LOW TEMPERATURE PHOTONIC SINTERING FOR PRINTED ELECTRONICS

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September 8, 2012
Topics

- Introduction to Pulsed Light
- Photonic Sintering for Printed Electronics
- Sintering Different Materials
  - Silver
  - Copper
  - Gold
- About Xenon Corp
- Roadmap of products for Photonic Sintering
- R&D tools for Ink Development
- Tools for Roll to Roll Production
- Strategy for rapid process development
- Satellite Test 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 used can determine the spectral content of the lamp.
- Lamps can explode due to excess energy through lamp.
  - Typically operate at 10% of explosion energy.
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.
- 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.
Flash Lamps

- We have developed many lamps over the years that have been designed for optimum performance for a given process.
Pulse Characteristics

Energy = Watt Second

Peak power = \((CV^2/2)/T\)

Pulse duration is defined as the half max width for the current graph (T)

Lamp intensity correlates well with Lamp Current.

Energy per Pulse is area under the V and I

By increasing the voltage we can increase the peak and total energy per pulse.

By using a Switch we can electronically control the pulse width
Functional inks

- Often use of Printed electronics demands a range of functions defined by their use
  - Resistively is the most common requirement
  - Transparency for touch panels
  - Adhesion
  - Flexibility
  - Reflectivity

- In the standard printing world these functions are not required

- Accuracy of the print process in terms of layer thickness and placement is more critical than for standard printing
  - Layer thickness relates with resistance $R = \rho \frac{l}{A}$
  - Poor accuracy may lead to shorts or open circuits
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
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:
  • Sintering Ovens
  • Arc Discharge
  • Laser
  • And now Pulsed Light.
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.
Photonic Sinterable Materials

- At Xenon Corp. we have tested many inks from different ink manufacturers here are a few that we can mention.
  - Copper
  - Silver
  - Gold
  - Nickel
  - Platinum
  - ITO
Particle Size of nano-inks

- Particle Size plays an important role in defining the absorption characteristics of the Nano ink.
- The tighter the control the better repeatability you have.
- Using broad spectrum source reduces your dependence on fixed particle size.

Silver (~5 nm)
Gold (~3-4 nm)
Palladium (~3 nm)
Platinum (~2 nm)
Spectral dependence of Size and shape

- Particle shape and size can determine the absorption characteristics of nanoparticles.
Some Case Studies- Silver

- Silver Nano-inks are generally simpler to manufacture and more prevalent
- Silver and its oxide are both conductive
- They require less energy to sinter
- They can show improvement with multiple pulses (reduce stitching effects)
- They have a large operational window
Silver Test Results

- Chemistry: Nanotech
  Nanosilver dispersion
  NT-S05IJo6-46 – 46 %
- Substrate: Pebax Green 72
- Dispense Method: Dip
- Resistivity: .083 ohms / square
- Dose: 657 J / 500 usec pulse

Comment: This application required sintering of a tube, Silver sintered easily, Adhesion was excellent and uniformity good even on a radius.
Case Study - Gold

- Chemistry: Nano Gold Dispersion - NTG-05IX-25
- Substrate: Pet
- Dispense Method: Dip
- Resistance: 5 ohms 1 cm
- Dose: 451 J at 500 usec

Comments: This gold is very easy to sinter, The adhesion is excellent and stitching problems minimal
Case Study Copper

- Chemistry: Applied Nanotech Copper
- Substrate: Polyimide
- Dispense Method: Drawdown
- Resistivity: 13.8 x bulk
- Dose: 1 pulse of 304 J – 1000 usec
- Application:

  This copper requires a fair amount of energy, Adhesion is good, Stitching marks can be seen but the resistivity is good across stitch
Xenon Corp- An Introduction

- We manufacture High Energy Pulsed Light systems for industry
- We have been established since 1964
- Have developed lamps for laser pumping
- Our Markets Include:
  - Optical disk manufacture
  - Pulsed UV sterilization
  - Food enhancement
  - Surface treatment
  - Photonic Sintering
- We manufacture 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
Xenon at a glance

• The leading World Wide provider of High Energy Pulsed Light Technology for industrial applications.

• Primary markets:
  – Printed Electronics
  – Optical disk: Blu-ray, DVD
  – Solar
  – Surface Sanitization
  – Food Enhancement

• 5 patents issued and 4 additional patents pending

• Founded 1964

• World headquarters in Wilmington (near Boston), Massachusetts USA
Xenon Corp Sintering Roadmap

- Sinteron 2000
- Active Control
- Sinteron 2005
- Active Control
- Sinteron 2010
- Sinteron 500
- Sinteron 5000
- MACS 6
- Sinteron 5000 10 Lamp
- Sinteron 5000 5 Lamp
- Active Control Sinteron 2000
- Active Control Sinteron 2005
- Sinteron 500
- Copper Sintering
- Silver Sintering

SPEED/ENERGY

ROLL TO ROLL

START/STOP

2010 2011 2012 2013

TIME

Present Day
Products: Sinteron 500

- Used for Sintering Silver inks
- Fixed Pulse Width -
- Voltage Adjustment
The Sinteron 2000
Our First Copper Sintering Solution for R&D

• Developed specifically for the high energies needed for Copper
  – Pulse width is adjustable
    • 500 μS
    • 1000 μS
    • 1500 μS
    • 2000 μS
  – Pulse Voltage Adjustment
    • 1.5KV to 3.4KV
  – Lamp can be spiral or linear Lamp Housing
  – Also has option for Linear Stage for large area processing
The Sinteron 2010
Introduces Active Control

- Programmable Pulse width 100-2000us
- Voltage Adjustment
- 2000 Joules /Pulse
- Suitable for Copper Applications
The Sinteron 5000
Our First R2R Offering

- Integrated Controller for lamp synchronization
- 10 Lamp System
- Integrated Conveyor
- Integrated Cooling
- Touch screen Computer based
MACS-6
Our Multi Lamp Active Control System for R2R

- Active control
- 30 in Lamp
- Cassette based Lamp housing for easy removal
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
Printing Process

- Different kinds of printing processes can be used for Photonic sintering. Choice determined by desired thickness and feature size.
Printing Technology

- The technology is well suited to small scale systems like ink jet printing and small scale gravure printing.
  - There are many lamp designs that can lend themselves to a retro fit for a staged system
  - Typically a lot more flexibility in speed, so can be accomplished with a single lamp solution
### Process speeds based on printing technology

<table>
<thead>
<tr>
<th>Basic Principle of Ink Separation on the Image Carrier</th>
<th>Resolution</th>
<th>Ink Film Thickness</th>
<th>Printing Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screen</td>
<td>50 µm</td>
<td>3 - 60 µm</td>
<td>8 m/s</td>
</tr>
<tr>
<td>Inkjet</td>
<td>20 µm</td>
<td>0.05 – 0.5 µm</td>
<td>2.5 m/s**</td>
</tr>
<tr>
<td>Flexography</td>
<td>20 µm</td>
<td>0.5 - 2 µm</td>
<td>5 m/s</td>
</tr>
<tr>
<td>Gravure</td>
<td>15 µm</td>
<td>0.5 - 8 µm</td>
<td>15 m/s</td>
</tr>
</tbody>
</table>

*Maximum speed based on what is used in traditional printing applications**** for 600 x 600 dpi

Source: WMU CAPE
Process Speed based on Photonic Sintering

- For photonic sintering process speeds are defined by the flash rate, energy per pulse and number of flashes required.
  - For optimal performance the lowest energy required with the shortest pulse needs to be identified for the process.
- These define the total energy demand of the system and the required cooling for safe operation of the lamp.
  - The lower the energy per pulse the faster the lamp can be flashed
- Flash lamp systems can be scaled to include multiple sources to keep up with process speed.
- Example values for a 16" lamp housing is 12 " x 1" optical footprint with a pulse rate of 3 Hz = 15 ft /min web speed
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
- Identify end to end working solutions
Satellite Sites
Satellite Sites

- Xenon corp. understands that successful deployment of photonic sintering requires collaboration with multiple technology groups.
- Xenon Corp. has led the formation of a consortium of manufacturers, integrators and universities called Printed Electronics Test Center Network.
- This network includes seven US and eleven International sites. These sites offer Laboratory, equipment and expertise to develop printed electronic solutions. Distributors.
- 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
Conclusions

- 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
- Roll to Roll offers unique challenges for pulsed light.
- Xenon is developing a strategy which includes all aspects of the development