NOVACENTRIX™

PulseForge™

# Curing Copper and other Thin-Film Materials at Production Speeds

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Oct 2009


# 2009

## PulseForge 3100 and Pulsed Thermal Processing

Printed Electronics AWARDS

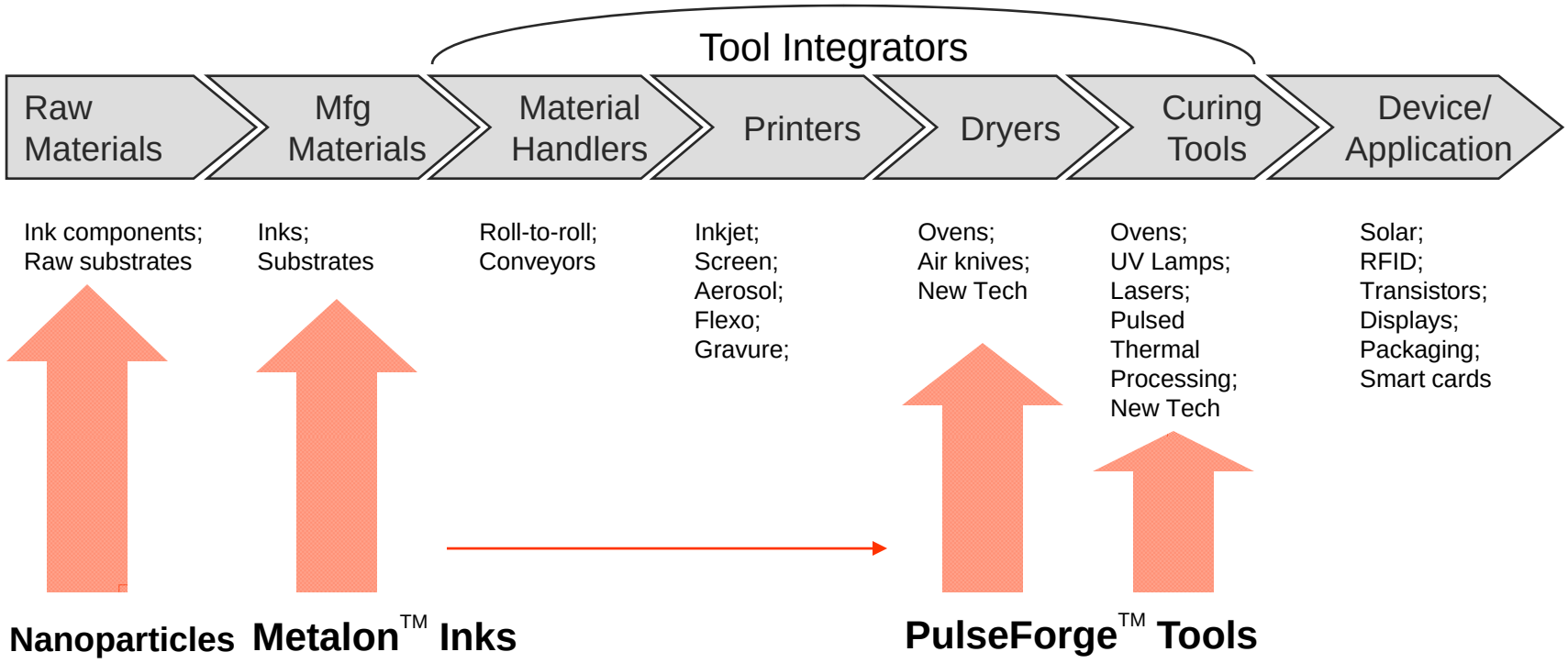
IDTechEx

**Winner 2008**

Technical Development: Manufacturing

# NovaCentrix in the Supply Chain

## Printed Electronics Manufacturing




## NovaCentrix Technologies and Products

# PulseForge™ Tools for Drying and Curing

PulseForge tools are designed to to enable the development and manufacturing of high-performance printed electronics applications. Inks and thin films can be dried, sintered, or annealed in milliseconds on flexible or rigid substrates.

PulseForge tools work by utilizing intense, pulsed light to heat thin films to a high temperature for a very brief amount of time.

- The power density is very high
- The total energy is low.

→ Thermally fragile substrates are unaffected.

PulseForge tools are the next step beyond Rapid Thermal Processing (RTP). They are faster and use less total energy.

# PulseForge Technology Unique Capabilities

Process functional inks and thin films in milliseconds, often in ambient air

- Processing includes drying, sintering, annealing, and densification
- Silver, copper, and other novel metals
- Semiconductors and other non-metals
- Polymers

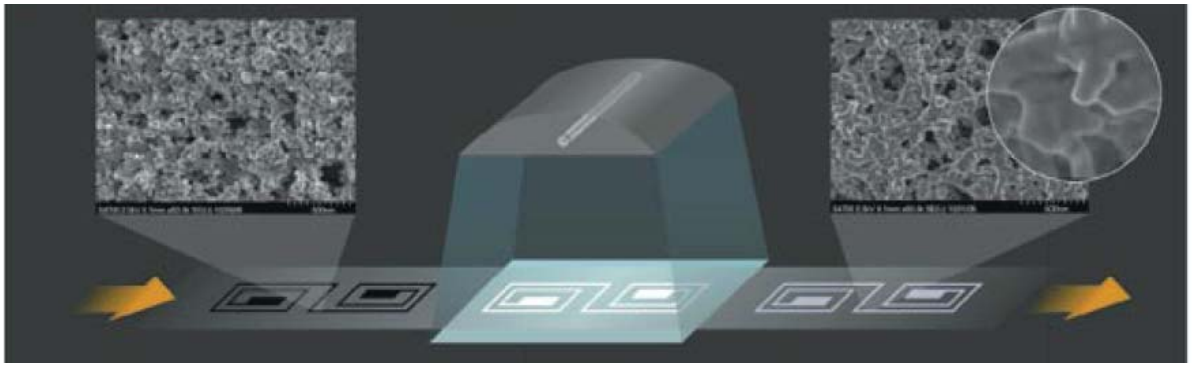
Enables use of very low temp and flexible substrates

- PET, PVC, etc.
- Papers

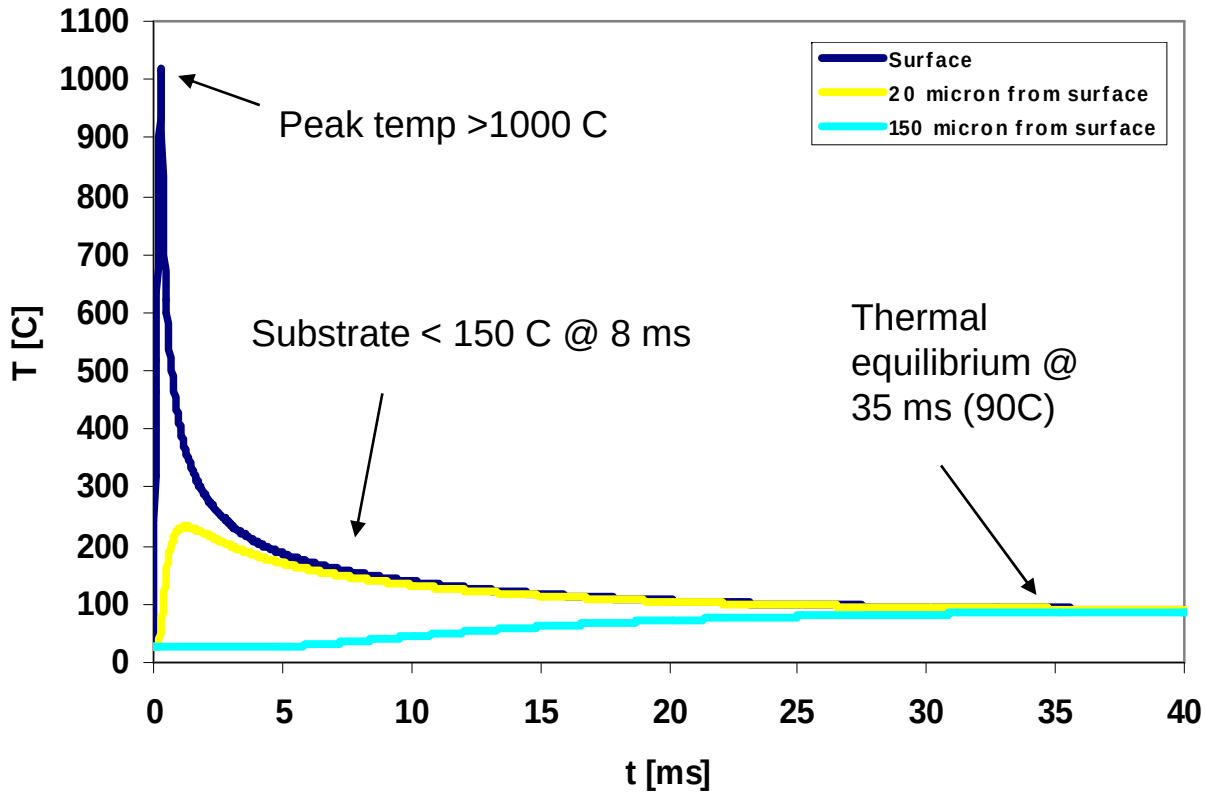
Compatible with all major print and deposition methods

Capable of high-speed roll-to-roll manufacturing, up to 1000 feet per minute

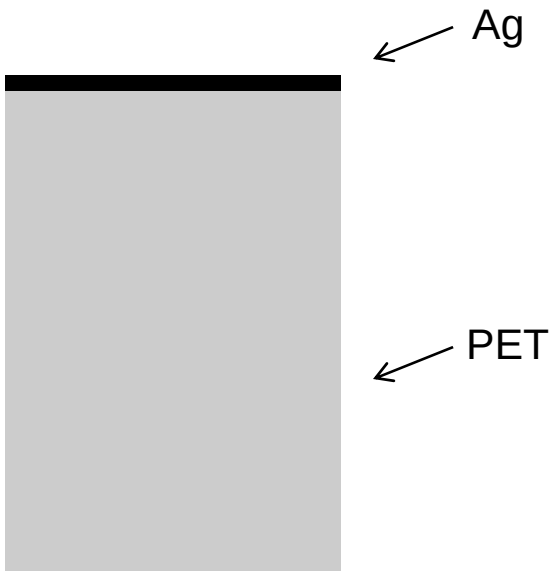
Scalable technology base for sustained printed electronics product innovation



# Typical Thermal Profile

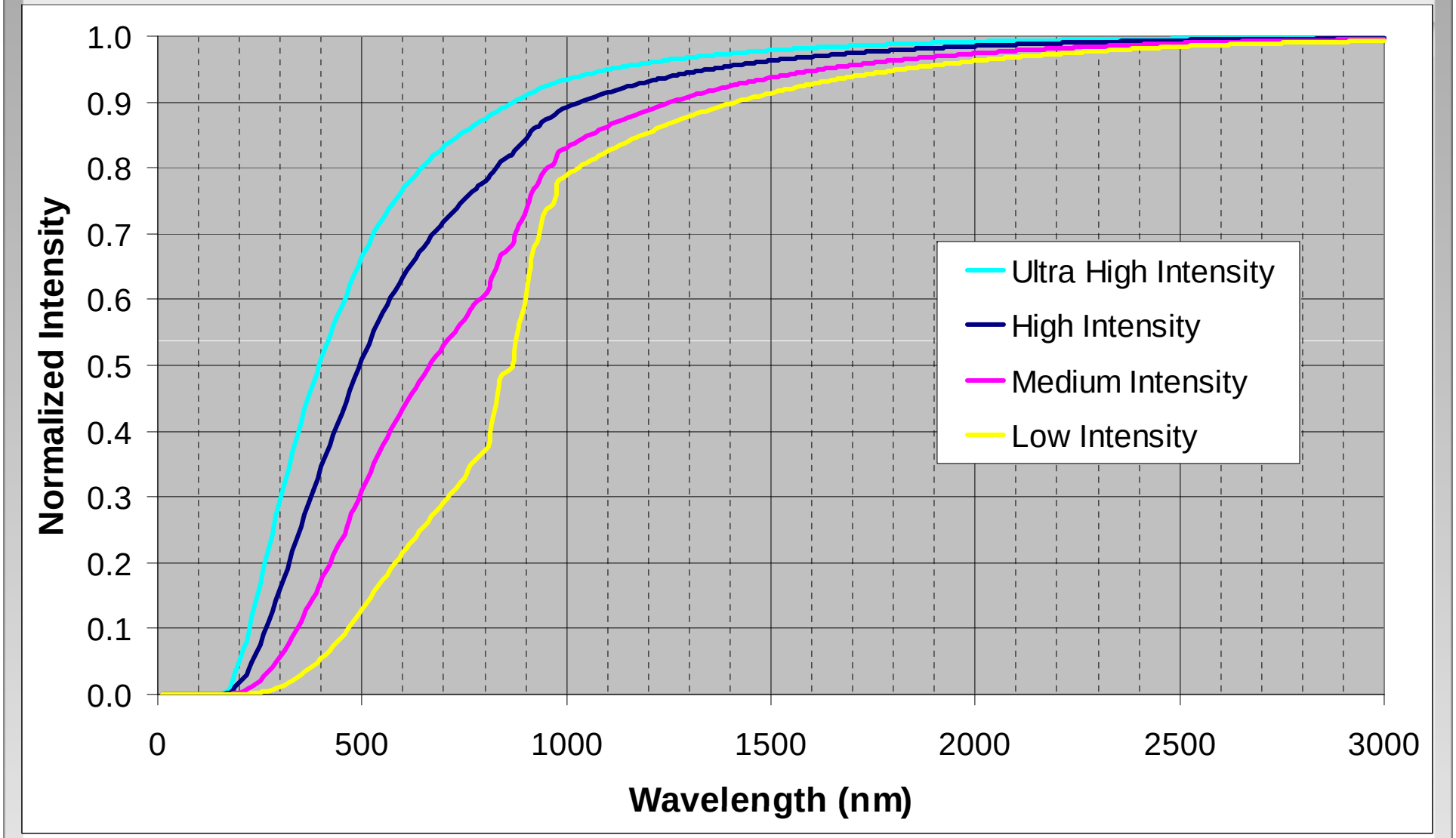



Conditions:
1 μ Ag on 150 μ(6 mil) PET
Radiant exposure: 1 J/cm$^2$
Pulse length: 300 μs




- High temperature processing removes excess solvent and enhances sintering.
- Substrate is undamaged.

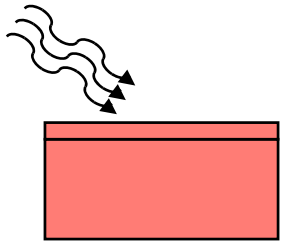
# PulseForge™ Cumulative Spectral Emissive Intensity



# Traditional Processing Methods

Ovens

| Positives | Negatives |
| --- | --- |
| • Wide area of processing | • Cure temperature is limited by the substrate (e.g. PET ~150C). |
| • Uniformity | • Curing times are long: >minutes |



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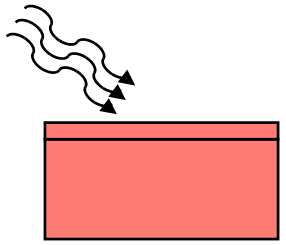


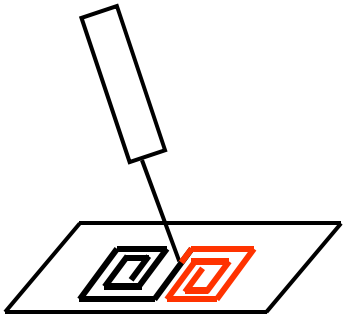
## Lasers

### Positives

- High power densities
- Spatial selectivity

### Negatives

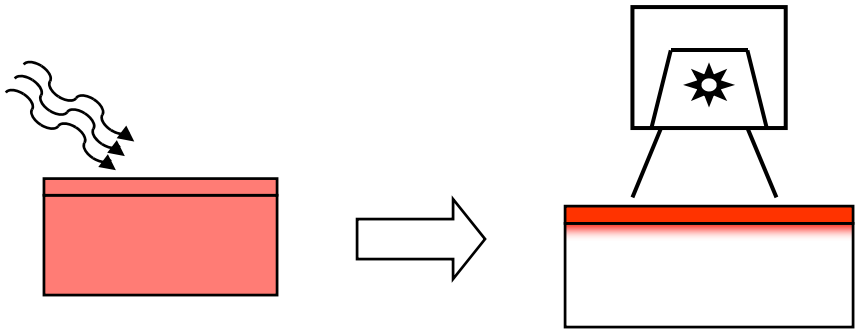
- Small exposure area requires rastering and registration
- Fixed wavelength
- Pulse lengths are too short
- Cost at production scale



# Combining Desired Processing Attributes

## PulseForge

- Wide area of processing
- Uniformity
- Cure temperature is not limited by the substrate (e.g. PET ~150C).
- Curing times are short: ~milliseconds



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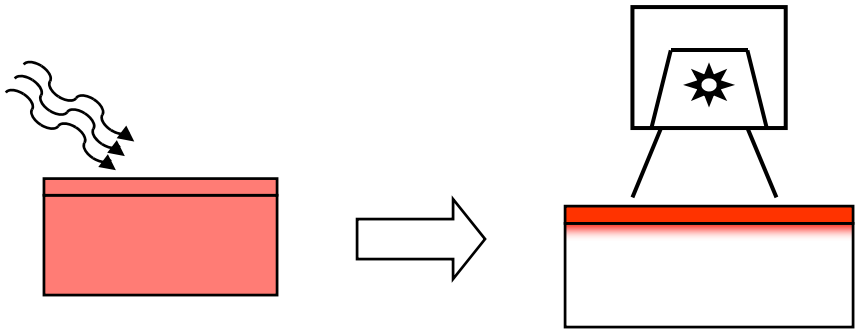
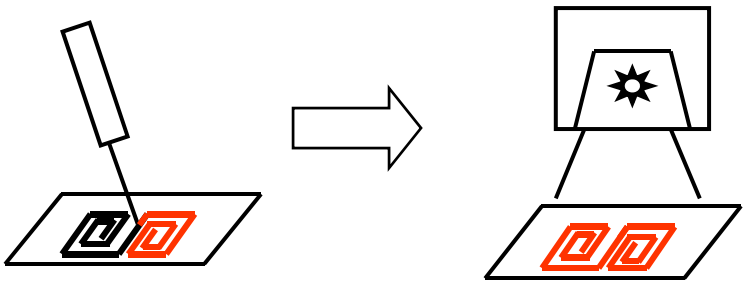


- High power densities
- Selective material processing
- Large exposure area does not require rastering or scanning
- Broadband adjustable spectrum
- Tunable pulse lengths from microseconds to milliseconds
- Economical production scale: >1m$^2$/sec



# Case Study: Ag on Photopaper

Material System

Ink material: Ag inkjet @ ~0.5 μ

Substrate: Photopaper w/ 110 °C max working temp

| Cure Condition | Oven | PulseForge |
|---|---|---|
| Temperature | 110 C | NA |
| Time | 20 minutes | 0.15 sec |
| Resulting sheet resistance | 1600 mΩ/sq | 80 mΩ/sq |
| Comments | 20x improvement in conductivity at 100 ft/min | |

# Case Study: Ag on PET

Material System

Ink material: Ag screen print @ ~25 μ

Substrate: PET w/ 150 °C max working temp

| Cure Condition | Oven | PulseForge |
|---|---|---|
| Temperature | 150 C | NA |
| Time | 30 minutes | < 1 sec |
| Resulting sheet resistance | 20 mΩ/sq | 15 mΩ/sq |
| Comments: | • 25% improvement in conductivity<br>• Can therefore require less Ag, saving cost<br>• Cure speed 50 fpm | |

# Case Study: Introducing Metalon™ ICI-001 Jettable Cu

Material System

Ink material: ICI-001 Copper @ ~0.3-0.4 μm equivalent thickness

Substrate: Photopaper w/ 110 °C max working temp

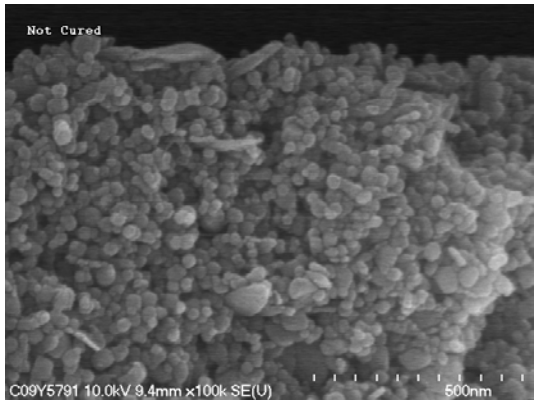
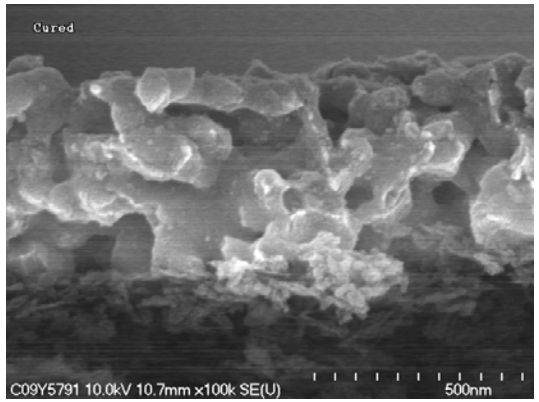
| Cure Condition | Oven | PulseForge |
|---|---|---|
| Temperature | 150 C | NA |
| Time | 30 minutes | < 1 sec |
| Resulting sheet resistance | ~inf (>MΩ/sq) | 140 mΩ/sq |
| Comments: | • Copper inkjet!<br>• 3x bulk Cu resistivity<br>• Processed Cu ink in ambient air conditions | |

# Case Study: Introducing Metalon™ ICI-001 Jettable Cu

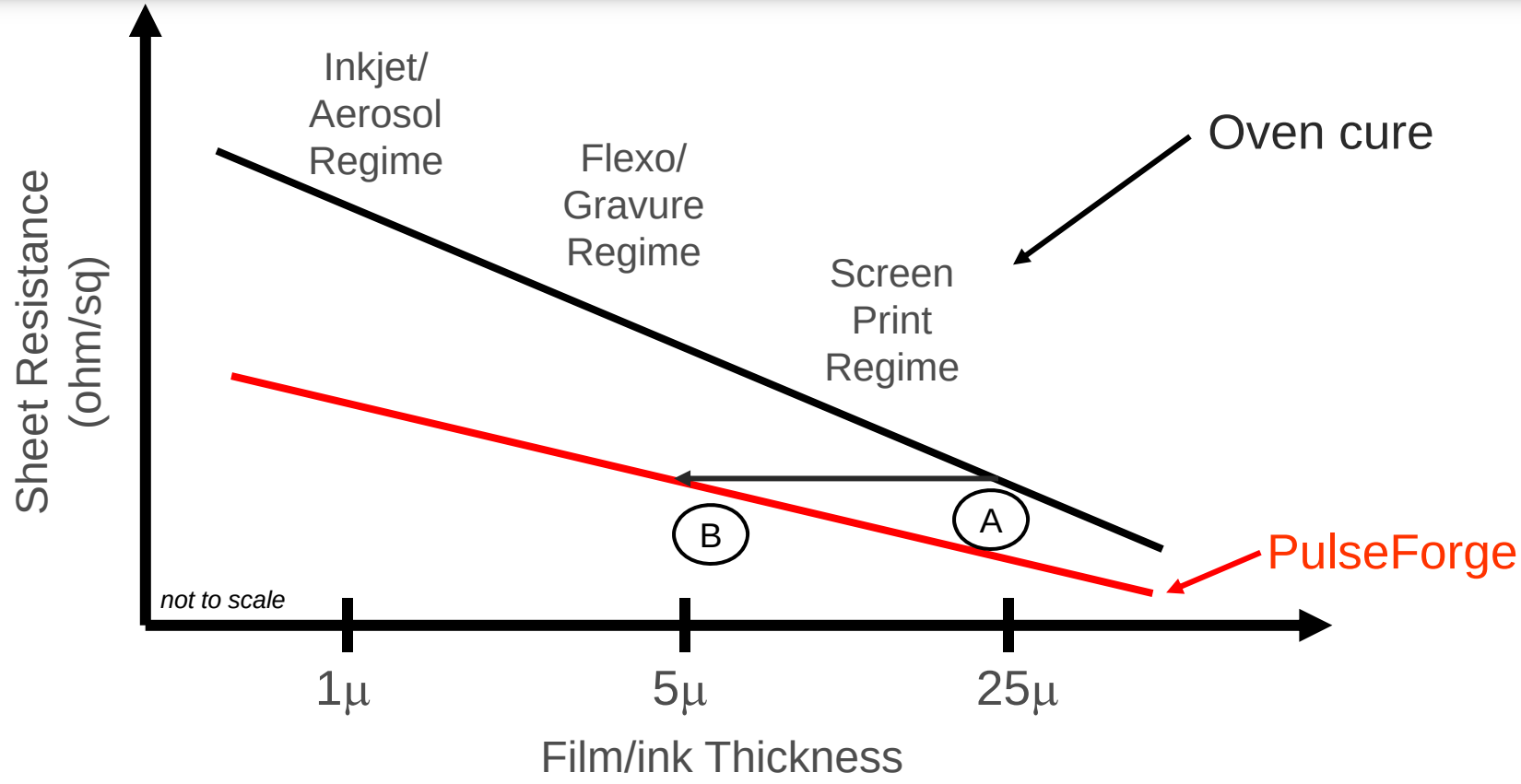
Material System

Ink material: ICI-001 Copper @ ~0.3-0.4 μm equivalent thickness

Substrate: Photopaper w/ 110 °C max working temp

| Cure Condition | PulseForge | SEM - Uncured | SEM - Cured |
|---|---|---|---|
| Temperature | NA |  |  |
| Time | < 1 sec | | |
| Resulting sheet resistance | 140 mΩ/sq | | |
| Comments: | •Copper inkjet!<br>• 3x bulk Cu resistivity<br>• Processed Cu ink in ambient air conditions | | |

# PulseForge Performance




- Thin films and inks: PulseForge cures better and faster than an oven.
- Thicker films and inks: PulseForge cures much faster than an oven, attaining similar or better performance.

A → B Comparable conductivity can be achieved using much less ink.

# PulseForge Product Family

## PulseForge 1100

Process Development Tool

- Suitable for metals and semiconductors
- Highly flexible system for R&D
- Exposure width:  ~1.5” X 6”
- Broad window of energy applied
- Pulse length from micro to milliseconds
- Pulse rate: manual
- Launched at IDTechEx San Francisco, November 2007

# PulseForge Product Family

## PulseForge 3100

Production Tool for processing *metal* inks

- Integrate directly with roll-to-roll systems, or as stand-alone with conveyor system
- Web width in 6” increments
- Exposure width: 6”,12”, 18”, etc.
- Line speeds > 300ft/min for sintering metal inks
- Exposure conditions maintained as line speed varies
- Suitable for inkjet, flexo, gravure, and screen-print applications
- Launched at InterSolar 2008/Semicon West, July 2008 in San Francisco

# PulseForge Product Family

## PulseForge 3300

Production Tool for processing *metal, semiconductor, and polymer* inks and thin films

- Integrate directly with roll-to-roll systems, or as stand-alone with conveyor system
- Web width in 6” increments
- Exposure width: 6”,12”, 18”, etc.
- Line speeds > 1000ft/min
- Exposure conditions maintained as line speed varies
- Suitable for inkjet, flexo, gravure, and screen-print applications
- Launch: Summer 2009

# Options for PulseForge Access

| PulseForge Options | Client Project Stage: Feasibility | Client Project Stage: Development/ Optimization | Client Project Stage: Production |
|---|---|---|---|
| | Can PulseForge improve product performance and economics? | How can performance be maximized and cost minimized? | Volume manufacturing of the developed device including in roll-to-roll formatting |
| **Services** Tools at our facility | NovaCentrix staff can help quickly assess the suitability of PulseForge tools for a given application | Clients can work with tools at our facility to optimize their applications performance and economics. Package rates are available. | NovaCentrix can be a part of the supply-chain by economically processing finished products. |
| **Leasing** Tools at client facility | Tools placed at client facilities can accelerate product development and provide access for multiple engineering groups. Leasing minimizes customer capital expense and allows maximum flexibility for PulseForge upgrades and support. | | |
| **Purchase** Tools at client facility | Tools permanently placed at client facilities come with technical support and consumables options. Purchased tools are best for organizations with many users and/or significant volume production expectations. | | |

# Summary

- PulseForge tools use a novel industrial process called photonic curing for rapidly sintering thin films, such as metallic and semiconductor inks, on low temperature substrates.
- The basis of PulseForge tools is the use of intense pulsed light from plasma discharge lamps to briefly heat the film without affecting the substrate.
  - Reduces or even eliminates the need for an oven to cure many materials
  - The process is able to cure materials that cannot ordinarily be thermally processed in air such as sintering a copper particle film
  - The process is broadcast by nature and maskless, with no need for registration
- The millisecond timeframe, high power, and deep uv spectrum of the tool makes it ideal for high speed processing applications for materials even beyond metal inks.
- PulseForge tools often outperform ovens and are much more scalable than laser processing.
- Low temperature materials such as cellulose and PET are now feasible substrates for high-performance printed electronics applications.

*Contact us with questions or for samples processing*

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