Photonic Curing:
Broad Implications in Printed Electronics

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NovaCentrix® in the Supply Chain

Printed Electronics Manufacturing

Tool Integrators (Material Handlers → Curing Tools)

	Raw Materials	Mfg Materials	Material Handlers	Printers	Dryers	Curing Tools	Device/ Application
Industry product types	Ink components; Raw substrates	Inks; Substrates	Roll-to-roll; Conveyors	Inkjet; Screen; Aerosol; Flexo; Gravure;	Ovens; Air knives; New Tech	Ovens; UV Lamps; Lasers; Pulsed Thermal Processing; New Tech	Solar; RFID; Batteries; Transistors; Displays; Packaging; Smart cards

Nanoparticles

Metalon® inks
Novele™ substrates

PulseForge® tools
SimPulse™ thermal simulator

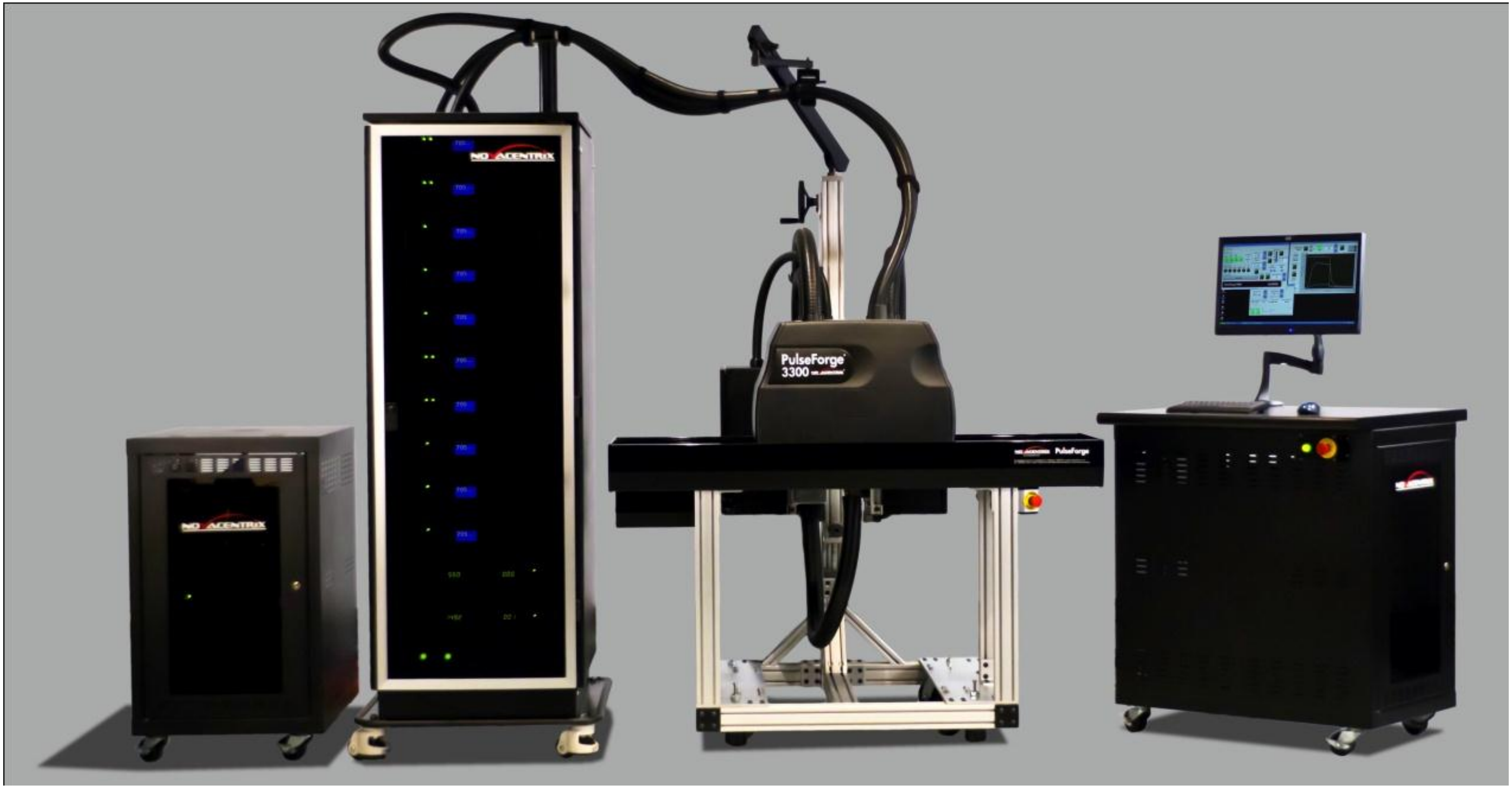
Commercial Product Release	**1999**	**2006 (inks)** **2009 (substrate)**	**2007 (tools)** **2010 (simulation)**

What is photonic curing?

The Power of Light

PulseForge® Origins: Photonic Curing

PulseForge® Toolset



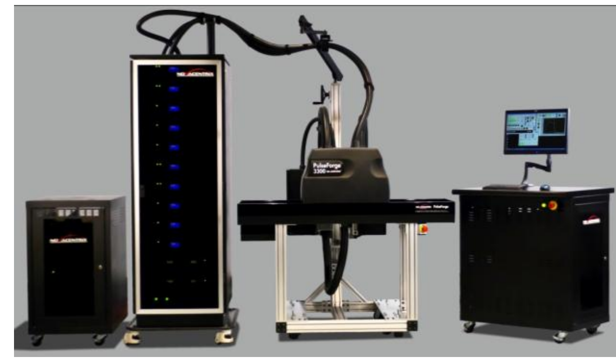
PulseForge® Tool Background

Concept

Innovation

>10 exposure parameters
Pulse lengths <25 micro sec
Digital exposure setting input
Uniformity better than +/-2%
Water-cooled
Configurable width >4meters
Touch-screen interface
R2R in excess of 100m/min
Long-lived quick-change lamps

Enabling new value

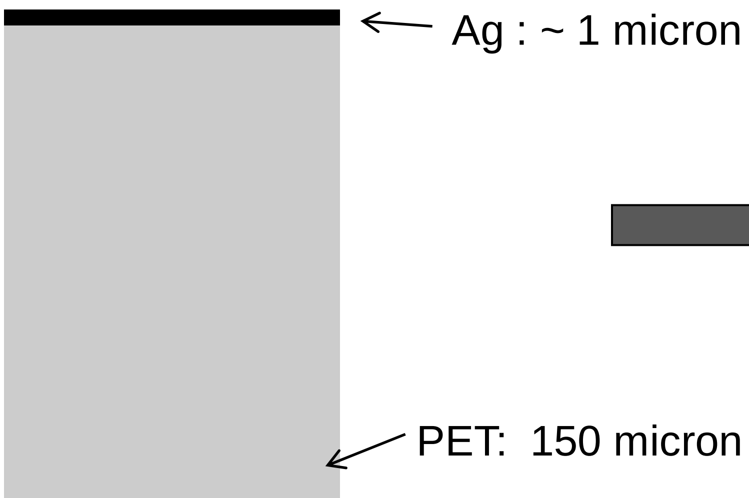


- The PulseForge 3300 (pictured) represents state-of-the-art processing capability.
  - Metals, semiconductors, ceramics on polymers and paper, glass ,quartz, others
- "Photonic Curing" was coined by NovaCentrix and first published in 2006 to describe the use of flash lamps to selectively heat functional inks without damaging low-temperature substrates.
- NovaCentrix has patented this technology, having over a dozen unique filings worldwide with issuances in the US (#7,820,097), Canada (#2,588,343), and China.

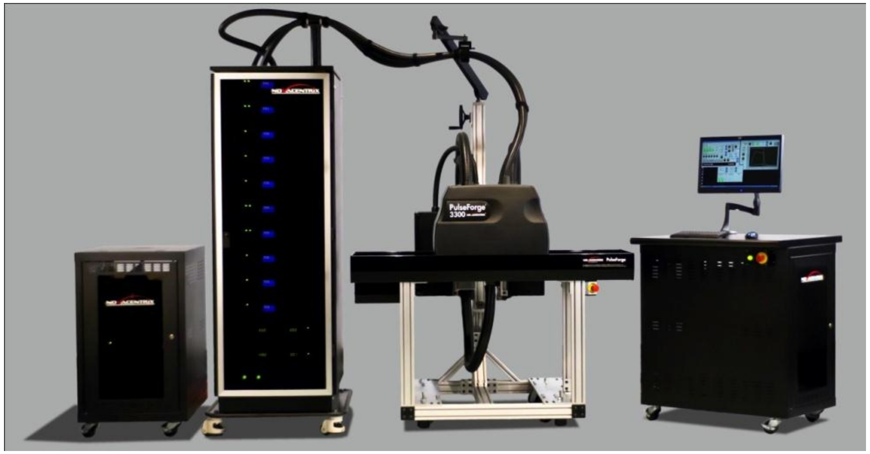
Why does photonic curing work?

Typical Application

Common Application Structure

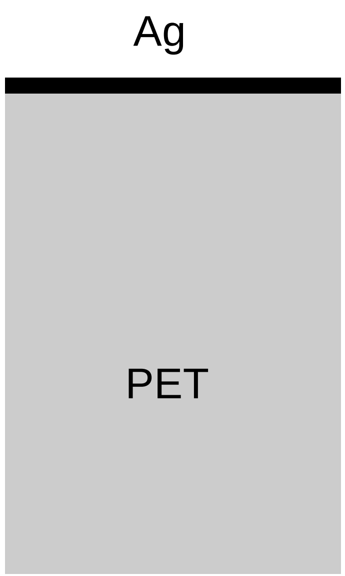


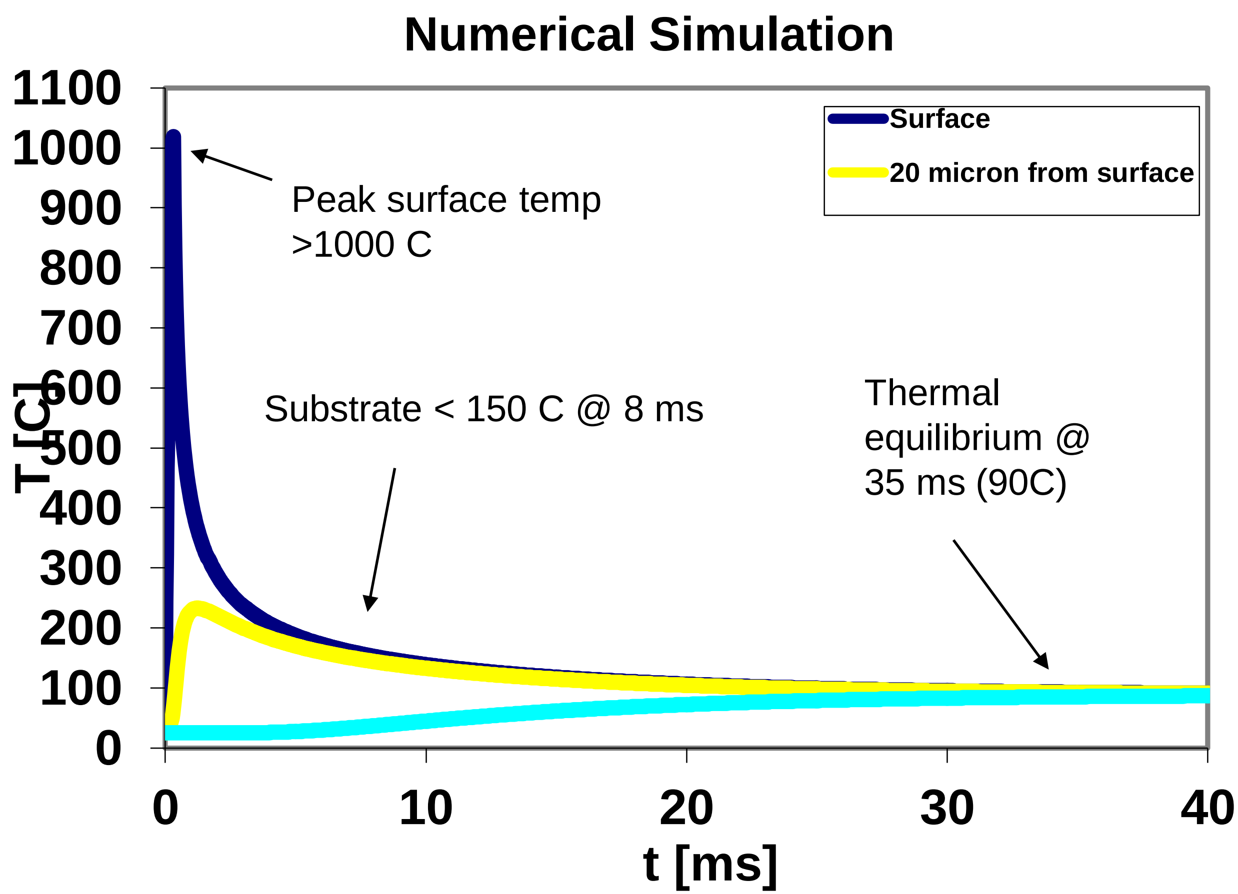
Common Exposure Condition



Energy: 1 J/cm^2
Pulse Exposure: 300 microsec

Typical Single-Pulse Thermal Profile





Conditions:
1 μm Ag on 150 μm(6 mil
Radiant exposure: 1 J/cm
Pulse length: 300 μs

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

Key Processing Parameters

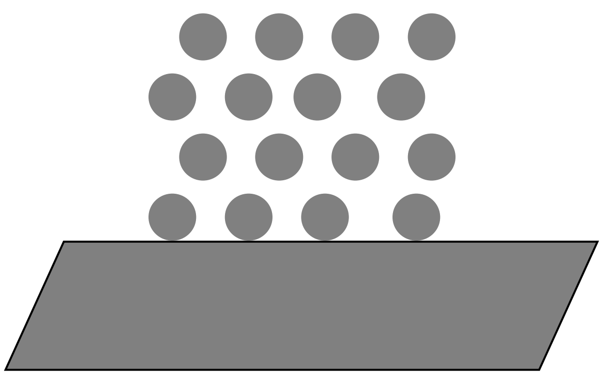
Material Characteristics

- Thermal / physical properties of ink and substrate
- Film/ ink thickness
- Particle morphology
- Substrate composition and thickness
- Barrier or intermediate layers

Tool Adjustability Requirements

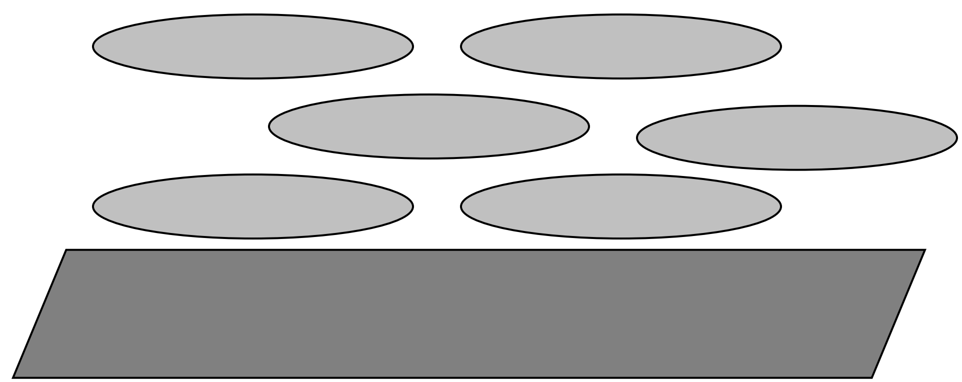
- Pulse energy/ amplitude
- Pulse duration
- Impinging wavelengths
- Number of pulses
- Speed of pulses
- Other parameters

Sample Inkjet Deposition



Nanoparticle inkjet
- ~500 nm thick

Sample Screen-print Deposition

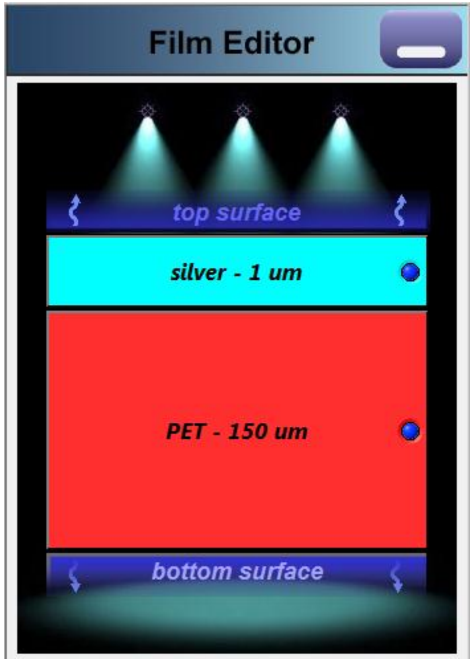


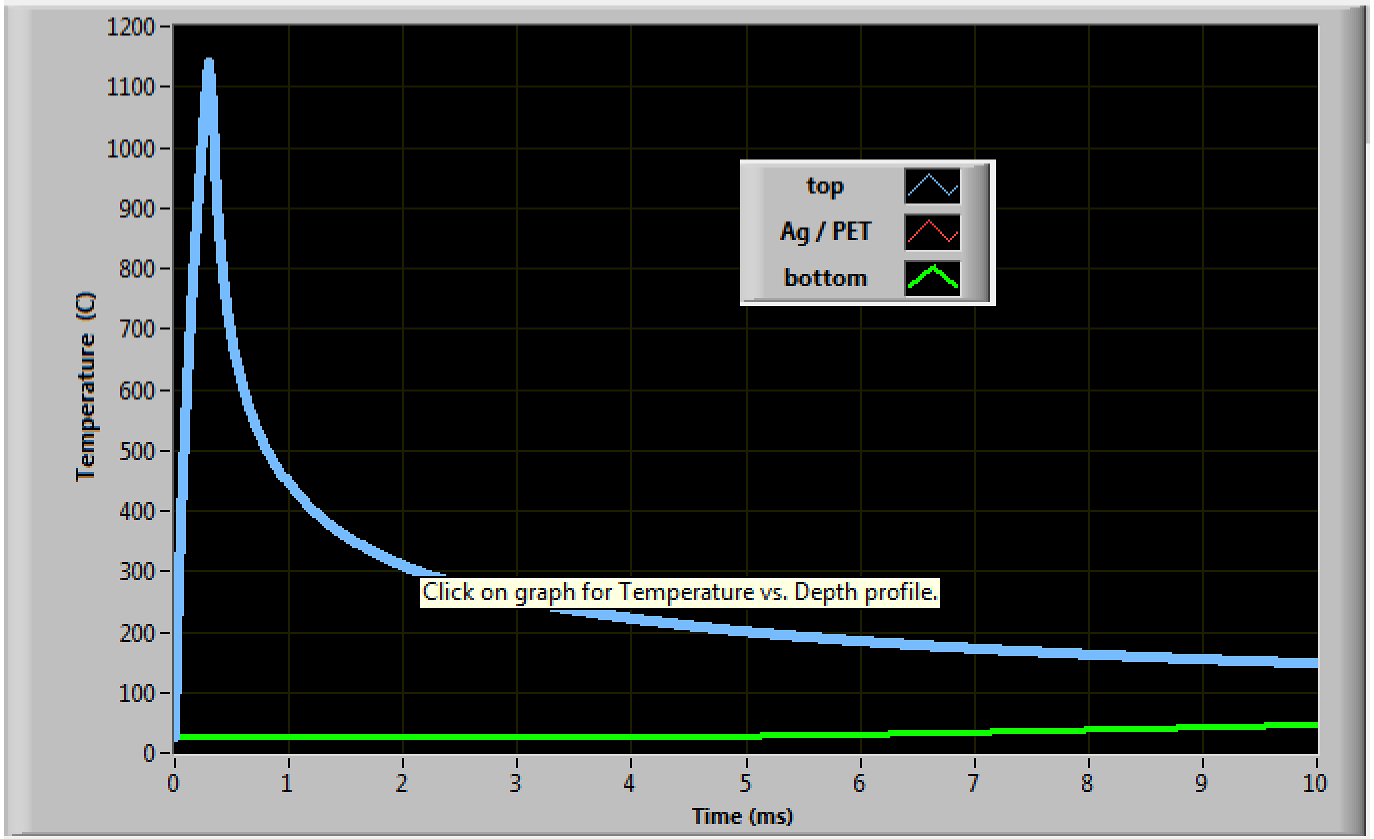
Micron flake screen print
- ~5-30 microns thick

A Brief Detour:

The use of simulation

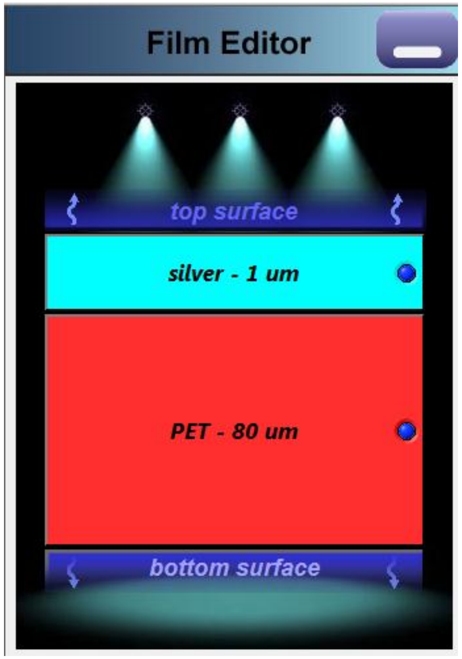
SimPulse™: PET Substrate @150 microns

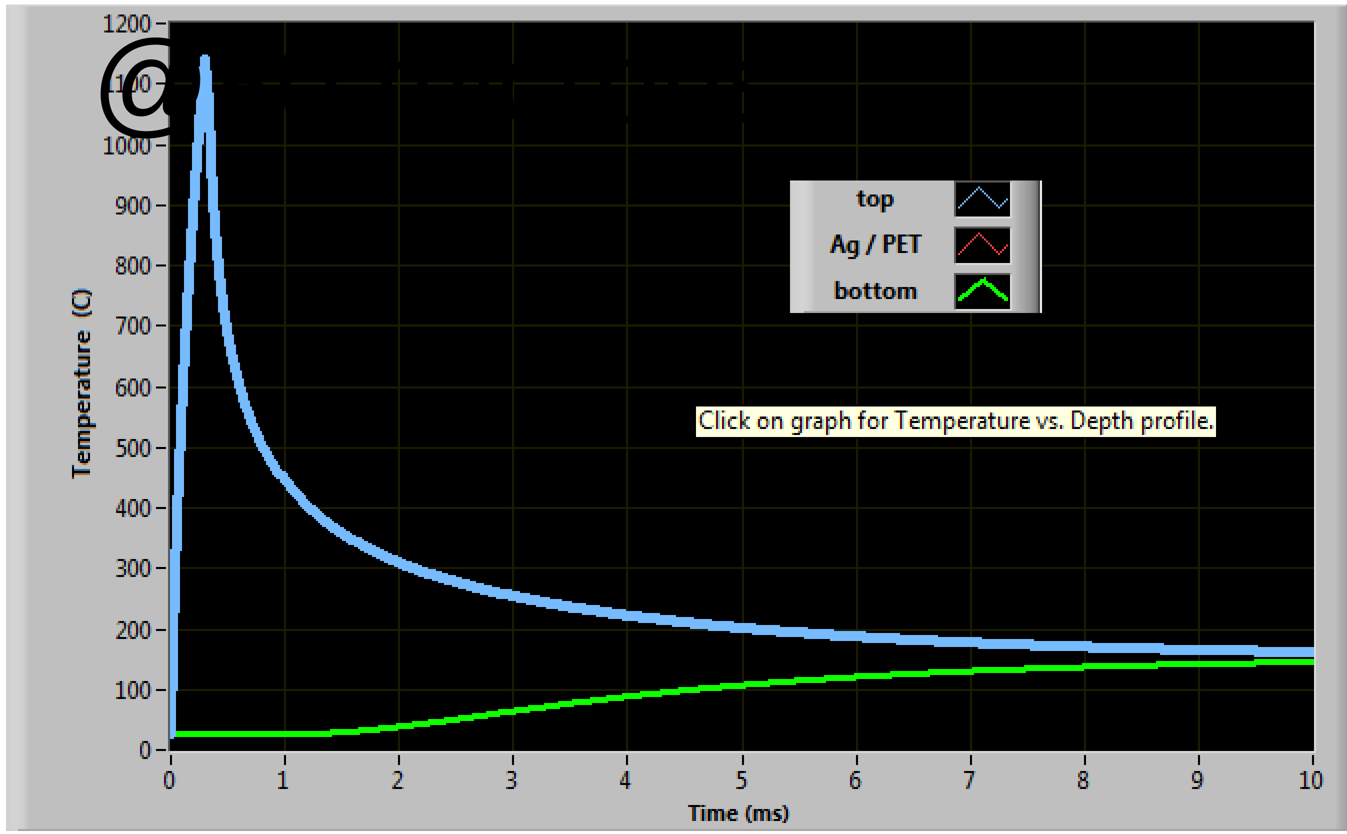




Substrate	Delivered Energy (J/cm^2)	Max Temp (C)	Thermal Cond (W/mk)	Mass Density (g/cm)	Specific Heat (J/kgK)	Thermal Diffusivity (m^2/s)
PET	1	1150C	0.24	1.4 g/cm^3	730	**2.35E-7**

SimPulse™: PET Substrate





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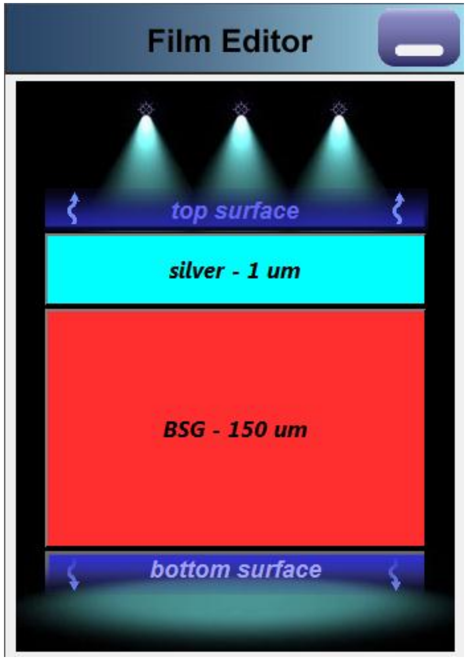
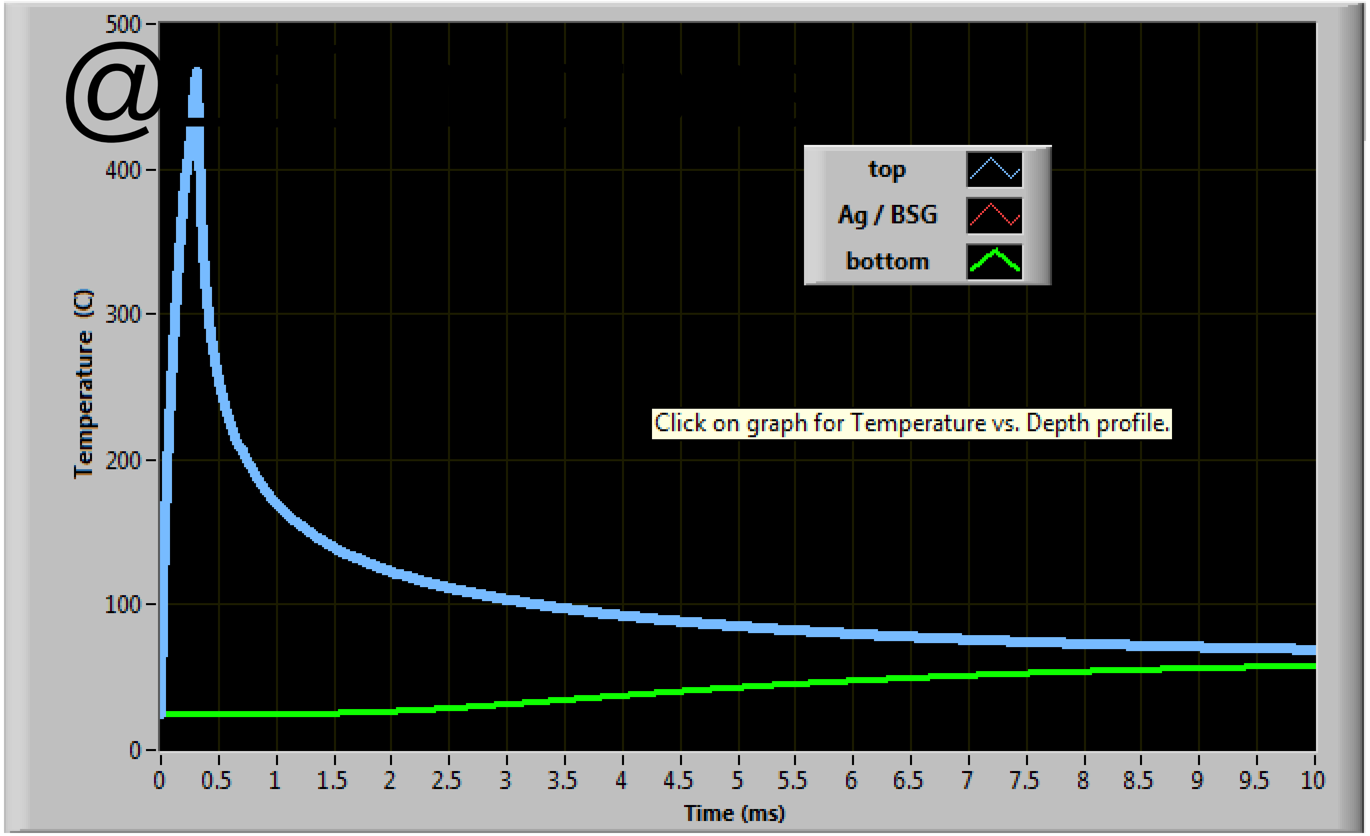
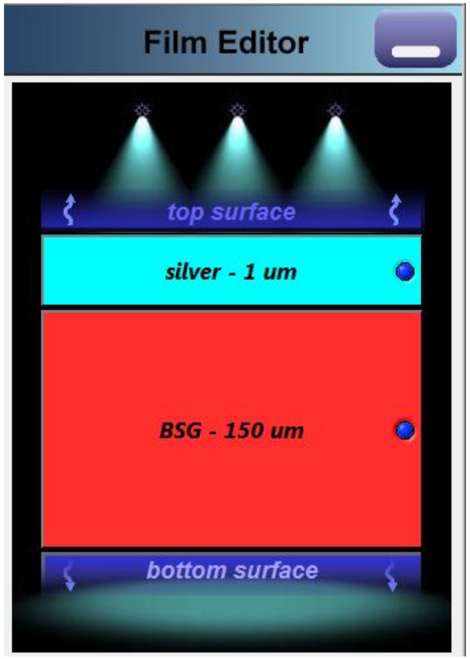
SimPulse™: Glass Substrate

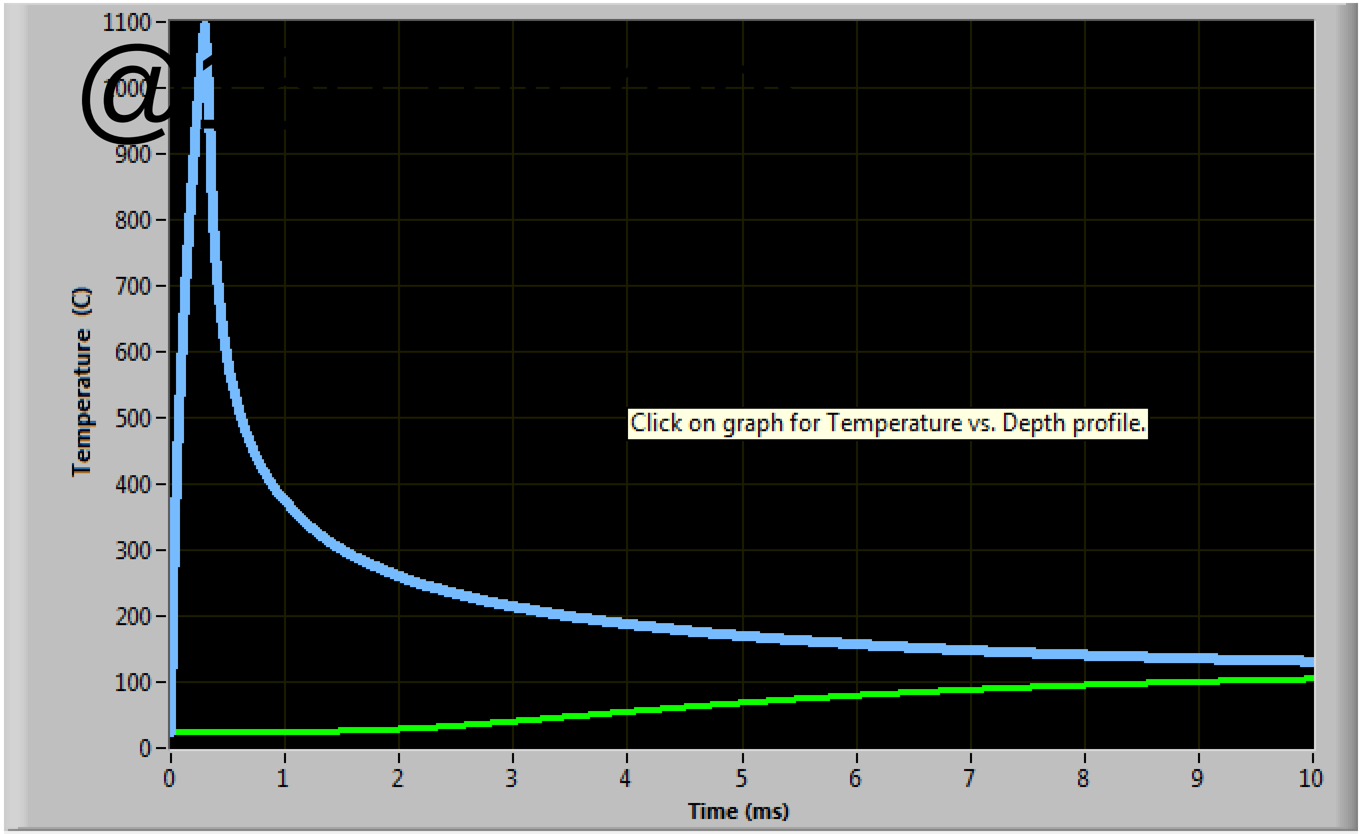




Substrate	Delivered Energy (J/cm²)	Max Temp (C)	Thermal Cond (W/mk)	Mass Density (g/cm³)	Specific Heat (J/kgK)	Thermal Diffusivity (m²/s)
Borosilicate glass	1	450	1.14	2.2	820	**6.32E-7**

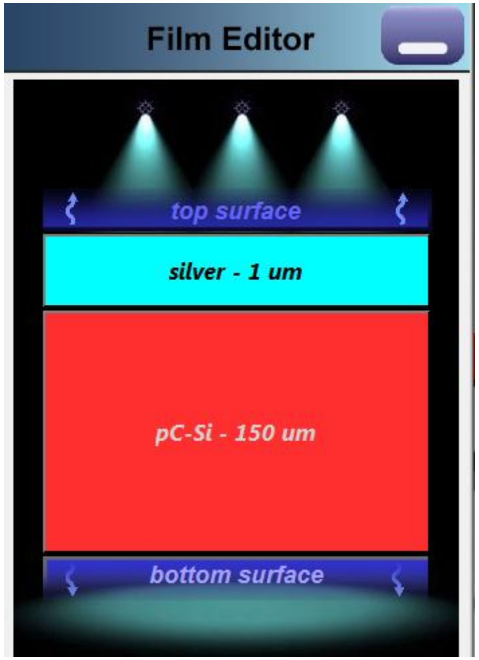
SimPulse™: Glass Substrate

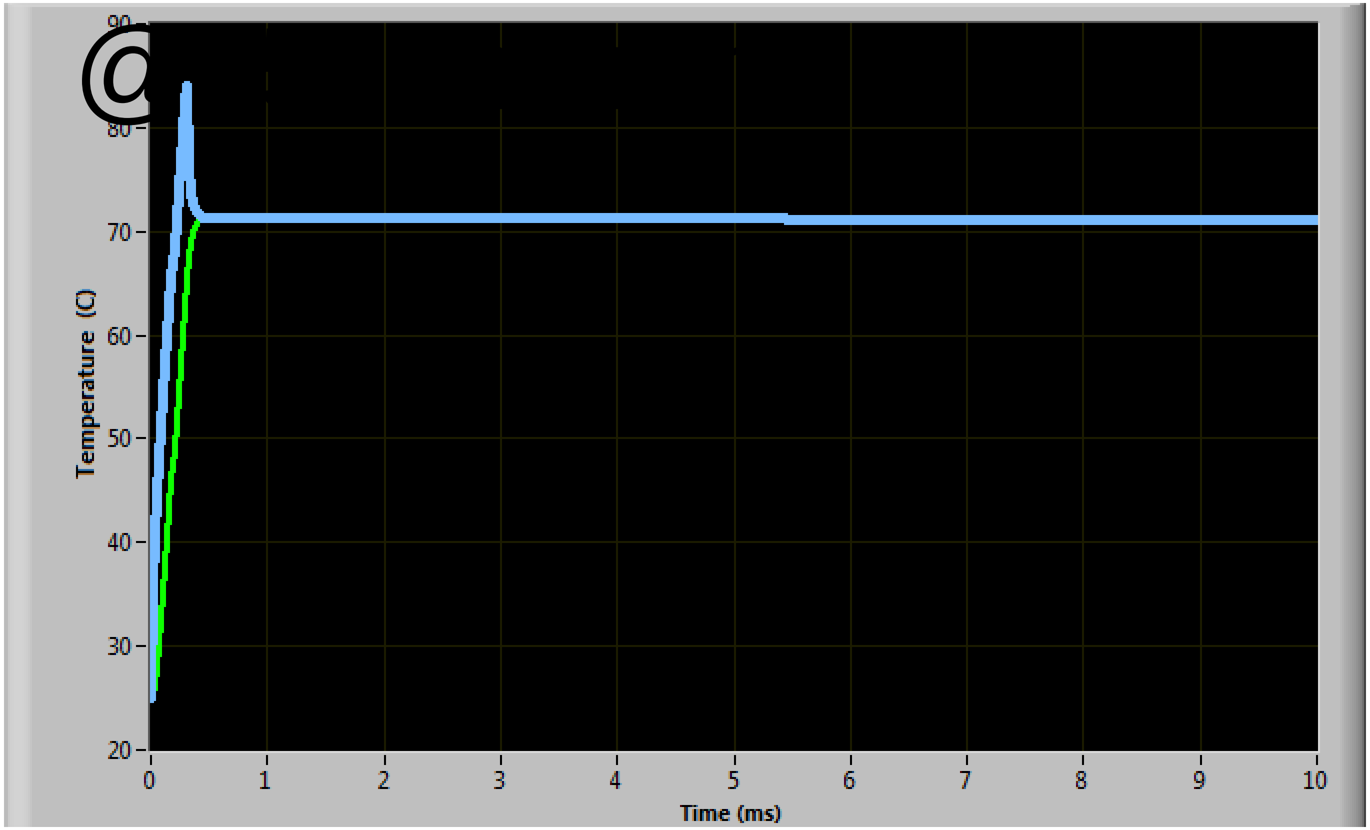




Substrate	Delivered Energy (J/cm^2)	Max Temp (C)	Thermal Cond (W/mk)	Mass Density (g/cm^3)	Specific Heat (J/kgK)	Thermal Diffusivity (m^2/s)
Borosilicate glass	2.6	1100	1.14	2.2	820	**6.32E-7**

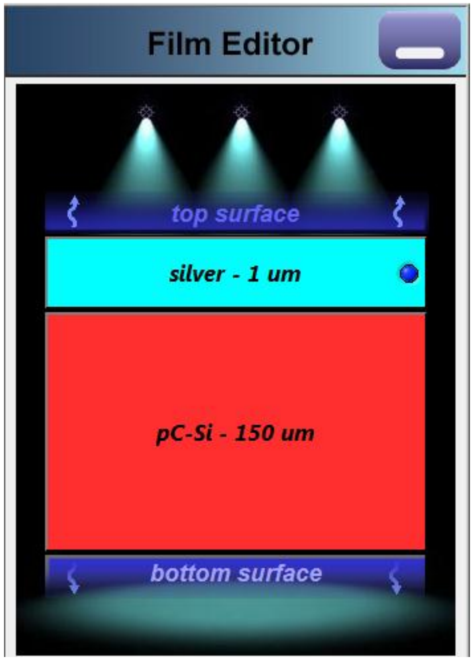
SimPulse™: p-Si Substrate

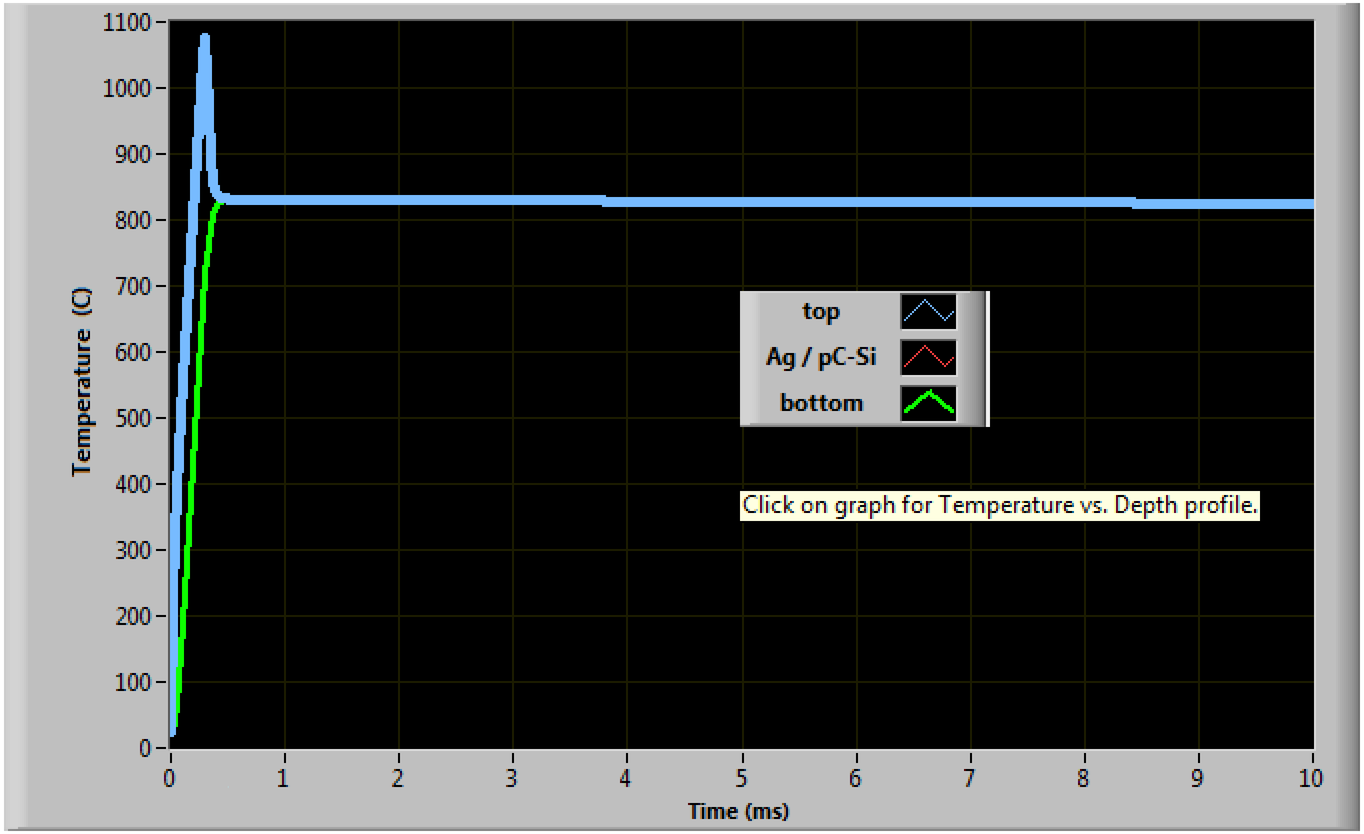




Substrate	**Delivered Energy** (J/cm^2)	**Max Temp** (C)	**Thermal Cond** (W/mk)	**Mass Density** (g/cm^3)	**Specific Heat** (J/kgK)	**Thermal Diffusivity** (m^2/s)
p-Si	1	85	140	2.3	751	**8.105E-5**

SimPulse™: p-Si Substrate @150 microns





Substrate	Delivered Energy (J/cm^2)	Max Temp (C)	Thermal Cond (W/mk)	Mass Density (g/cm^3)	Specific Heat (J/kgK)	Thermal Diffusivity (m^2/s)
p-Si	23	1150	140	2.3	751	**8.105E-5**

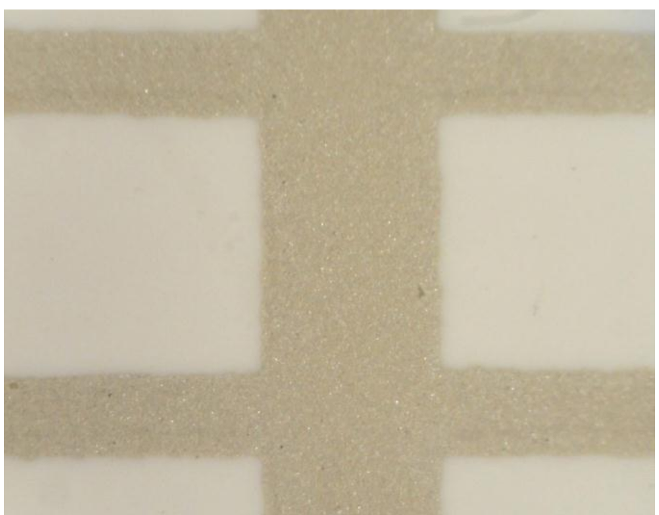
How can photonic curing be used?

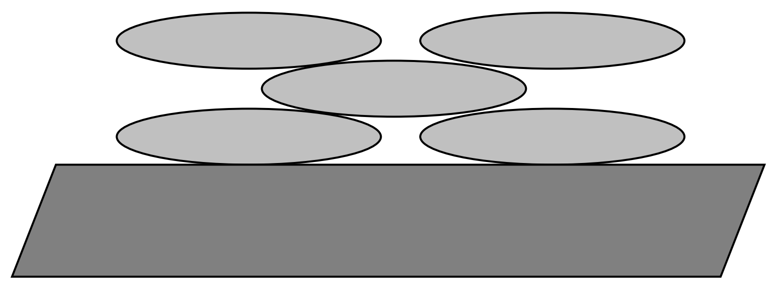
Drying and sintering

Example: Processing DuPont Silver Flake Ink

Material Set-up

- Ink: Dupont 5025: silver flake (micron scale), organic binders
- Substrate: Melinex 329 (white), temperature limit ~150C
- Ink thickness: ~10 microns
- Sheet resistance: <10milliOhms/sq
- Cure Conditions:
  - Conventional: ~140C, 10-30 minutes
  - PulseForge tool process: ~500C, ~1 millisecond

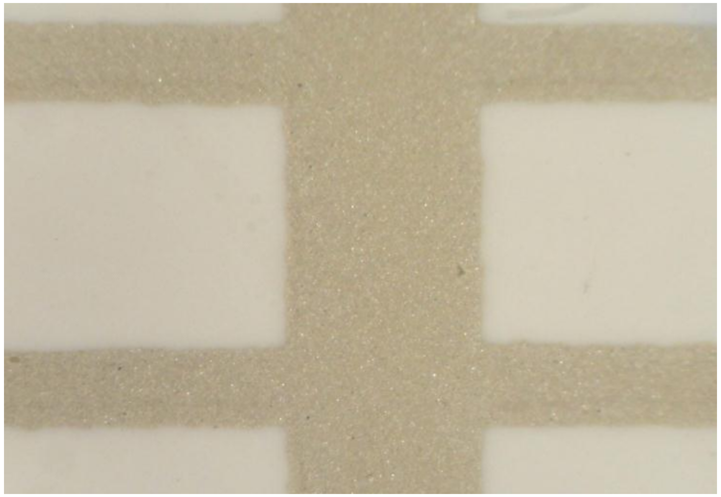




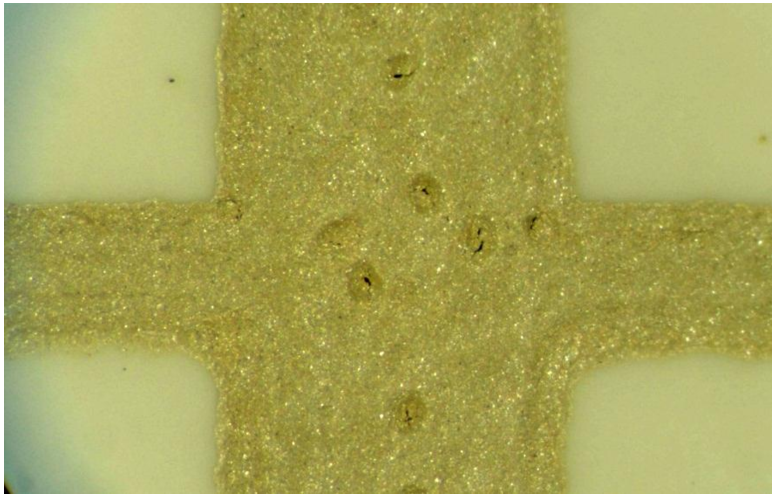
Depiction of processing result:
Good flake contact for electrical conductivity

The Importance of Configurable Pulses

Good



Bad



Ugly

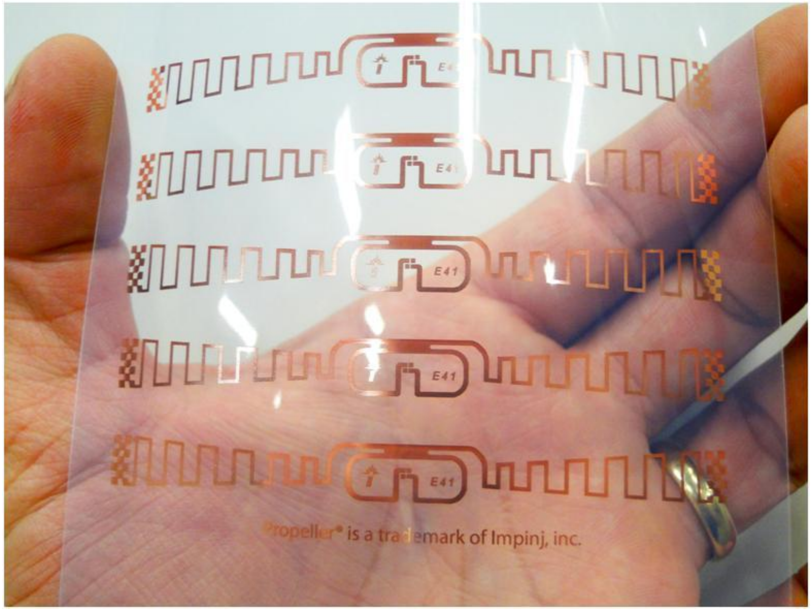
How can photonic curing be used?

Drying and sintering

Enabling the use of new materials
via in-situ reactions.

Cost Reduction Using Copper Inks

- Good
  - Cu costs 100X less than Ag
  - Cu has 90% of the conductivity of Ag
- Bad
  - True Cu inks want to oxidize, especially nanoparticle inks
  - Stable nanoparticle inks of true Cu are usually expensive, outweighing cost benefits



Metalon ICI ink processed on coated PET with PulseForge tools

- New Approach
  - Instead of fighting oxidation, begin with particles in their terminal state: fully oxidized.
  - CuO ink formulation:
    - Nano CuO
    - Reduction agent
    - Water and ethylene glycol
  - Converts to conductive Cu during PulseForge processing.
  - Initially developed for paper (smart packaging), now being adapted for nonporous substrates (photovoltaics, other apps)

$75/kg in volume

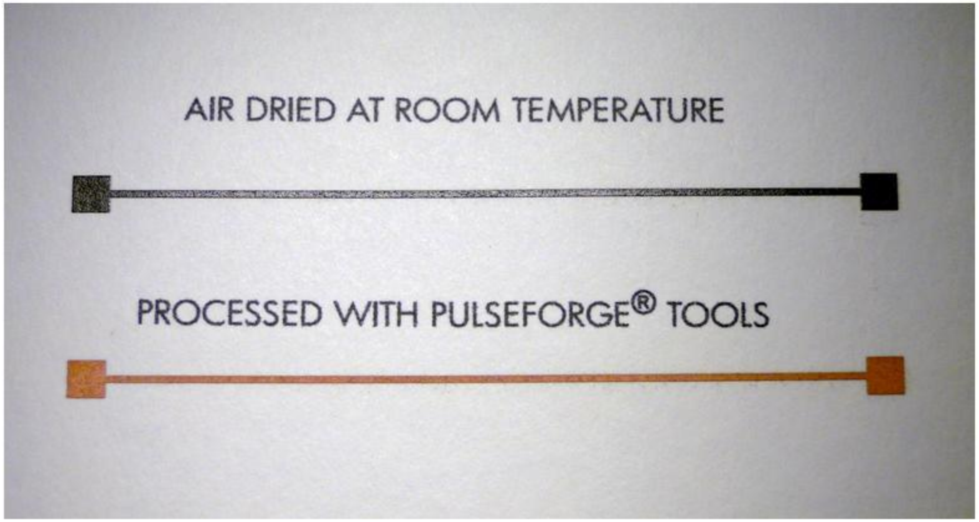
Metalon® ICI CuO Screen Ink

Case Study: Screen CuO on Paper

Material System

Ink material:	Metalon ICI-021 CuO screen print
Substrate:	Standard 110 lb. cardstock
Print method:	165 mesh screen

Cure Condition	PulseForge
Temperature	NA
Time	5.5 millisec
Resulting sheet resistance	<20 mΩ/sq
Comments:	• Cure speed 75 fpm in ambient air conditions • Cannot be cured in ordinary oven



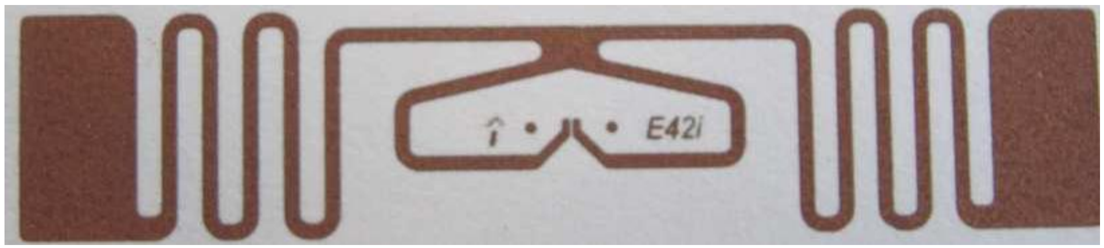
How can photonic curing be used?

Drying and sintering

Enabling the use of new materials via in-situ reactions.

Better execution of existing applications

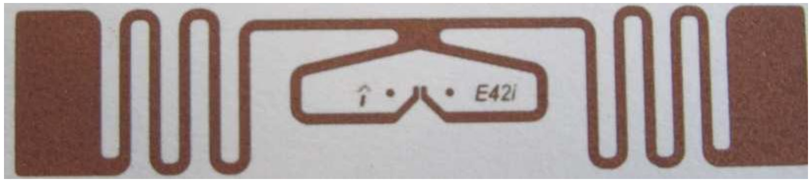
Application : RFID



Design:	Impinj® E42i*
Freq:	UHF 800-1000 MHz
Ink:	Metalon® ICI-021
Substrate:	110lb paper
Chip:	Monza 4

* Used under license

Application : RFID



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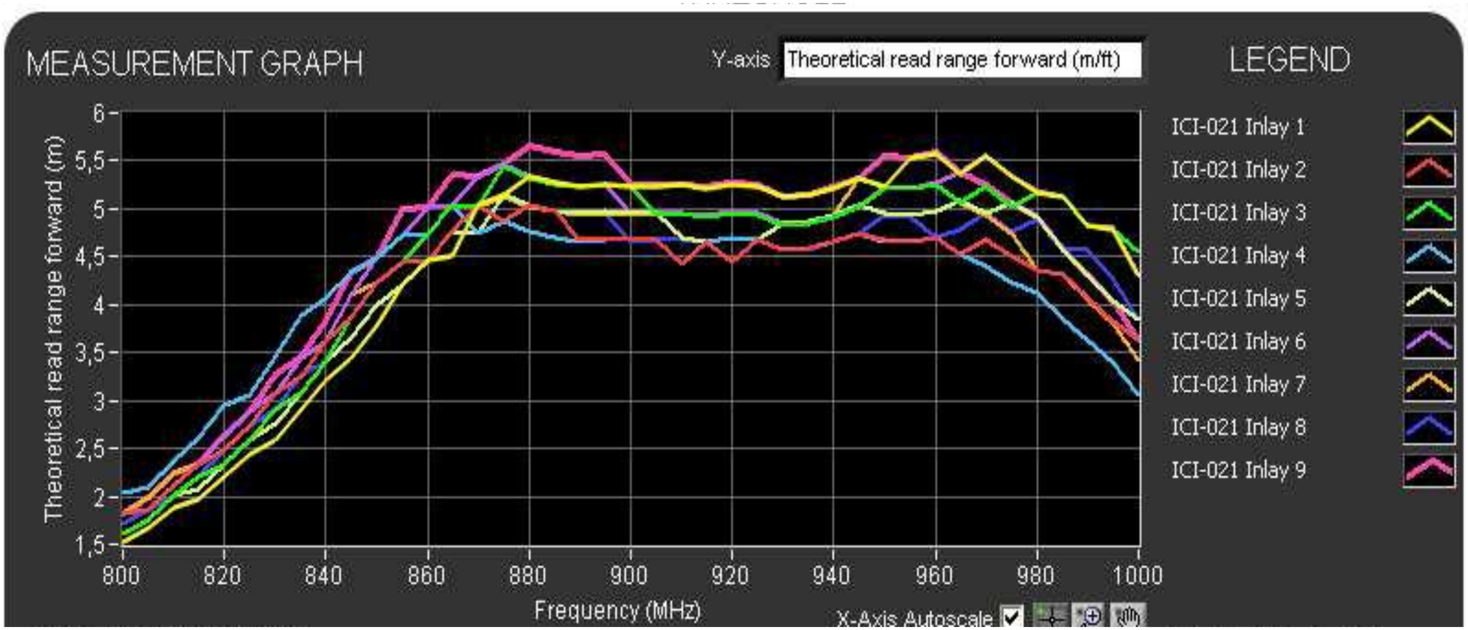
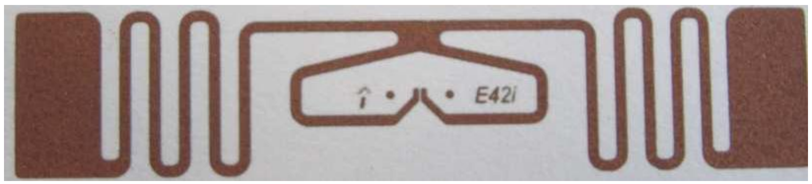


Read range: 5.5 meters

Application : RFID



Design:	Impinj® E42i
Ink:	Metalon® ICI-021
Substrate:	110lb paper
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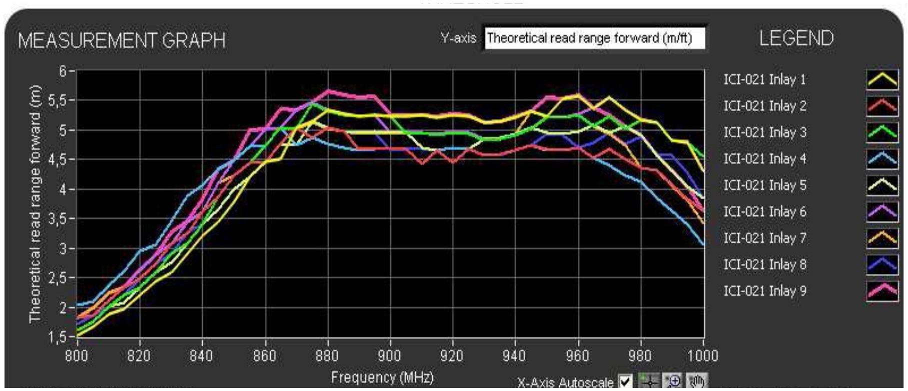
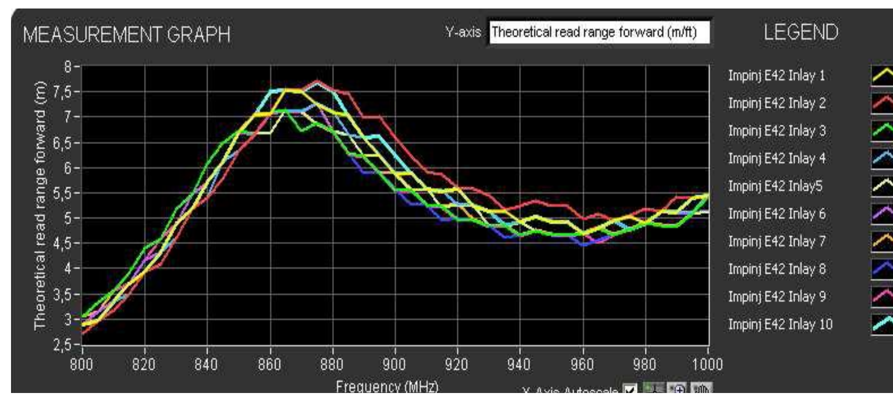
ICI ink



5.5 meters

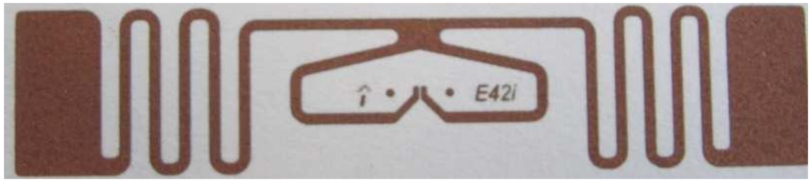
Etched aluminum



Peaks at 7 meters, drops to 4.5

Read distance now at 7 meters with ICI ink matches etched aluminum

Application : RFID

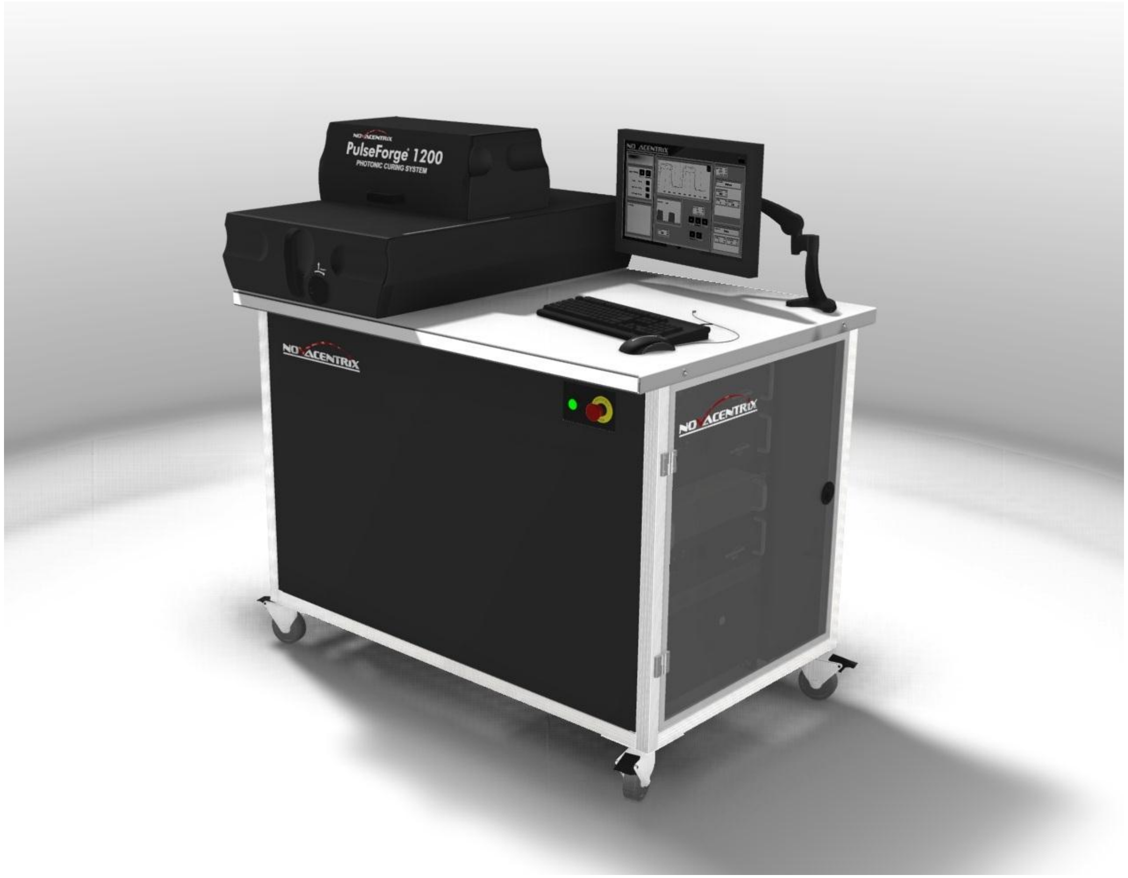


Design:	Impinj® E42i
Ink:	Metalon® ICI-021
Substrate:	110lb paper
Chip:	Monza 4

Cost Comparison

	ICI screen ink	Silver screen ink
Ink cost/ kg	$75	$1000
Ink cost/tag	$0.003	$0.012
Paper cost/ tag	$0.0008	
PulseForge equipment cost/tag	$0.0002	
Total	$0.004	$0.013

Introducing the PulseForge® 1200 for R&D



Immediate availability

- Low-priced PulseForge tool for R&D.
- Self-contained high power photonic curing system with automated linear stage.
- Same controls and power as industrial PulseForge systems but with smaller area and lower throughput.
- Direct translation of machine settings to industrial PulseForge tools.

Summary

- Photonic curing uses high-intensity flash lamps to selectively heat target materials.
- The PulseForge tools are based on the patented use of photonic curing and are designed for use in development and production.
- Photonic curing is used for drying, sintering, reacting, and annealing. The use of the tools enables exciting new types of materials to be used in printed electronics, such as the copper oxide reduction inks.
- The Metalon ICI series of copper oxide reduction inks are formulated with a reducing agent to convert copper oxide to copper thin film on the substrate after printing. Sheet resistance < 20 mOhm/sq.
- Applications impacted include RFID, displays, photovoltaics, sensors, and others.
- Many opportunities for innovation and competitive advantage are still open.
- We have introduced an R&D photonic curing system, the PulseForge 1200, to accelerate this development.

- *Contact our partners or us directly with questions or for samples processing*

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