Lighting Research Center

Revolutionizing the Solid-State Lighting Industry with 3-D Printing

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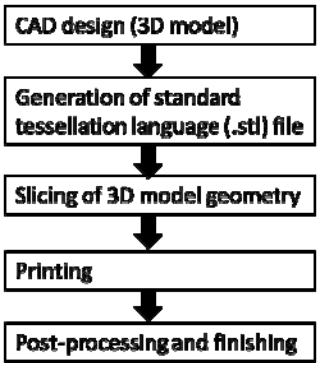
Introduction

In recent years, additive manufacturing technology (better known as 3-D printing) has taken hold as an expedient tool for developing prototype or custom parts and products across a number of industries, including automotive, aerospace, and medical device. The reasons for using 3-D printing in these industries include product development acceleration, custom designs, and production flexibility.[1] 3-D printing technologies have become available to the masses and are showing up in laboratories, prototyping workshops, and even high school engineering classrooms.

The light-emitting diode (LED), a type of solid-state lighting (SSL), has become the mainstream lighting technology employed in numerous general illumination and specialty lighting applications because of its energy efficiency, durability, reduced size, and fewer maintenance requirements. With these advantages, LEDs and SSL offer additional benefits to the built environment, including the ability to customize lighting fixtures that cater to the specific design and needs of the space to be illuminated. Considering the recent trend toward product customization across many industries including lighting, 3-D printing is a natural fit for SSL. The benefits of 3-D printing for SSL include custom fixtures and components, improved visual appeal and functionality, rapid prototyping, faster new product introductions, and reduced fixture cost.[2] The use of 3-D printing would allow lighting professionals to manufacture custom lighting fixtures on-site during new construction and retrofit building projects. Additionally, with rapid developments in LED technology and the exploding number of LED fixtures introduced into the market every year, manufacturers are forced to stock a growing number of systems and parts (SKUs) to service their customers for years after a sale. This is another area where 3-D printing can help manufacturers by reducing stocking requirements for fixtures and parts, and instead printing them as needed. Overall, 3-D printing within the SSL industry could pave the way for mass customization and changes to architectural lighting practice through on-time, on-demand manufacturing of lower cost, custom lighting systems and components. Furthermore, on-demand production could help develop local manufacturing businesses that cater to OEMs and individual construction projects within a local region.

Research of Specific Opportunities for 3-D Printing of SSL

With 3-D printing technology, a product is fabricated by depositing material using print heads, nozzles, or other material deposition or solidification processes using a layer by layer approach with digital information from a computer-aided design (CAD) model. The most common 3-D printing processes include material extrusion, vat photopolymerization, material or binder jetting, and powder bed fusion. The most common technology due to the explosion of hobbyist and desktop level printers for 3-D printing is fused filament fabrication (FFF), a material extrusion technology in which a thermoplastic filament is

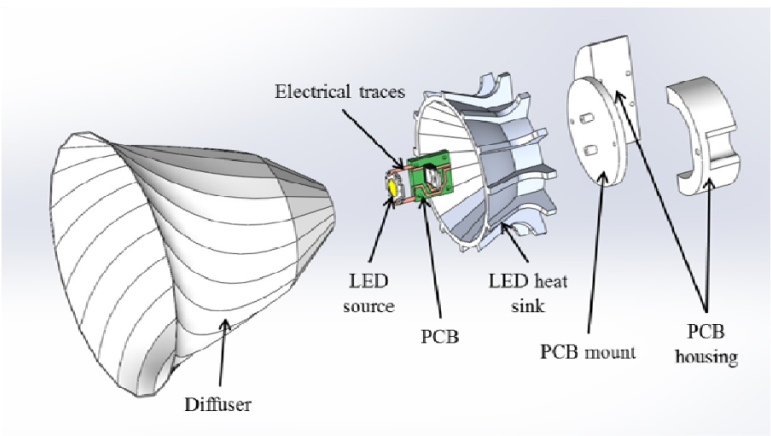


3-D printing process workflow

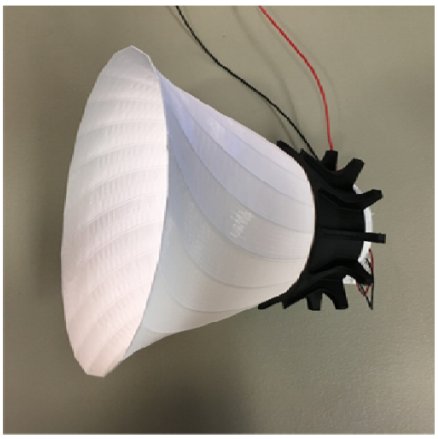
[1] Columbus, L. 2017. The state of 3D printing, 2017. *Forbes*, 23 May 2017.
[2] Narendran, N., et al. 2017. Opportunities and challenges for 3-D printing of solid-state lighting systems. *Proc. SPIE* 10378: 10378-35.

heated and extruded through a nozzle that moves in the x-y plane to complete a layer. In stereolithography (SLA), the oldest 3-D printing process classified under vat photopolymerization, an object is made by selectively photopolymerizing a thin fluid layer and then curing each subsequent photopolymer resin layer one by one with a UV laser. In material jetting, a photocurable or thermocurable plastic resin is deposited using piezoelectric or thermal print heads where droplets of build material are selectively deposited, while in binder jetting, a liquid bonding material is selectively deposited to join a powder material. Another common print process called powder bed fusion uses thermal energy from an electron beam or laser to selectively fuse regions of a thin layer of powdered metal, glass, ceramic, or polymer material.

Within the SSL industry, there are several potential opportunities for 3-D printing. One unique aspect of LED fixture manufacturing is that an LED system requires thermo-mechanical, electrical, and optical components. While past investigations have demonstrated successful 3-D printing of attractive lighting fixture enclosures, others have explored the use of 3-D printing for creating the functional components needed for system operation. The Lighting Research Center (LRC) has conducted its own preliminary research to understand the advantages and challenges of custom SSL components, including heat sinks, electrical traces, and optics.[2]



Example of different components of a solid-state lighting fixture



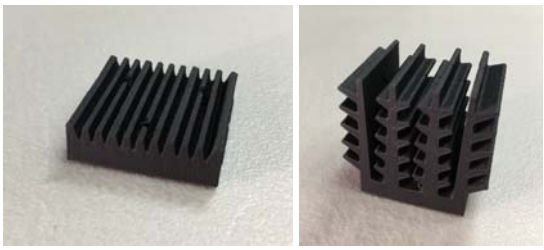
Assembled functional 3-D printed lighting fixture

Example of different components, including heat sink, electrical, and optical subassemblies, of an LED lighting fixture (left) and an assembled, functional 3-D printed fixture prototype (right)

LED Heat Sinks: Heat sinks are used to extract heat from LED systems to keep the semiconductor junction temperature low in order to maintain good performance and reliability. Heat sinks are commonly made from aluminum or other metals, which have the drawbacks of extra weight, expense, and over-designed thermal properties. A few studies have investigated the use of 3-D printing processes for creating thermal management solutions.[3,4] The LRC investigated whether FFF technology and commercially available filament materials can be used to 3-D print custom polymer heat sinks with suitable thermal properties. The results showed that higher thermal conductivity values were achieved for components printed using filaments with metal filler materials and that thermal conductivity values strongly depend on the print orientation. However, the achieved thermal

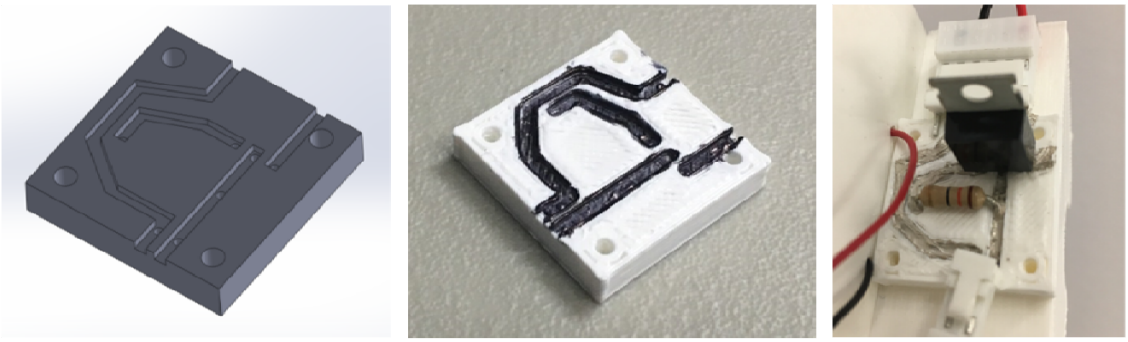
[3] Krishnan, S., et al. 2012. Design of complex structured monolithic heat sinks for enhanced air cooling. *IEEE Trans. CPMT* 2(2): 266–277.
[4] Kalsoom, U., et al. 2016. A 3D printable diamond polymer composite: a novel material for fabrication of low cost thermally conducting devices. *RSC Adv.* 6: 38140–38147.

conductivity values may not be sufficient to meet the thermal management needs of higher power LEDs with smaller footprint heat sinks. In general, commercially available filament materials currently do not possess the thermal properties needed to challenge the existing extruded or machined heat sinks.[5] However, it is worthwhile to continue research in this direction because the thermal performance of a heat sink depends on its geometric form as well. With 3-D printing, system engineers and designers can create heat sink designs that can meet not only the performance requirements but also add aesthetics to the light fixture that are not possible with traditional manufacturing methods.



3-D printed examples of different heat sink geometries

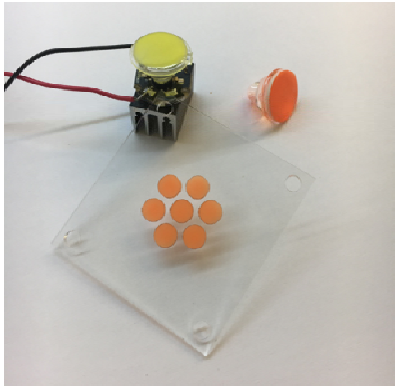
Electrical Traces: In LED lighting systems, electrical traces are often used to conduct electrical current between different electrical and electronic components. Making electrical conductors in 3-D orientations is important for constructing a practical light fixture. The LRC studied whether electrical traces can be 3-D printed with suitable electric and geometric properties. The study found that nanoparticle-based silver inks and liquid metal conductive inks could achieve a resistivity comparable to copper; however, these materials cannot be processed using unmodified FFF-type 3-D printers. Future improvements are required to make 3-D printing a viable option for making functional electrical connections in SSL fixtures.



Example of 3-D printed functional electrical traces with electrical and electronic components

[5] Terentyeva, V., I.U. Perera, and N. Narendran. 2017. Analyzing theoretical models for predicting thermal conductivity of composite materials for LED heat sink applications. *Proceedings of the IES 2017 Annual Conference*, August 10-12, Portland, Oregon.

Optics: Optical component manufacturing is one area where 3-D printing has already gained footing. The potential benefits include ease of creating complex geometric designs and speed of manufacturing. The LRC analyzed how print resolution and orientation using the SLA method affected light transmission and light scatter. The results showed that post-processing, print orientation, and print resolution are all important factors to be considered. A print resolution better than 50 µm can produce adequate optical performance for lighting applications. Nevertheless, the longevity of 3-D printed optical components is not known and requires further investigation.



Examples of conceptual 3-D printed optics and remote phosphor optical components

Challenges That Need Addressing

The potential benefits for 3-D printing in the SSL industry are clear, but challenges need to be overcome in order to successfully explore these opportunities. These challenges include the availability of suitable materials to meet the required functions of the printed subcomponents. An integrated approach is also needed to combine different parts to fabricate a product with multiple materials and functionalities. Finally, faster fabrication and integration are required to meet the needs of LED luminaire fabrication and use in various applications, such as on-demand fabrication. Overcoming these technical challenges will aid not only the SSL industry, but also other industries that require electrical, thermal, optical solutions such as consumer electronics, medical, automotive, and aerospace.

The LRC is in the process of establishing an alliance among researchers, manufacturers, and other organizations to help overcome the technical barriers impeding the use of 3-D printing and make it a viable resource for the SSL industry. On behalf of the alliance, the LRC will conduct research, demonstration, educational, and industry-wide consensus building activities to help the lighting industry realize the benefits of 3-D printing and add value for users of solid-state lighting. Learn more at http://www.lrc.rpi.edu/programs/solidstate/3DPrinting.asp.

For more information about participating with the LRC in its SSL 3-D printing research, contact N. Narendran, narenn2@rpi.edu or (518) 687-7100.

3-D printed wall sconces 3-D printed pendant fixture 3-D printed table lamp

Examples of 3-D printed LED lighting fixtures