

Spring 2014

Design of a UV Curing Cartridge for 3D Inkjet Printing

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Recommended Citation

Wiswell, Richard, "Design of a UV Curing Cartridge for 3D Inkjet Printing" (2014). *Thinking Matters Symposium Archive*. 30.
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Abstract

In printing multi-layer electronic circuits, each layer must be formed as a continuous pattern in high resolution from ink jetted liquid droplets and be in precise alignment with the other layers, precluding substrate removal for UV curing. This research seeks to determine the optimal method for in-situ UV curing of the ink jetted material in a single pass. The inkjet replacement cartridge designed for this purpose was constructed of aluminum, fit into the printer head assembly in good alignment with the other ink cartridges, and contained a UV LED for in-situ curing and a cooling fan to maintain safe operating temperatures for the LED. Measurements of heat transfer and UV exposure determined the optimal characteristics for the cooling mechanism and the LED, respectively, and the temperature profile was modeled prior to construction. The aluminum cartridge remained in proper alignment; the 5W-rated 365nm LED provided instant, in-situ curing; and the cooling fan kept the LED within its optimal temperature range. This design allows the printing of multi-layer electronic circuits without substrate removal for UV curing.

Background

Materials ink jet printers are used to print materials to construct 3-dimensional mechanical objects and to print 2-dimensional circuits and electronic devices for printed electronics. Materials are ink jetted as liquid drops either (a) in the form of dispersions, which must be heat treated to evaporate the carrier liquid, or (b) in the form of a curable polymer ink, which must be exposed to ultraviolet radiation at specific wavelengths and intensities after being printed. The latter requires ultraviolet light with wavelengths between 365nm and 405nm and an exposure dose greater than 200mJ/cm².

Electronic circuits are printed in layers, each of which exhibits different electrical properties. Each layer must be formed as a continuous pattern in high resolution from the jetted liquid ink droplets and be in precise alignment with the previously ink jetted layer. It must also form a film that is dried, cured, stabilized, and ready to receive the incoming droplets of the next material layer without being affected by it. Taking the substrate out of the printer for curing or drying would affect alignment, and realignment errors would compound as the number of layers being printed increased. Therefore, a mechanism must be created to facilitate in-situ, and preferably instant, curing of the printed droplets during the printing process.

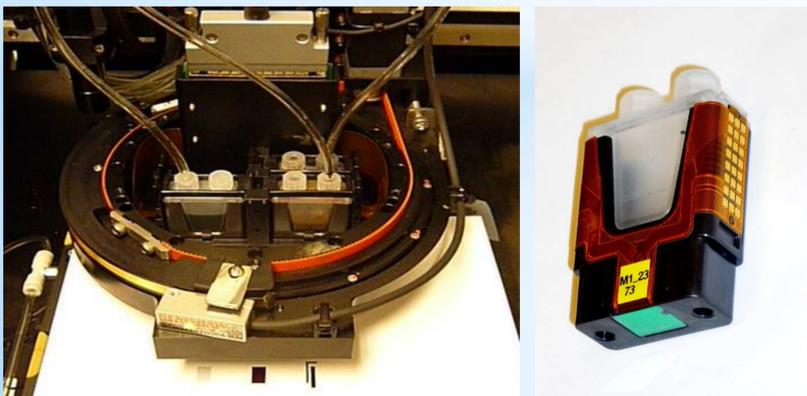


Figure 1. Cartridge Head and Cartridge for Materials Printer

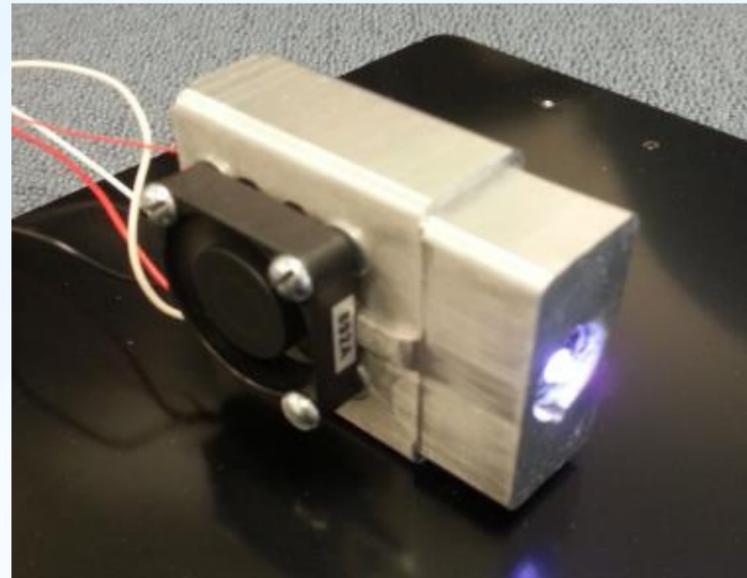


Figure 2. UV Replacement Cartridge

Objective

The primary objective is to design, construct, and test a mechanisms to cure the material as it is being printed. Such an in-situ, instant curing of printed droplets can be achieved by using an inkjet replacement cartridge which fits into the printer head assembly (Figures 1 & 2), aligns with the other ink cartridges of the printer, and houses a UV LED powerful enough to provide the necessary exposure in one pass over the ink jetted drops. The cartridge must be designed to allow the heat generated by the high powered UV LED to be removed to avoid exceeding the LED's maximum safe operating temperature limit while still fitting into the printer head assembly tightly for consistent alignment with the other print cartridges.

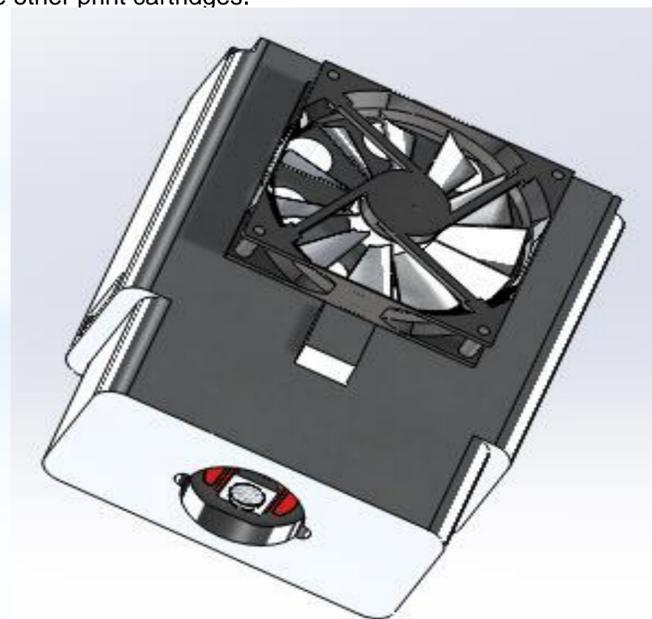


Figure 3. SolidWorks Model

Methods

Before any form of construction began, the cartridge was drafted in SolidWorks (Figure 3.) and a 3D plastic prototype was printed using the department's 3D printer to verify dimensions and alignment. Aluminum was chosen for its machinability and high thermal conductivity. A thorough thermal analysis was performed to aid in the selection of a suitable material and cooling mechanism. The aluminum cartridges were machined using a precision CNC machine and a manual mill. The LED was held in place using thermal paste to assure a good thermal contact to conduct the heat away from the LED base. In-situ exposure was performed on test samples to verify that the LED would provide adequate irradiance to cure the photoresist in a single pass.

Results

As predicted from the thermal analysis (Figure 4.), the aluminum cartridge with a cooling fan kept the LED cool enough to prevent rapid degradation. In-situ curing tests were performed using the cartridge with an embedded 5W LED with a 365nm wavelength, the optimal wavelength for our inks. At the nominal printing speed of our printer, (i.e., 3 cm/s), the samples responded well and solidified at all exposure levels we tried, 6 passes, 2 passes, and 1 pass, resulting in an estimated minimum exposure value better than 25 mJ/cm², which is a typical exposure sensitivity for most UV sensitized inks and photoresists. Since the LED was actually powered at about 50% of its rated maximum, less sensitive UV inks or doubled printing speed could be reasonably accommodated.

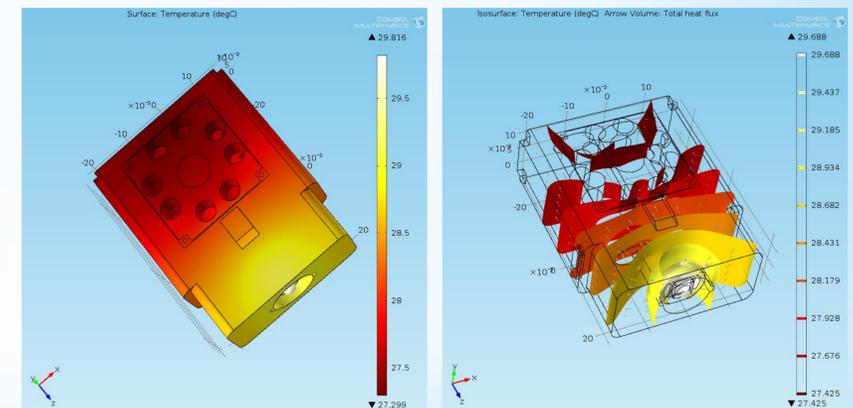


Figure 4. COMSOL temperature profile

Conclusions and Future Work

This work showed that the in-situ curing of material inks was possible via the design and construction of a properly cooled UV replacement cartridge. The production of a working design and rapid prototyping of a UV LED cartridge allowed the instant curing of the printed droplets as they were printed in a materials inkjet printer, thereby verifying our hypothesis.

Future work is planned to include drying/baking/annealing through in-situ heating of non-UV ink patterns by exposing them to visible and/or infrared radiation. Such processes, compared to UV curing, demand much higher intensities and LED power, and therefore constitute a greater challenge for thermal design. We expect to overcome these higher power challenges to design and produce in-situ heat-treating high power LED embedded cartridges for materials inkjet printers that will meet the needs of printed electronics fabrication.