MASTERING
PRINTED ELECTRONICS
PRINCIPLES

Photonic Drying – Pulsed Light as a low Temperature Sintering Process

Lou Panico

Xenon Corporation

Presentation Overview

- A Market In Development
- What is Sintering
- Significance of Nanoparticles
- Conductive Nanoparticle Inks
- Silver Sintering
- Copper Sintering
- Copper Circuits Before and After Sintering
- Pulsed Light Curing Technology
- Using Pulsed Light for Sintering
- Meeting the Needs of High Speed Printing
- Conclusions

A Market in Development

- Printable electronics is still an emerging technology, and there are technology gaps to be met before widespread adoption can occur.
- One such gap is the need for low temperature curing (or sintering or annealing) methods.
  - Conductive inks are typically metallic-based, and must be sintered to realize high conductivities, which requires time and temperature.
  - Lower temperatures generally mean longer processing times.

What is needed is a low temperature and rapid process for curing or sintering of thin film on low cost substrates such as PET.

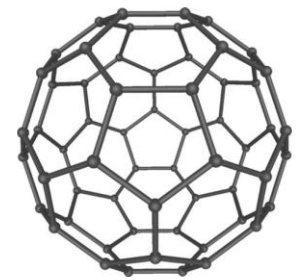
What is Sintering

- Definition
  - Sintering is a method for making objects from powder typically **below its melting point**
  - Traditionally use heat, pressure and time
- History
  - 1906 First patent on sintering Using Vacuum by A. G. Bloxam.
  - Decades of Development with around 640 Patents
- Some Current Methods of Sintering include:
  - Sintering Ovens
  - Arc Discharge
  - Laser
  - And now Pulsed Light.

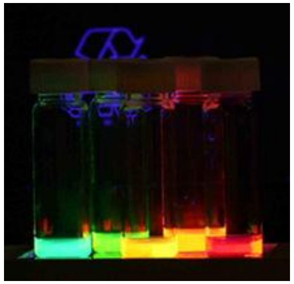
Vacuum Sintering Oven

SIGNIFICANCE OF NANOPARTICLES

- All materials have basic properties
  - Melting point, light absorption (color) etc.
  - Governed by laws of particle physics
- These are independent of particle size
  - Melting point for a gram of copper is the same as for a kg of Copper. It still looks like the same material
- Once materials become around the size of 1 to 100 nanometers quantum physics becomes significant
  - Their Melting point changes
  - Optical absorption characteristics change: Quantum Dots
  - Opens up new possibility of sintering at significantly lower temperature when compared to bulk material.
    - Gold 1064˚C bulk -- 300˚C when 25nm



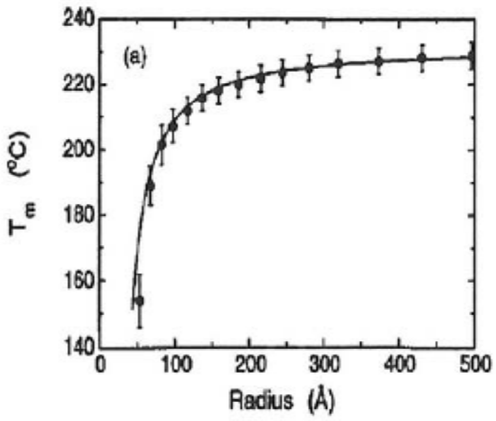
Classic Nanoparticle Buckminsterfullerene C60



Quantum Dots. Same Material Different sizes have different colors

Conductive Nanoparticle Inks

- Basic Principle
  - Start with nanoparticle conductive ink
  - Deposit on substrate
  - Use low temperature to achieve sinter
  - Convert to Bulk conductive material,
  - Nanoparticle properties change
    - Melting point, color etc.
- Two different categories of conductive nano inks
  - Basic Sintering –e.g. Silver
  - Reduction and Sintering –e.g. Copper
- Why Sinter Conductive Inks
  - Melting point of metals are usually higher than plastics (the substrate)
  - Would make conductive traces (printed circuits) on flexible materials
  - Could be applied by regular printing process like roll to roll or inkjet



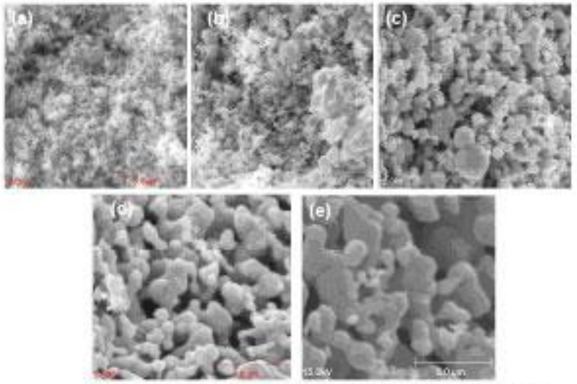
Melting point of Tin Clusters

Sintering Silver Nanoparticles

- Silver is relatively easy to sinter
  - Silver is Conductive as is Silver Oxide
  - Nanomaterial is easy(er) to produce
  - Yield is high even if bulk is expensive
  - Energy required is low nanoparticle size 5-

- Traditional process
  - Use 120˚C thermal for around 10 minutes.
  - Shiny finish good conductivity.

- Using Pulsed Xenon Flash Lamp
  - One flash < 1 second
  - Excellent Conductivity
  - Matt finish due to rapid formation

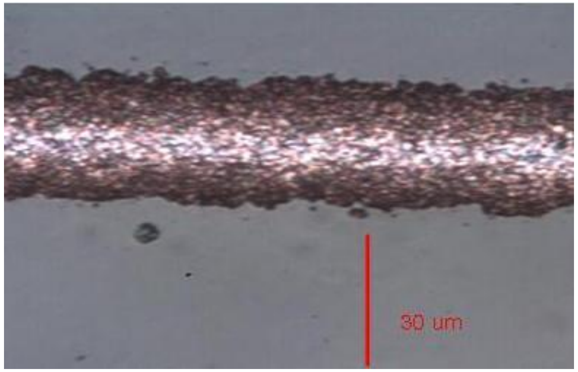


(a) non treated, (b) 100 °C, (c) 150 °C, (d) 200 °C and (e) 250 °C.

Silver going from powder to Bulk

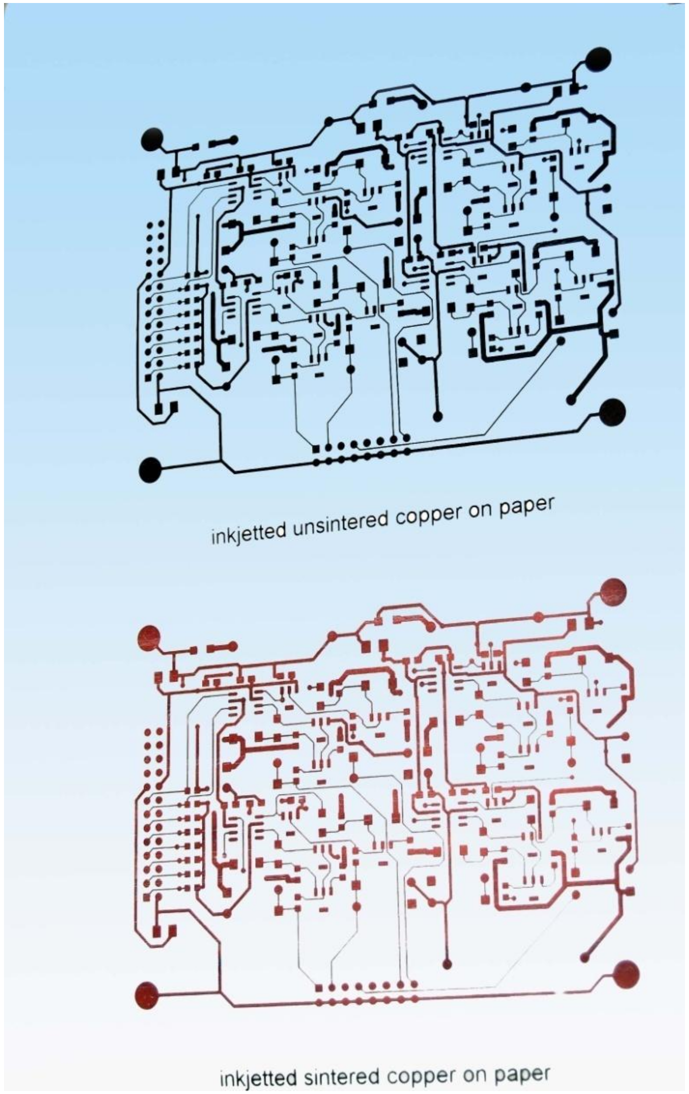
Copper Sintering

- Copper Is harder to sinter
  - Copper is conductive - but copper oxide not a good conductor. Copper readily oxidizes
  - Nanomaterials are harder to produce
  - Yield is low even if bulk is cheaper
  - Energy required is significantly higher
  - Cu is the “Holy Grail” for Printed electronics technology
- Typically Sintering also requires a reduction of copper oxide to copper.
  - Some Oxidizing material in the ink may be required
  - Small margin between energy to sinter and energy to evaporate material



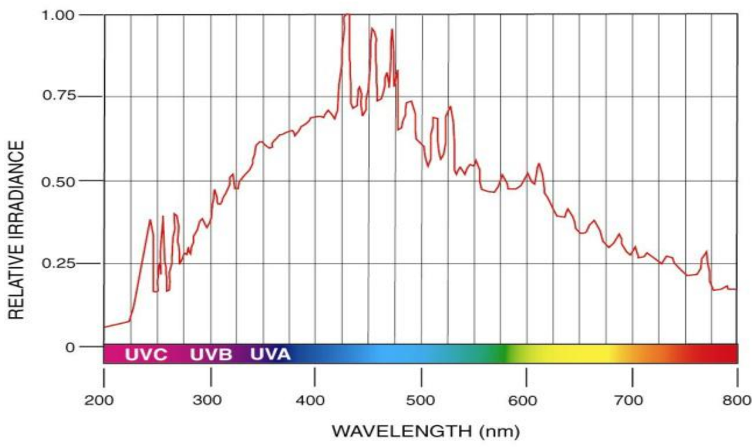
ANI Copper Inks Aerosol Jetted and cured on Glass

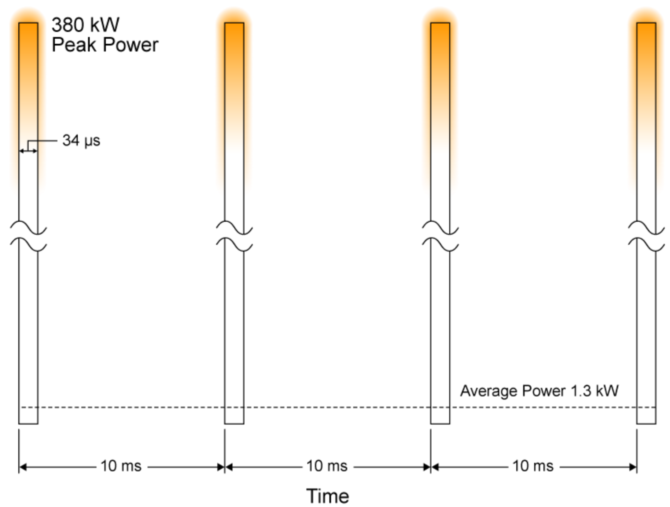
Copper Circuits – Before & After Sintering



PULSED LIGHT CURING TECHNOLOGY

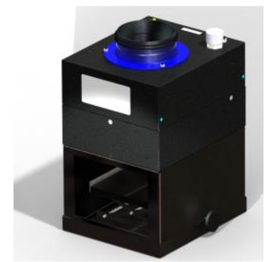
- Xenon Flash Lamps have a broad spectrum of Light from Deep UV to IR
- By Compressing energy over a short duration higher peak power can be delivered
- Peak Power Phenomenon results in greater penetration depth into material
- Instant ON/OFF control of pulses
  - Match speed of printing
  - Lower overall energy usage
- Superior to Mercury lamps
  - Must be ON at all time





Using Pulsed Light For Sintering

- Pulsed Light can Sinter !
  - Non Contact Sintering
  - Non Thermal Process
  - No Chemicals
  - Fast
  - Relatively Simple to deploy
- Technology is still in infancy
  - New materials are being developed
  - New processes are being considered
  - Need to have simple tools to evaluate technology
- Systems Offer Flexibility
  - Selectable pulse width
  - Selectable pulse energy
  - Flashlamp wavelength selection
  - Flashlamp length selection
    - Offers different sintering areas



MEETING THE NEEDS OF HIGH SPEED PRINTING

- In addition to low temperature curing, there are additional benefits of pulsed light curing that make it suitable for printable electronics.
  - By reducing the time to cure in milliseconds, pulsed light curing can be compatible with high-speed printing processes such as gravure and flexography without a large amount of dedicated floor space. In essence, the time to cure becomes matched to the time to print.
  - The process is suited to nanoparticle-based materials, which also makes it well-suited to high resolution deposition methods and applications.
  - The speed with which sintering occurs makes it possible to cure copper in air, which normally must be cured in an inert or reducing environment.
  - Once a material has been sintered, it will typically no longer absorb light. Thus there is the potential for building multilayer circuitry that does not thermally stress the underlying layers.

CONCLUSIONS

- Sintering nanoparticles is an emerging and exciting technology
- Using Pulsed UV Light for Sintering has shown great promise
- Pulsed UV Light systems have been applied in many diverse applications for over 30 years
  - Wood Coatings
  - Blu ray Disc
  - Medical Devices

Thank you for the opportunity to provide this background on the application of sintering in the Printed Electronics Industry.