Using Pulsed Light to Achieve High-Throughput, Wide-Width PE Sintering

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Introduction

To move Printed Electronics (PE) applications into full-scale production, manufacturers need a process that can rapidly cure metallic nanomaterial inks and is capable of operating over the complete width of large web presses. These two process challenges have been difficult to solve using traditional curing techniques such as ovens. In this article a millisecond sintering process is discussed that overcomes both challenges and also allows the use of lower cost substrate materials that are sensitive to heat.

Traditional oven curing can operate over a relatively large substrate area, but it uses low temperatures, on the order of 180 °C, requiring a long curing cycle, up to 30 minutes or longer. This severely limits throughput and negates much of the advantage of using a high-speed press for continuous large area manufacturing.

An alternative approach is to use light pulses to deliver high energy, which works nearly instantly, on the order of milliseconds. Pulsed light, as opposed to continuous sources, has the additional advantage of being a low temperature process. This is because even though there is intense pulse power (in the range of a few megawatts per pulse) the “on” time is very short (in the order of a few milliseconds). This is analogous to touching a hot plate with your finger and moving away very quickly. Because the dwell time in the high-energy zone is short compared to the off period, thermal inertia of materials does not allow material temperature to rise significantly.

XENON has more than 3000 pulsed light systems now in 24/7 operation at various worldwide manufacturing sites. However, applying pulsed light technology over an area of 50” (1.27 meters), a standard width for high-volume web presses, has presented both technical and economic challenges.

XENON’s engineering team has been addressing this problem for some time, and in March of 2015, XENON introduced the S-5100 system, the first wide-width pulsed light PE sintering system capable of operating on roll-to-roll (R2R) web presses at volume production speeds. The system can deliver up to 5 joules per square centimeter with minimal energy variability over the full width of an R2R web press, and is capable of sintering copper and silver nano inks, as well as pastes, on a variety of thin film substrates.

Many challenges had to be overcome to create a practical solution that would work on a full-width web press. These challenges were:

- Uniform energy delivery over wide area
- Scaling from characterization to production
- Flexibility to change inks and substrates
- Programming and control
- Easy integration into printing line

[Figure 1 Caption]
The XENON S-5100 system, capable of delivering up to 5 joules per square centimeter with minimal energy variability over the full width of a R2R web press

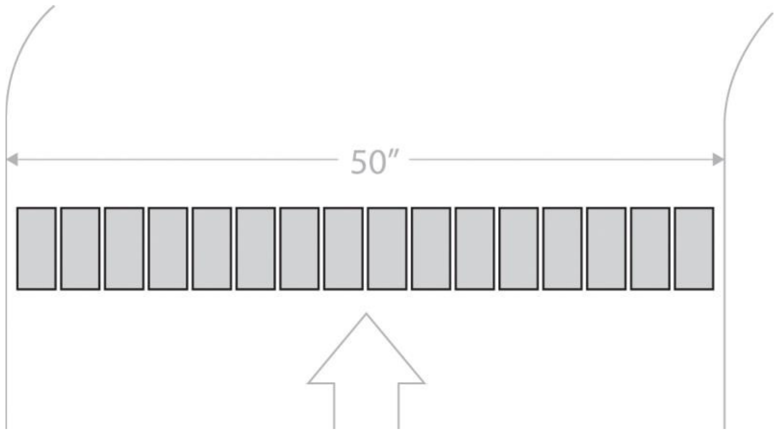
Uniform energy delivery over wide area

The primary challenge in developing a wide-width sintering system is uniformly delivering high energy over such a large area. Uniformity is required for even curing of inks to achieve consistent conductivity of sintered inks.

In the early applications of light-based PE sintering, especially in R&D, it was only necessary to deliver energy to a relatively small area. This allowed some manufacturers to use lamps typically 6" to 8" in length. Figure 2 illustrates how these small lamps are applied in a printing line: the lamps are arranged parallel to the direction of printing because this is the easiest arrangement technically (it avoids a problem known as striping discussed below). As can be seen, this approach typically requires four lamps to cover a 12" inch width.

However, this approach becomes impractical when the area to be sintered is across a full web press, which is typically 50" wide. Sixteen lamps would be required, at a relatively high lamp cost.

To make wide-width sintering cost-effective, it was necessary to take a different approach, namely to develop longer lamps and place them axial to the printing line, as shown in Figure 3. This was possible because XENON designs and manufactures a wide range of flash lamps and lamp housings, matching specific application requirements. Building on expertise and experience gained in long-lamp applications in other industries, the XENON design team developed both new longer flash lamps as well as a robust, lamp housing with a specially designed reflector. Designated model LH-510, this lamp housing can deliver up to 5 joules per square centimeter across the entire width of a web press with minimal energy variability (+/- 5% max). The S-5100 electronics are designed to power a total of four LH-510 lamp housings.



[Figure 2 Caption]
Lamps parallel to printing line: up to 16 required to span press width

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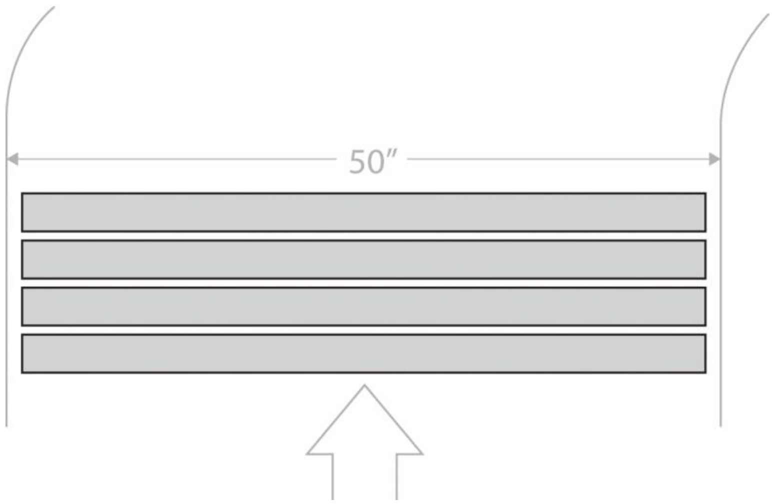


[Figure 3 Caption]
Lamps axial to printing line: one lamp system spans the full width

The size and power of the lamps required for wide-width PE sintering pushed the boundaries of current technology. Specifically, two problems had to be overcome to create a workable system: energy switching and a phenomenon known as striping, or stitching.

Energy switching

PE sintering is based on delivering extremely high-energy light pulses that are sufficient to sinter metallic inks without generating heat that would damage the heat-sensitive substrate. The larger the lamp, the greater the energy required to drive the lamp. Further, to sinter on a running press, the lamps must be pulsed at a high rate of speed, utilizing on and off switching circuits. With long lamps operating with from 1500 to 3000 volts, XENON found that conventional high-voltage, high-current switches were unable to handle the power requirements.

To solve this challenge, XENON again borrowed from experience in other applications to arrive at a proprietary active switching technology that can switch thousands of amps at high speed—fast enough to keep up with a running press.

Striping

Striping, also called stitching, is a phenomenon that refers to the uneven sintering that can occur in the interfaces between lamp flash areas. This problem is relatively easy to solve when the lamps are parallel to the printing line as in Figure 2. The problem is more challenging when the lamps are axial to a moving printing press as in Figure 3. If the lamps are not flashed at precisely the right time, the flashes will overlap creating uneven sintering with some areas under-sintered and other areas over-sintered. These areas will be in the form of stripes perpendicular to the printing line.

To solve this problem, XENON developed a continuous control interface that links the system to the tachometer of the printing press, enabling the light pulses to be synchronized with the press speed. Once the proper flash sequence is established and programmed by the process engineer, the system is able to maintain the correct flash frequency even if the press speeds up or slows down.

Additionally by defining the axial intensity profile and controlling the overlap between the pulses, problems associated with stitching can be mitigated. These parameters can be modified by defining the offset of the lamp from the material and by programing the controller to define the overlap ratio. Though this method can be applied to all ink types, it works optimally with inks that require two or more pulses to completely sinter.

Scaling from characterization to production

In PE sintering, before entering full production, process engineers must first establish the pulse profile necessary for a given ink and substrate. This involves adjusting pulse energy and duration until the desired conductivity is achieved. Once the process is validated, it must be applied in the same way for production.

The axial lamp design developed by XENON makes this scaling a simple process. By using lamps that traverse the full width, the only issue to resolve when transitioning to production is throughput. Engineers can characterize and validate processes with a single lamp at slower speed, then move to production simply by adding lamps without changing the result. To double the press speed, it is only necessary to double the number of lamps, along with the associated rack. One implementation of this approach is illustrated in the design of XENON's S-5100 R2R system. Each S-5100 system handles up to four lamp housings, and additional S-5100 systems can be easily added to the base system.

Thus it is possible to have a separate line with one lamp for characterization, and a production line with multiple lamps for high-speed production. Or manufacturers could start with one or two lamps to begin production and then scale up to meet demand as their product becomes successful in the marketplace.

Note that this kind of scaling is not possible using lamps that are parallel to the printing line, as in Figure 2. In that case, to properly characterize a process, lamps would be needed across the full width of the press.

Flexibility of inks and substrates

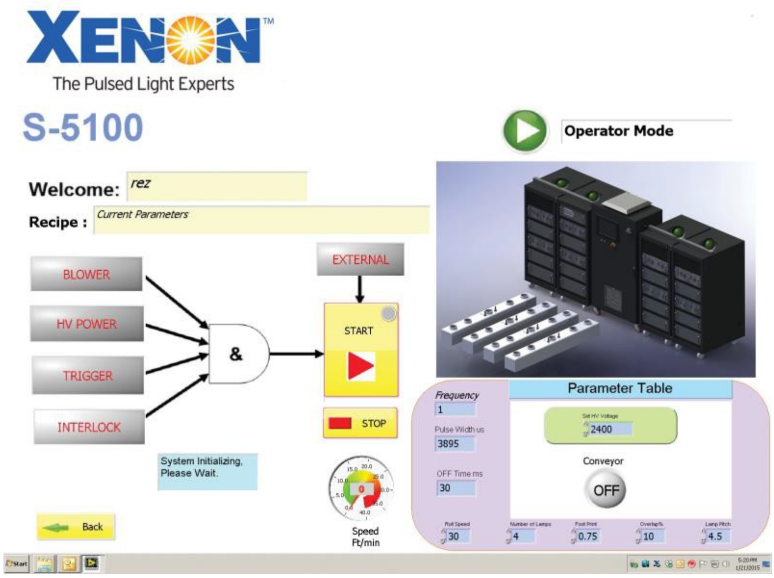
Manufacturers that invest in full-scale PE production will want the ability to leverage that investment for more than one product. Some photonic sintering systems are only successful in sintering one kind of ink, or are limited in the kinds of substrates they can handle, which in turn limits the applications they can be used for.

The XENON design team adapted the same proprietary technology already in use in hundreds of XENON's smaller-width R&D and production applications. This technology has proven to be effective with both copper and silver inks from multiple suppliers and has been successfully applied to many substrates including PET, PI, and paper. Sintering of gold, nickel, and silver nano wires are examples where this technology has had significant success.

Testing, programming & control

To develop new applications and improve processes, engineers need the ability to adjust pulse parameters, testing and tweaking sintering "recipes" based on the behavior of a variety of new nano inks and lower cost, heat-sensitive substrates.

XENON designed the touchscreen interface of the S-5100 system to provide easy and clear software control over all system parameters (see Figure 4). Engineers can easily program pulse energy, width and frequency to achieve the desired results. Recipes can be stored and recalled when needed, to speed research or to accelerate change-overs on the printing line.



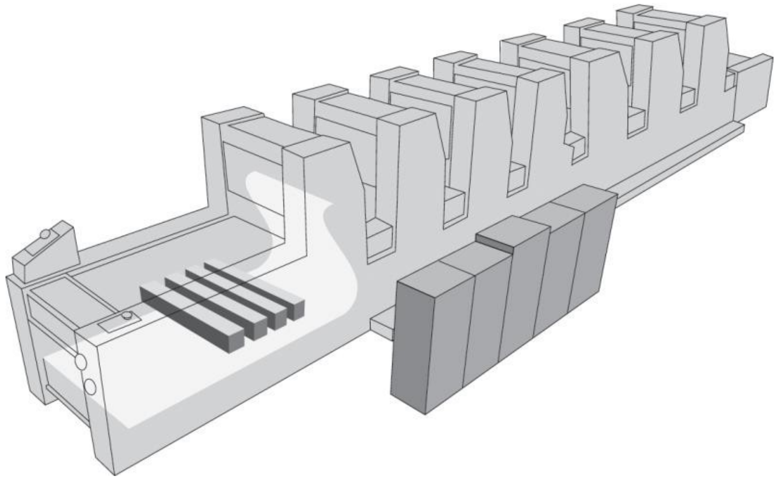
[Figure 4 Caption]
A touchscreen interface aids process development and production control

Easy integration into printing line

With the technical challenges solved, the final challenge was to design a system that can be easily integrated into existing printing lines.

As shown in Figure 5, LH-510 lamp housings can be placed where needed in the line and controlled remotely with the S-5100 system's easy-to-use operator interface and simple electrical connectivity to the lamp housings. To further simplify deployment, XENON utilized air-cooling for all lamps, avoiding the complications and costs of water-cooling.

Once in production, the touchscreen interface provides a simple interface for choosing recipes and operating the system.



[Figure 5 Caption]
Lamp housing can be placed anywhere in a printing line, for easy integration into processes

Conclusion

The lack of a wide-width solution for rapidly sintering metallic inks on sensitive substrates has hindered the growth of some PE applications, especially where high-volume is required. By applying experience from other industries, and by designing special lamps, switches, and other components, the XENON engineering team was able to overcome the challenges of wide-width sintering.

The S-5100 system meets the essential requirements of a practical R2R sintering solution: it delivers uniform energy over the entire area, scales easily from characterization to production, can be used with various inks and substrates, provides intuitive programming and control, and can be integrated into existing printing lines.

As this paper is being written, the S-5100 system is being evaluated by a consortium of manufacturers in Asia for possible applications in high-volume Printed Electronics production. XENON is optimistic that this system will play an important role in bringing pulsed light sintering into the mainstream of manufacturing, and will help spur the PE industry to launch new and cost-effective products.

About XENON

XENON is the world's leader in Pulsed Light technology for Printed Electronics. XENON's S-Series systems are used to rapidly sinter conductive metallic inks at room temperature, making it possible to print on heat-sensitive flexible substrates such as PET and paper at high speeds. XENON also produces high-performance Pulsed Light systems for applications in decontamination, UV curing and food enhancement. With over 50 years of experience in Pulsed Light technology, XENON has thousands of systems operating on industrial production lines worldwide.
To learn more visit www.xenoncorp.com.