# SHAPED PULSE PROFILES IN PHOTONIC SINTERING FOR PRINTED ELECTRONICS

## Saad Ahmed observes the challenges faced by direct printing of circuits with conventional printing processes

**One of the challenges in producing commercial printed electronics products has been the effective sintering of inks on substrates that can be damaged by high temperatures. Photonic sintering, which uses high-energy light pulses, has solved this challenge in some applications, but many other applications still pose difficulties. A new "dual pulse" approach to photonic sintering, utilising two pulse profiles operating as a single pulse, may hold the key to addressing these more challenging applications.**

Photonic sintering is a process where high energy pulses of light are used to melt together small particles of material, enabling the direct printing of electronic circuits using conventional printing processes such as ink-jet printing, the screen process or gravure. When used with conductive inks that are able to sinter at relatively low temperatures due to particle size, photonic sintering is able to transform printed lines into solid conductive traces.

Photonic sintering delivers high intensity pulses of light which are in the order of a few milliseconds, that results in a minimal temperature rise in low-temperature substrates. Low temperature ovens that are traditionally used for sintering often take too long to achieve similar results because increasing the temperature to accelerate the sintering process typically leads to damage of the substrate. Photonic sintering promises to be a key enabling technology for high throughput printed electronic systems that utilise low temperature substrates.

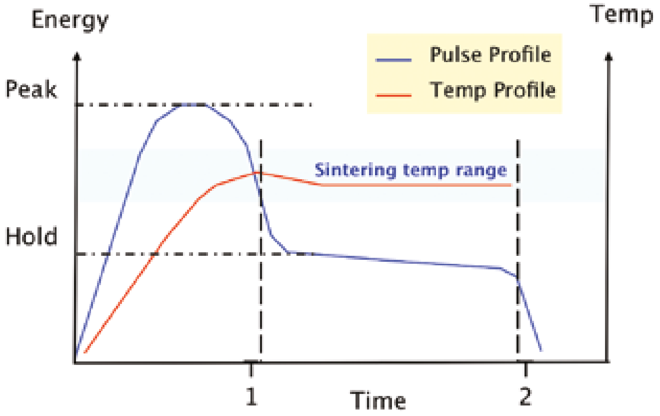

*Figure 1: a dual pulse profile system where the peak, hold amplitude and durations of are independently controlled. The red plot shows the intended thermal characteristics on sample.*

### EMERGING CHALLENGES

In its simplest form, photonic sintering uses light to impart thermal energy onto ink with a controlled pulse or a chain of pulses that brings the ink up to the sintering temperature. In printed electronics applications, there are numerous functional parameters that need to be considered including resistivity, adhesion, transparency, and flexibility. In a photonic pulsed system, the pulse amplitude, width, and frequency are adjustable parameters that are used to define the optical energy delivered. The majority of commercially available photonic sintering tools offer these adjustments, and these are adequate for some applications. However, numerous types of inks, substrates, printing processes, and functional characteristics often require tighter control of the photonic energy.

For example, thick conductive layers, like those printed using screen-printing techniques, pose an additional challenge in dealing with depth of cure. In this case, it is not sufficient to reach the sintering temperature; that temperature must also be maintained to allow the heat to penetrate into the thick ink layer and sinter more deeply into the material. If the temperature is not maintained, un-sintered ink remains under the top layer, which leads to wasted ink, higher resistivity, and weaker adhesion.

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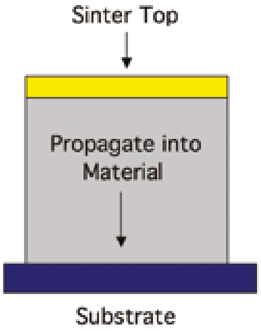

*Figure 2: for thick films the peak section of the pulse is used to initiate sintering of the top surface and the hold section of the pulse used to allow sintering propagation into the material.*

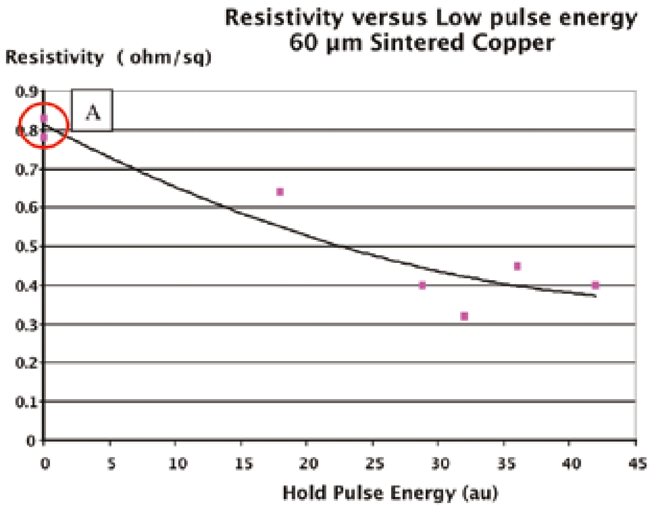

*Figure 3: a process for sintering thick layer copper ink was optimised with adjustment of the peak pulse only with no energy in the hold region (Points A). A 50% improvement in resistivity is shown as more energy is applied to the hold region.*

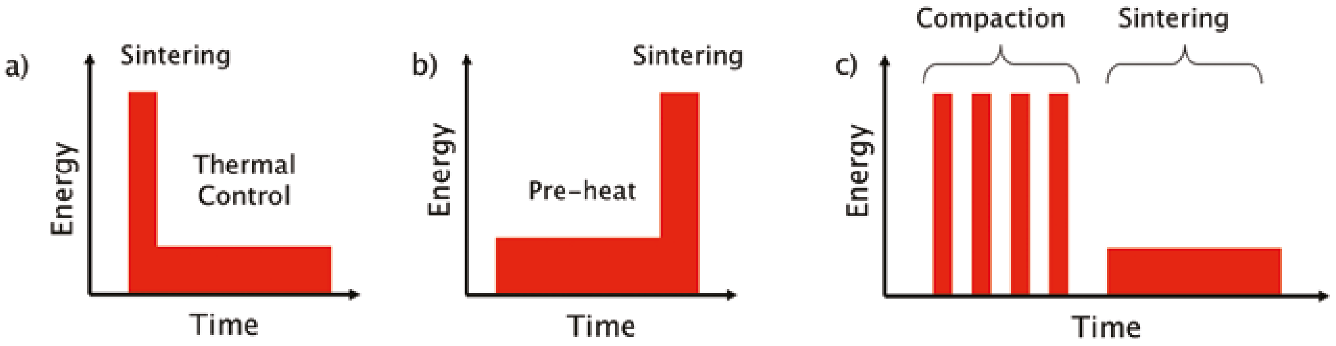

*Figure 4: a) sintering and then thermal management for better depth of cure b) Showing how dual pulse profile can be used to preheat material prior to sintering and c) burst of pulses for improved compaction prior to sintering.*

## THE DUAL PULSE APPROACH

The dual pulse process was developed at Xenon Corporation to address this particular issue. By using an arrangement of power supplies and energy storage pulse networks, it is possible to deliver a unique pulse profile combining two independently controlled pulse features implemented in a single pulse. This allows the user to define a peak energy component, which brings the ink to the sintering temperature, and a hold energy component, which maintains the temperature for some time. The amplitude and duration of the peak and hold profiles can be independently controlled, providing optimum process flexibility while maintaining simple user control.

Having two independently controlled pulse profiles allows a single pulse to accomplish multiple tasks. Usually photo-sinterable conductive inks are complex in nature. This is particularly true for copper, which requires techniques to either prevent oxidisation or remove solvents and carriers in the ink. Furthermore, there may be binders or agents to improve adhesion or tune the ink for a given printing technique. The complexities of the ink mean that a number of different processes are required to sinter it. As an example, hot air driers or IR (infra-red) lamps are used to pre-heat the ink to remove solvents. The temperature required is below that for sintering to allow for better evaporation. Alternatively, the substrate can be heated to just below sintering temperature to improve adhesion. In a dual pulse system, the lower-power hold profile can be programmed to occur before the peak profile, which effectively pre-heats the ink prior to sintering. Where hot air or IR lamps require additional equipment and process time, a dual pulse process combines the preheating and sintering steps into a single pulse lasting only milliseconds.

*Figure 5 The S-2300 System developed by Xenon for R&D with dual pulse capability*

There are a number of photo-sinterable inks that require multiple pulses for optimal results. For example, certain silver inks respond well to integrated energy over multiple pulses where using a single high-energy pulse could damage the substrate. Generating an arbitrary number of pulses with different voltage peaks could achieve the task of compaction prior to sintering. Although two separate pulsed light systems configured to address each task can achieve the same effect, a dual pulse system provides the optical solution in a single system.

## CONCLUSION

The use of pulsed light for photonic sintering is still a fledgling technology with a diverse range of inks, printing processes and applications. There is currently a huge thrust by governmental, academic, and industrial organisations to develop process solutions that lend themselves to high-speed roll-to-roll printed electronics. Indeed, photonic sintering is up to the challenge and already has seen production-level deployment. Due to the diverse range of ink types, substrates, printing methods, and functional requirements, a tool that provides flexibility in the way that it can control and deliver light is essential to address many applications. The dual pulse process, combined with the proper advanced control capabilities to utilise it effectively, offers a practical solution that opens up new opportunities for printed electronics. ■

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