Modeling and Design of Material Inkjet Printer Ultraviolet LED Curing Cartridges Using COMSOL Multiphysics® for Printed Electronics Applications

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Abstract

Introduction: Material Ink Jet printers are used to print various functional materials to make 3-dimensional mechanical objects and also to print 2-dimensional circuits and electronic devices for printed electronics. Materials are inkjetted as liquid drops either in the form of (a) dispersions which need to be heat treated to evaporate the carrier liquid or (b) in the form of a curable polymer ink which needs to be exposed to ultraviolet radiation at specific wavelengths and intensities after being printed. For the latter, ultraviolet light with wavelengths between 365nm and 405nm are needed with more than 200mJ/cm² exposure dose.

In printing electronic circuits many different layers each with different electrical properties need to be printed. Critical in the process is not only the formation of each layer as a continuous pattern in high resolution from the jetted liquid ink droplets, but making sure that the next layer printed is in precise alignment with respect to the previously inkjetted layer and forms a film dried, cured, stabilized and ready to receive the incoming droplets of the next material layer without being affected by it. Obviously, taking the substrate out of the printer for curing or drying of the previously printed layers creates alignment issues when the substrate is placed back in the printer. This realignment issue gets worse by the number of layers being printed. Therefore, a mechanism has to be created to facilitate in-situ and preferably instant curing of the printed droplets during the printing process.

Such an in-situ and instant curing of the printed droplets can be achieved by using an inkjet cartridge replacement which fits in the printer head assembly and aligned with the other ink cartridges of the printer and houses a high-powered UV LED powerful enough to provide the exposure needed in one pass over the inkjetted drops. The work being reported here is an effort to design such a cartridge.

Primary challenge in this design has been the removal of the heat generated by the high-powered UV LED so that the LED's maximum safe operating temperature limit is not exceeded. Associated with heat removal is the constraint that the shape and the size of the cartridge housing the power LED cannot be changed since it has to plug into the printer head assembly tightly for consistent alignment with the other print cartridges. Figure 1 shows the inkjet cartridge (a Samsung "SEMJET Mini") used in our materials printer (UniJet, Co.'s OmniJet 100 Deluxe model). Seen at

the bottom center of the cartridge as a bright green square, the cartridge employs a 16 nozzle Silicon MEMS chip for inkjetting. A 3D CAD model of this cartridge was created in Solidworks® from which a precise replica could be produced in plastic using a 3D printer, or in metal by employing a digitally controlled precision CNC machine. Figure 2 shows the 3D model including a 5W rated UV LED diode in Mini Round MCPCB package embedded in a circular cavity replacing the MEMS chip. This model could easily be imported into COMSOL Multiphysics® for analysis as well as being used for digital prototyping.

The 3-D printed version of the prototype replacement cartridge, however, proved to be unsuitable because of the very poor thermal conductivity (about 0.2 W/K•m) of the 3D printer materials available. Therefore, the design and simulation work presented here was done using a high thermal conductivity Aluminum alloy with about 3 orders of magnitude higher thermal conductivity of 200 W/K•m. The aluminum alloy material is also suitable for casting for production of the UV LED cartridge in large quantities.

Use of COMSOL Multiphysics: Because of the use of high powered LEDs, heat dissipation is critical to prevent excessive heat buildup resulting in the LEDs UV output to drop, or worse, burning out. The optical output and longevity of LEDs greatly diminishes as temperature raises making heat dissipation a key factor in this design. The SolidWorks® model of the cartridge was conveniently imported into COMSOL Multiphysics. The Heat Transfer in Solids (ht) physics interface was used to solve for the ability of the aluminum to conduct the heat away from the LED and dissipate it to the surroundings. Figure 2 shows the thermal analysis of a UV cartridge powered by an embedded 395nm wavelength LED operating at 5W, which was deemed to be the most critical case. The convenience of easy interfacing of Solidworks® 3D CAD model with COMSOL facilitated quick turnout of design modifications and multiphysics verifications to be made to check out the improvements achieved.

Results: As depicted from the Heat Transfer analysis in Figure 2 a cartridge machined out of aluminum is suitable for the required heat dissipation. This analysis was performed assuming a 20 °C ambient temperature. It is observed that aluminum body of the cartridge conducts the heat flux with less than a few degrees temperature drop. The temperature rise of up to 50 °C in the cartridge is mostly due to insufficient removal of the heat from the surface to the ambient with air convection. Inside a materials printer the ambient temperature can potentially reach up to 50 °C , bringing the LED case temperature above 80 °C, a critically high value for LED degradation and failure. Figure 3 shows the improvements achieved with the addition of heat dissipating fin structure on one side of the cartridge. This modest change in the design results in about 15 °C reduction in temperature and shows feasibility of a UV LED replacement cartridge to be made with a UV LED operating at as high as 5W power level for in-situ and instant curing of the printed droplet in a materials printer.

Conclusion: Combined Solidworks® 3D CAD models and COMSOL Multiphysics analysis resulted in a fast design and design verification work to be completed to achieve a working design and rapid prototyping of a UV LED Cartridge for use in the instant curing of the printed droplets as they are printed in a materials inkjet printer.

Figures used in the abstract

Figure 1: Materials Printer Inkjet Cartridge.

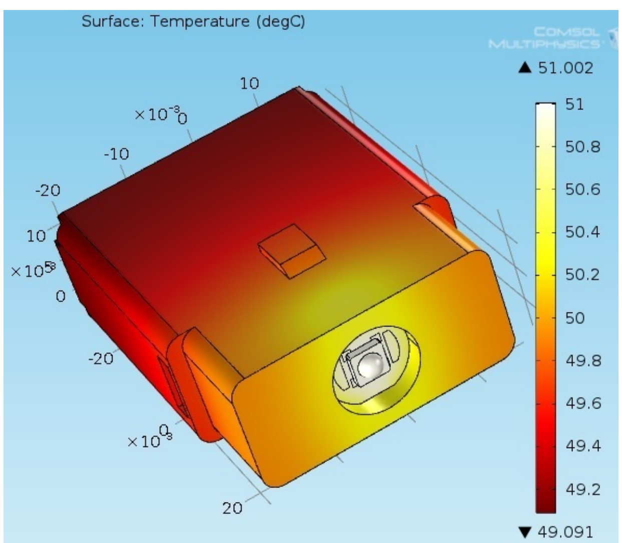

Figure 2: 3D CAD model of UV LED mounted cartridge.

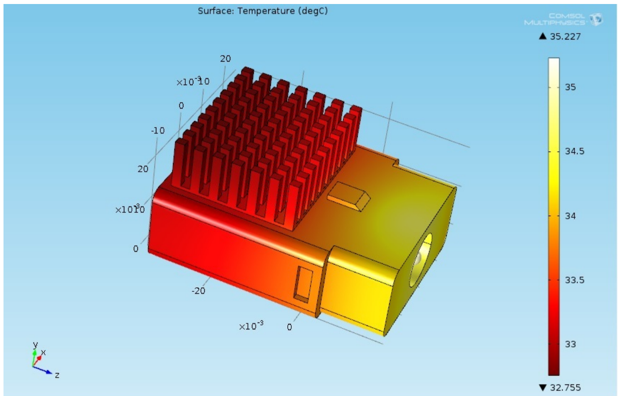

Figure 3: Improved UV LED Cartridge Design with additional heat dissipating fin structure.