MASTERING
PRINTED ELECTRONICS
PRINCIPLES

Photonic Drying – Pulsed Light as a low Temperature Sintering Process

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Presentation Overview

- What is Printed Electronics
- Materials
- A Market In Development
- What is Sintering
- Significance of Nanotechnology
- Conductive Inks
- Silver Sintering
- Copper Sintering
- Pulsed Light for Sintering
- Conclusions

What is printed Electronics?

- Printable electronics represents the merger of electronics and printing.

- The concept is to use high speed printing equipment to build electronic devices using specialized inks that when cured provide the basic building blocks of circuits: conductors, resistors, semiconductors, and dielectrics.

- Compared to standard equipment for manufacturing semiconductors and electronics, printing equipment is fast, inexpensive, and large area (i.e. “wide-web”), factors which together enable the promise of low cost and large area printable electronics.

MATERIALS

- Conductive materials are critical to the growth of printed electronics
- Many researchers and manufacturers are developing products for the marketplace
- Conductive inks and coatings are manufactured using metallic flakes, such as silver and copper
- NanoMarkets forecast market for conductive silver inks would reach $1.2 billion by 2014

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, for example, are typically metallic-based, and must be sintered to realize high conductivities, which requires time and temperature. Lower temperatures generally mean longer processing times.
  - A cure time of one minute on a 2,000 FPM (feet per minute) web necessitates a curing oven with nearly a half mile heated web path.
  - Higher temperatures, on the other hand, can reduce the sintering time, but at the cost of requiring expensive substrates that can withstand the high temperatures.
- What is needed is a low temperature and rapid process for curing or sintering of thin film on low cost substrates such as PET.
- This where pulsed light technology comes in.

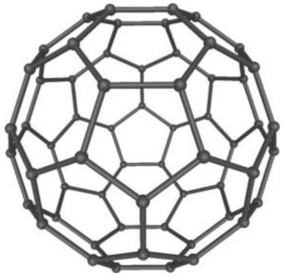
Sintering

- 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.

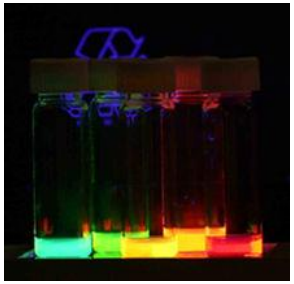
Vacuum Sintering Oven

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



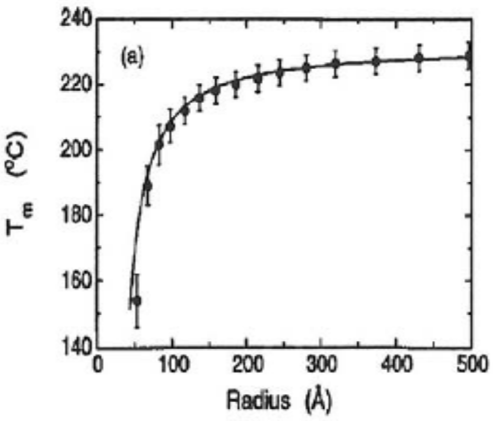
Classic Nanoparticle
Buckminsterfullerene C60



Quantum Dots. Same Material
Different sizes have different colors

CONDUCTIVE NANOPARTICLE INKS

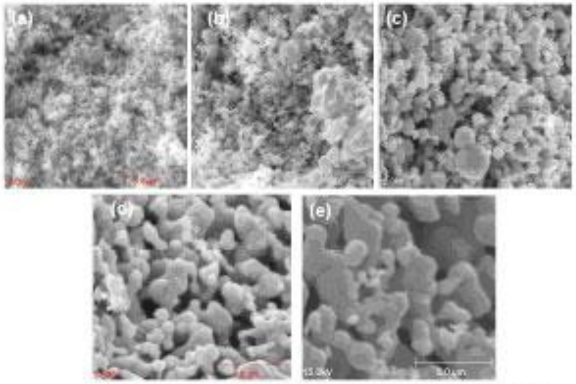
- Basic Principle
  - Start with nanoparticle conductive ink
  - Deposit on substrate
  - Use low temperature to achieve sinter
  - Convert to Bulk conductive material,
  - nanoparticle properties change
    - Melting point, color etc.
- Two different categories of conductive nano inks
  - Basic Sintering –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

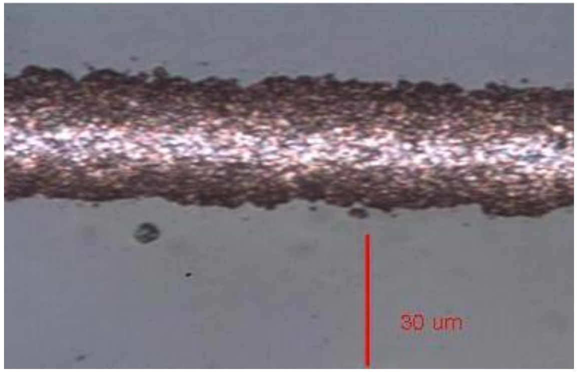


(a) non treated, (b) 100 °C, (c) 150 °C, (d) 200 °C and (e) 250 °C.

Silver going from powder to Bulk

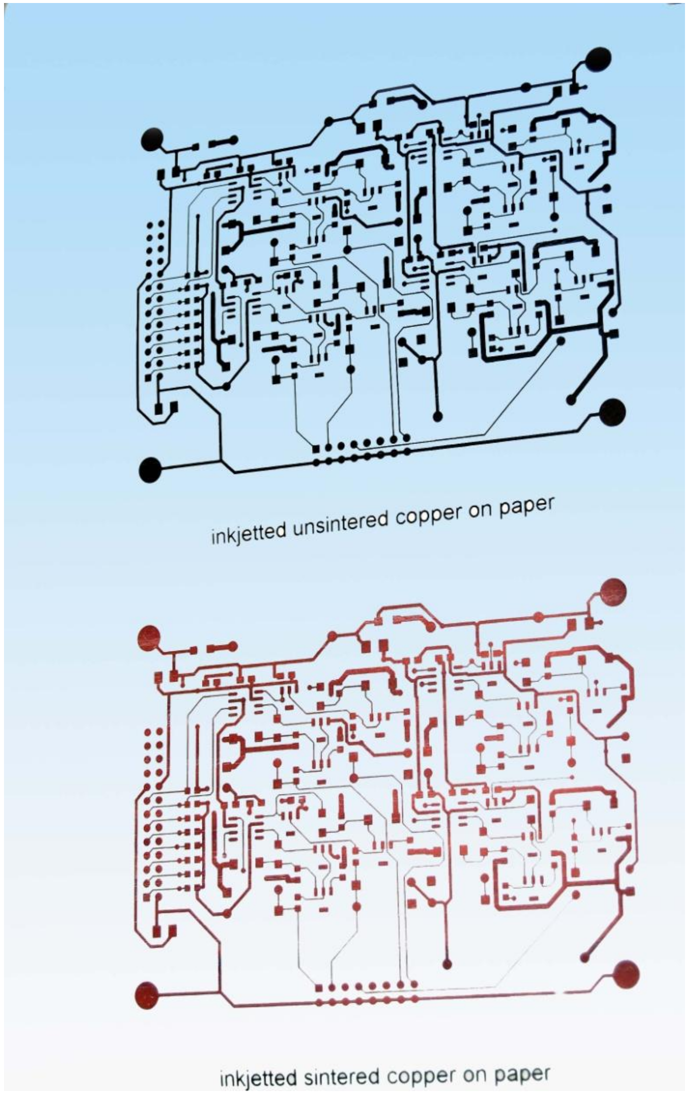
Copper Sintering

- Copper Is harder to sinter
  - Copper is conductive, 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
  - 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



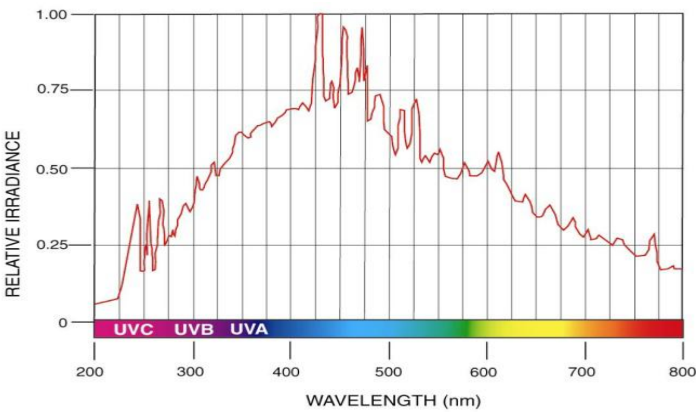
ANI Copper Inks Aerosol Jetted and cured on Glass

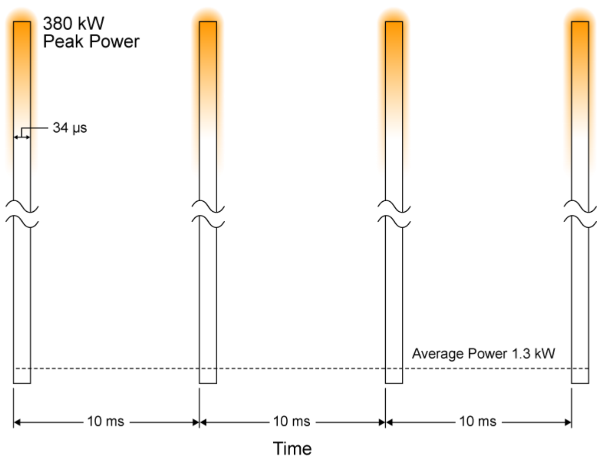
Copper Circuits – Before & After Sintering



Pulsed Light Technology

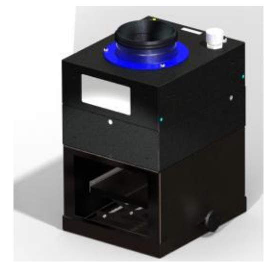
- Xenon Flash Lamps have a broad spectrum of Light from Deep UV to IR
- By Compressing energy over a short duration higher peak power can be delivered
- Peak Power Phenomenon results in greater penetration depth into material
- Short Pulses of Light means that there is minimal heating
- Superior to Mercury based continuous systems





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
    - 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 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 15 years

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