second.
- Continuous systems like mercury or halogen lamps cannot deliver these kinds of peak power.
- High peak power means the system is more efficient at delivering useful energy; more photons faster.
- Intensity attenuates as it penetrates into a material so peak power phenomenon allows for deeper penetration depths
- Shorter pulse duration means that the process can take place quicker
- Pulsed is instant on-off. It is harder to do that with continuous systems
- Pulsed systems can be frequency adjusted to allow time for cooling





Current Printed Circuit Process

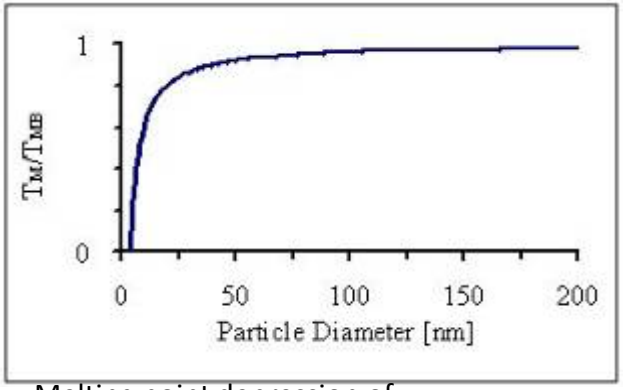
- Current process for printed electronic system requires multiple process steps
- They do not lend themselves to Reel-to-reel Systems
  - Flexible Substrates
  - Low Temperature Substrates
  - Complex Steps
- A simpler process would be to print conductive traces and cure to form conductive traces



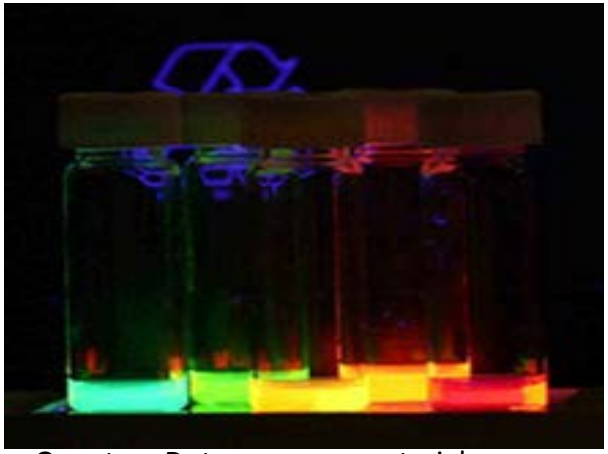
Comparison of Standard Printed Circuit Manufacture and Photonic Sintering

Photonic Sintering Basic

- Low temperature sintering of metal inks are possible because when particles become small their melting point is reduced. This phenomenon is called “Melting Point Depression”
- When particles become small their absorption characteristics change
- Nanotechnology is where particles are in the range of 1 to 100nm in size and it is at this particle size that these special effects take place
- Nano conductive inks can absorb light and sinter at a low temperature.
- Once sintered they behave like bulk material



Melting point depression of
Gold nanoparticles



Quantum Dots are same material
but with different size which changes color

Advantages of Photonic Sintering

- Conventional method of sintering conductive inks is to use low temperature ovens
- The time to achieve sintering is many minutes and not suited to Roll-to-Roll process
- Photonic Sintering can take place in fractions of seconds
- Photonic Sintering is a non contact process
- It requires no additional chemicals or special environment
- It is a low temperature process allowing use of low temperature flexible substrates like paper and PET
- It is easy to configure for different ink types, substrates and printing process.
- It can be fitted inline with an existing process without taking the space required for ovens or off-line solutions.

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XENON Corp - An Introduction

- We manufacture High Energy Pulsed Light systems for industrial applications.
- We began in 1964 developing high energy pulsed lamps for Laser Pumping.
- We have 51 years of experience with our core technology of pulse light.
- Over 3,000 pulsed light systems worldwide on Industrial Production lines.
- Our Markets Include:
  - Photonic Sintering
  - Optical Disk Manufacture
  - Pulsed UV Sterilization
  - Display
  - Surface Treatment
- We manufacture in the U.S.A. our own Lamps and Electronic Systems
- We build “the engine” that integrates into industrial systems that need to run 24/7
- Pulsed light is our expertise we pick up where other sources cannot compete in terms of energy, peak power and low temperature

Products: S-1000

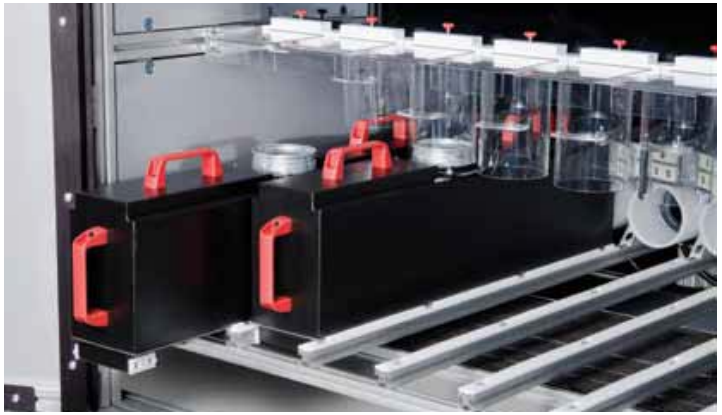
- Used for Sintering Silver inks
- Fixed Pulse Width -
- Voltage Adjustment

S-2100
Introduces Active Control

- Programmable Pulse width 100-2000us
- Voltage Adjustment
- 2000 Joules /Pulse
- Suitable for Copper Applications

S-5000
Our First R2R Offering

- Integrated Controller for lamp synchronization
- 10 Lamp System
- Integrated Conveyor
- Integrated Cooling
- Touch screen Computer based
- Modular Design for Integration into OEM Equipment
- Custom systems



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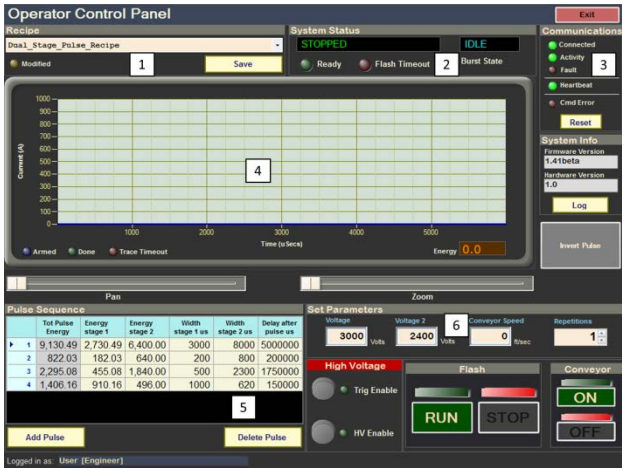
Modular Units for Integrators

- Automation Proven
- Flexible Integration
- High Volume Pricing
- Over 3,000 Systems Online

S-2300 Dual-Stage Sintering System

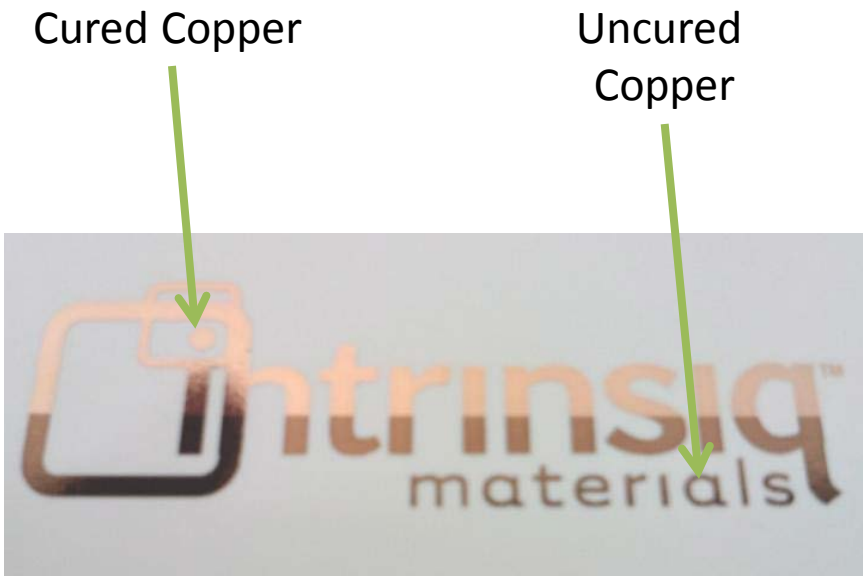
- Touch Screen PC based interface with recipe storage, programming and control
- A single pulse with two independent level control



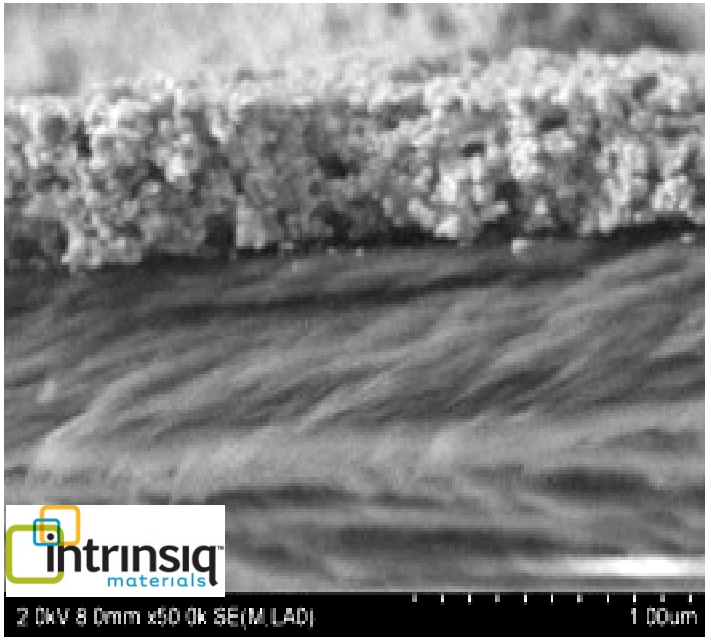
S-5100 Wide Web R2R

- First true Wide Width Photonic Sintering System
- Multiple 50in Lamp housing with 1m wide web capability (system shown can drive 4 50in Lamps)
- Touchscreen display for precise control of process parameters with tachometer speed control.
- Unprecedented uniformity along length +-5%
- High power 5J/cm^2
- Modular design for scalability

Copper Ink Sintering



Printed Image on Paper – Partially Cured



SEM image of the cross-section of the copper printed onto polyimide and after photonic curing

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Thin Films for HDI

- Current process for creating thin copper films uses Vacuum Sputtering
- This is not applicable for In-line Roll-to-Roll Process
- A process alternative is to use Slot dye Copper ink and Photo Sinter

Etch

Plate

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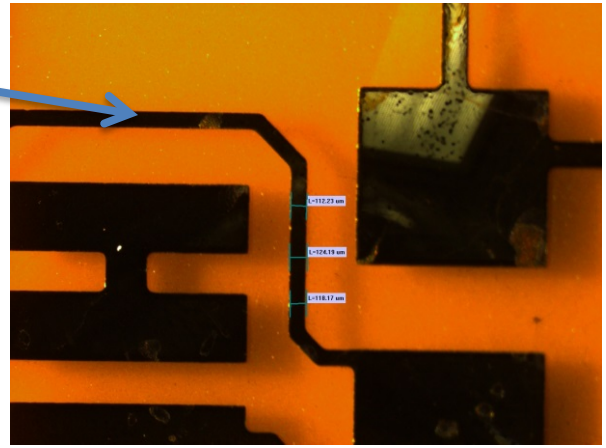
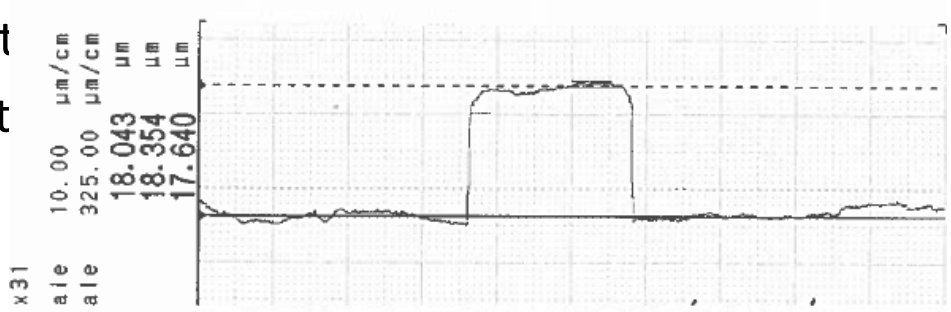
Advantages of Copper Sintering Process

- Coating with IM's nano copper solution will achieve 0.5-2um thickness copper foil over polyimide, single or double sided.
- Ultra thin FCCL can be used by traditional plating and etching process to achieve thin lines.
- It has smooth copper/polyimide interface, easy to make and low cost
- Porosity of Sintered copper makes it easy to etch for better profilometry

<100um





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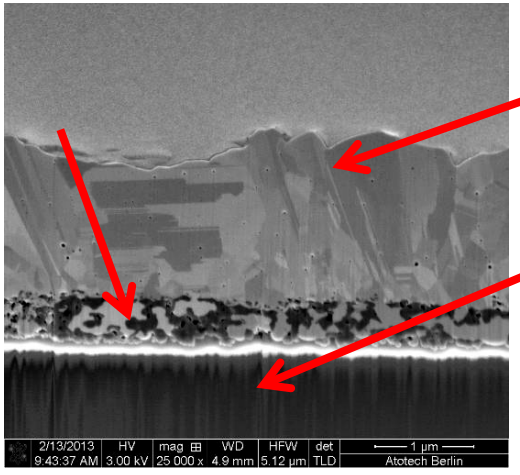
Advantages Continued

- Uses Minimal Nano-ink for lower cost
- Uses Standard Processes
- Double Side Possible
- Smooth interface between copper foil and polyimide, help signal integrity for high speed applications.

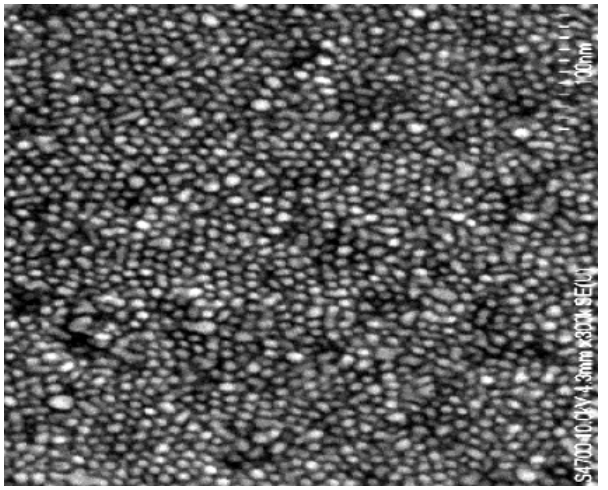
Nano-SEED layer (IML)



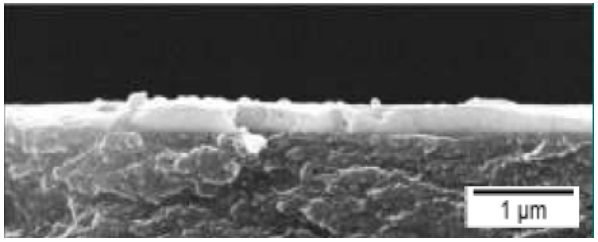
Feature	Advantage	Benefit
Ultra thin copper layer can be under 1 µm	Can create features smaller than industry standard using standard PCB technology	Increased circuit density and functionality
Thin film can replace lamination step	Reduced process steps, cycle time, and material waste	Lower cost, easier handling, and added functionality
Highly electrically and thermally conductive copper film	Equivalent performance to laminated foil	High performance
Deposited through conventional printers (inkjet, screen printers)	Minimal re-tooling	Low cost
Airhandleable, no vacuum or environmental controls needed	Operates in an open environment	Lower cost & smaller footprint
Photonic sinter, lower temperature	Can use temperature sensitive substrate such as paper, plastic	Added flexibility and functionality, with lower cost

Silver Sintering

- Silver inks are well suited to photonic sintering
  - Both silver and its oxide are conductive
  - Formulation and manufacture of silver nano inks are easier and more prevalent
  - Their operational window is large
  - Their size can be tightly controlled
  - They can show improvement in their functionality with multiple pulses (contrary to the concept of nanoparticle advantage)



SEM of Silver Nano particle
5-6nm in size



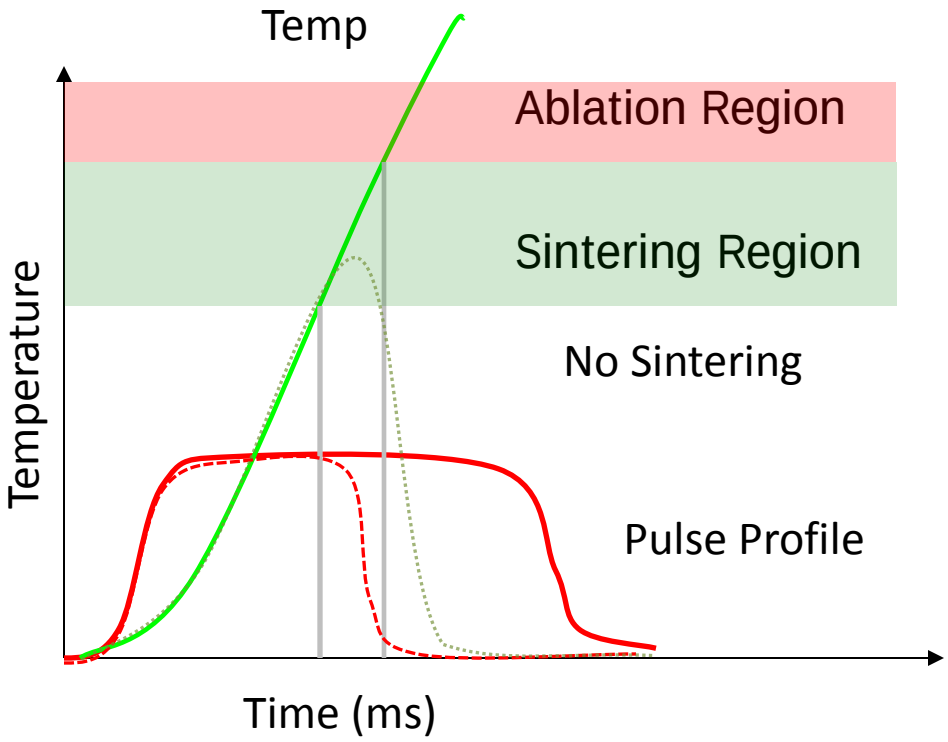
AG Film on PET
After sintering

Flexibility In Ink Sources

- At XENON we have tested many inks from different ink suppliers and here are several we can mention.
  - Silver
  - Copper
  - Ceramic
  - Gold
  - Nickel
  - Platinum

Thermal Aspects of Sintering

- For many conductive inks there is a temperature range that sustains sintering action.
- Above the range we ablate the ink
- Below the sintering region there is no change
- The original Sinteron tools were designed to produce a flat uniform intensity output with time
- This means that the operational window is small and we cannot process thicker films

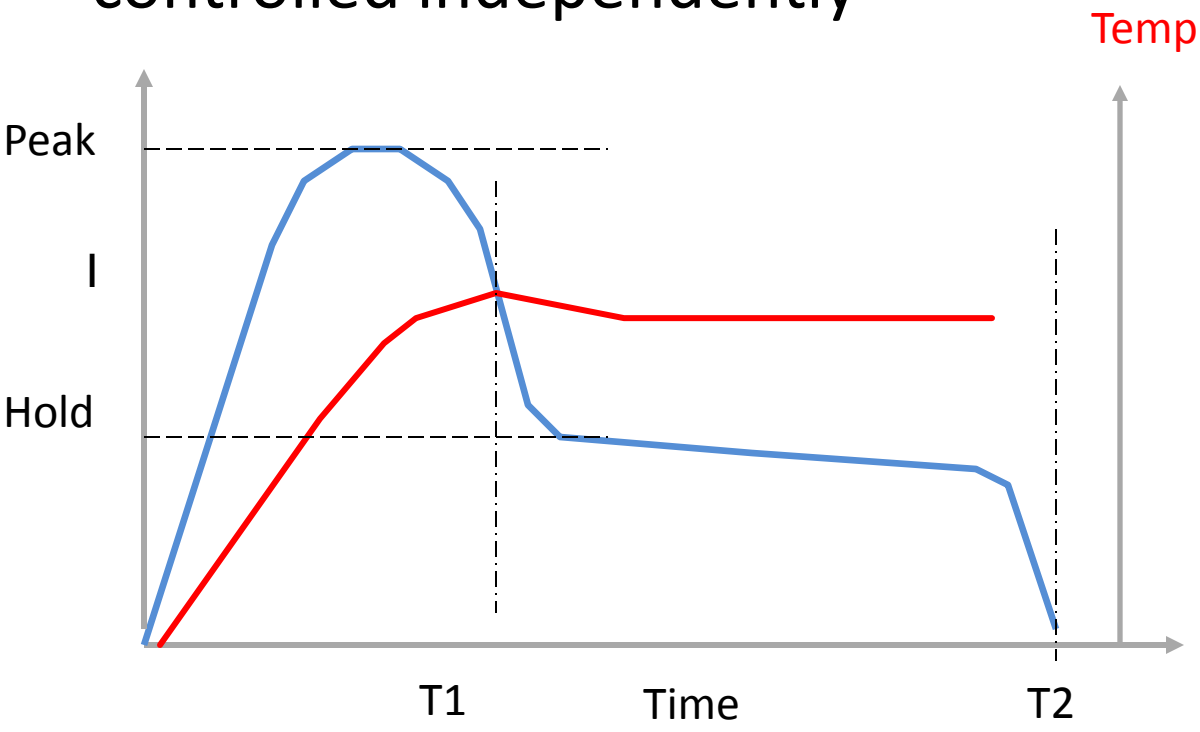


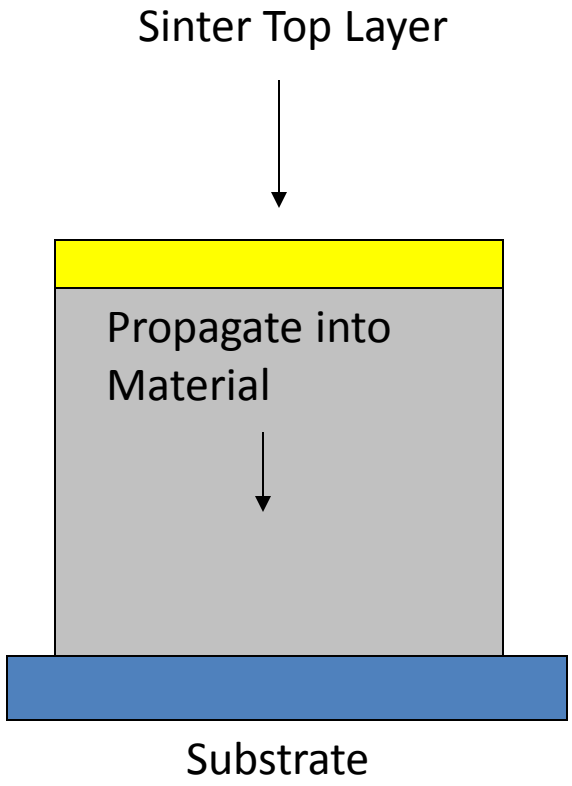
Thermal Management for Sintering

- The S-2100/S-1000 generate a flat pulse output.
  - This gives us a uniform relation with time and energy
  - However this is not optimal for thermal management
- For Thermal management of Sintering we need two features of a pulse
  - One to bring the material to sintering Temperature
  - Second to hold the temperature for penetrating into material
  - This is essential for a deep and even cure.

Enter the S-2300

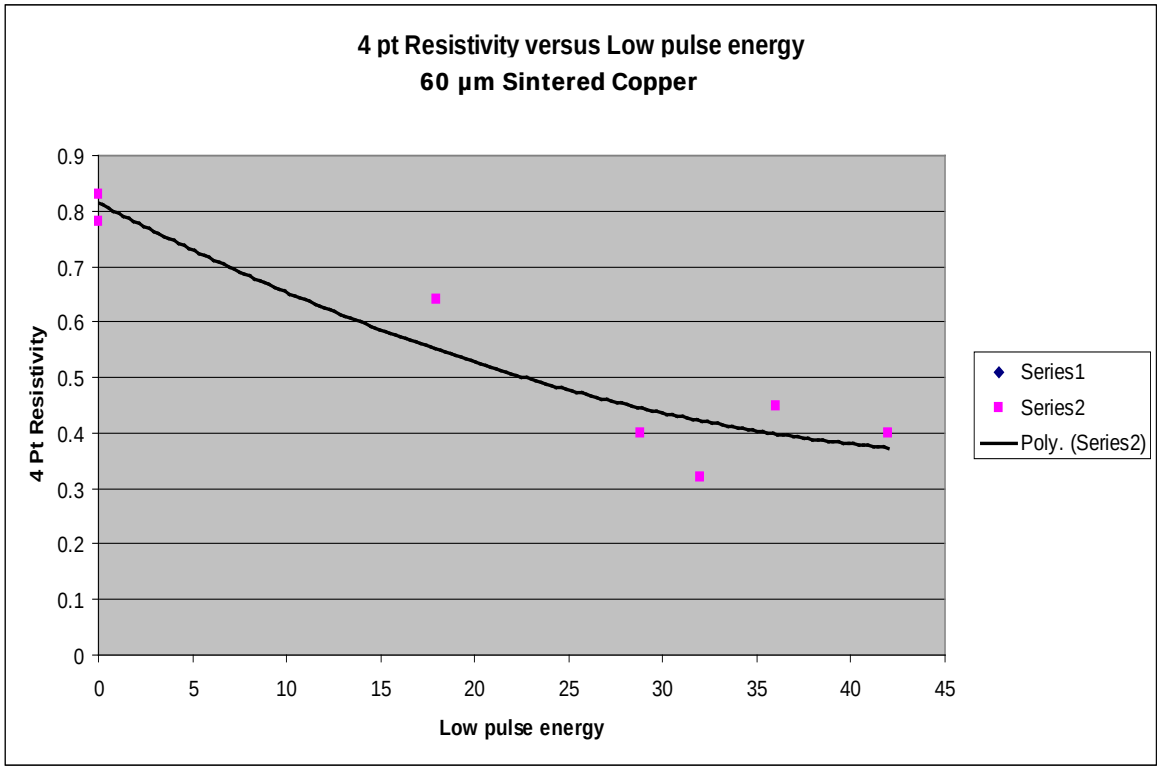
- This system has a dual stage profile where each pulse can be controlled independently





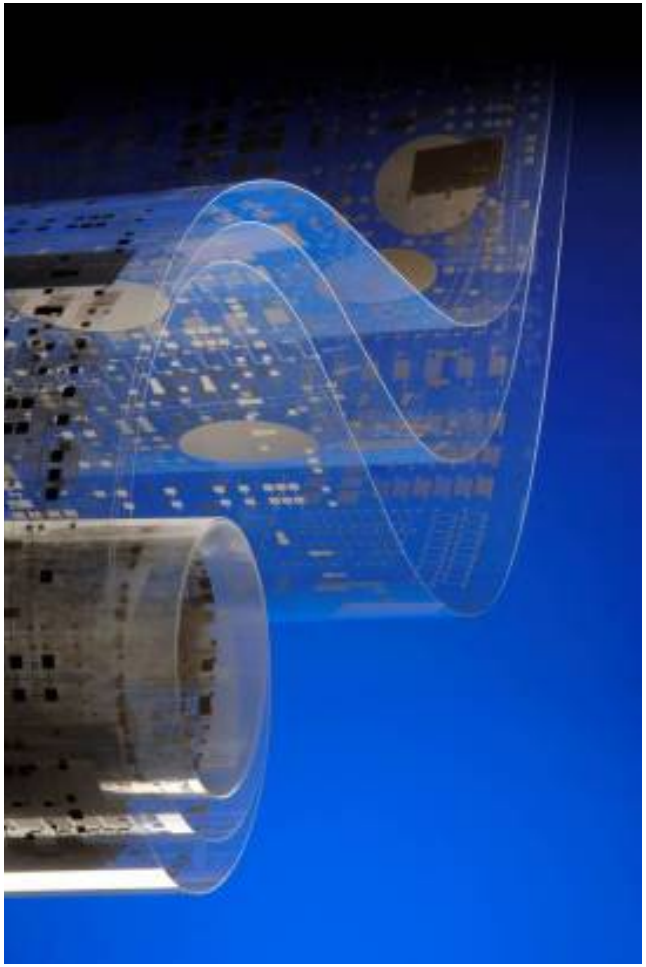
The Dual-Stage Advantage

- We bar rolled Copper ink on a paper substrate.
- We adjusted the Sinteron with a single pulse profile to get the best resistivity value
- We used the S-2300 and adjusted the second pulse profile
- We achieved better than 50% improvement in final resistivity
- We have observed better adhesion, and a wider operating parameter range based on this technique.



Roll-to-Roll Challenges

- Roll-to-roll applications have unique requirements
  - Process speeds 5ft/min to 100s ft/min
    - Faster throughput increases efficiency and reduces costs
    - Synchronization is important
  - Web based systems demand higher reliability
    - Down time and failure generates waste
  - Web size can vary
  - Flexibility is required
    - Different inks, different substrates, different applications
  - Functional Uniformity of result is important.
    - Tolerant to ink thickness and printing process



The Strategy for Successful Deployment

- Create R&D low cost tools that can be used for Evaluation of Ink Formulation
- Develop Application Lab support for Fast track process development
- Create Key Partnerships
  - Ink Developers
  - Print Technology Groups
  - Substrate Manufacturers
  - Process Integrators
  - Academic Institutes
  - Government Funding
- Develop Satellite sites for evaluation of technology and enhanced collaboration
- Identify end to end working solutions

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Satellite Sites

Satellite Sites

- XENON Corporation understands that successful deployment of photonic sintering requires collaboration with multiple technology groups.
- XENON has led the formation of a consortium of manufacturers, integrators and universities called **Printed Electronics Test Center Network.**
- This network includes ***14*** US and ***12*** International sites. These sites offer laboratory, equipment and expertise to develop printed electronic solutions.
- Please visit www.xenoncorp.com for more information.

Moving to Roll-to-Roll - The Future

- Large web width sintering
- Low energy sinterable inks
- Low cost ink/Substrate solutions
- High speed printing capability
- Dynamic monitoring of functionality
- Sinterable semi-conductive materials
- Novel interconnect solutions between flexible electronics and devices

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Conclusion

- Photonic Sintering:
  - Works with many conductive nanoparticles for printed electronics needs
  - Requires high energy which can be generated by a flash lamp
  - Fast, compact and cost effective alternative to ovens
  - Easy retrofit to existing process for roll-to-roll deployment
  - Needs to be flexible to work with various ink formulations
  - Should be scalable for different process speeds
  - Providing system that have meaningful controls for pulsed light opens new opportunity for dealing with the diverse range of process requirements.
- Roll-to-Roll offers unique challenges for pulsed light.
- XENON is developing a strategy which includes all aspects of the development process including thermal management with our new S-2300 system.

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Thank you

Questions and Comments