Bright Idea for Headlights

Momentive Performance Materials successfully reduced the time required for physical testing by using simulation to optimize the heat sink design for an LED automotive headlight. This simulation yielded a design that demonstrated a two-fold increase in the brightness of the headlight while operating at the same temperature.

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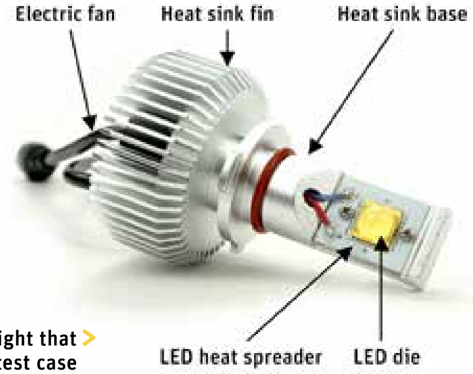
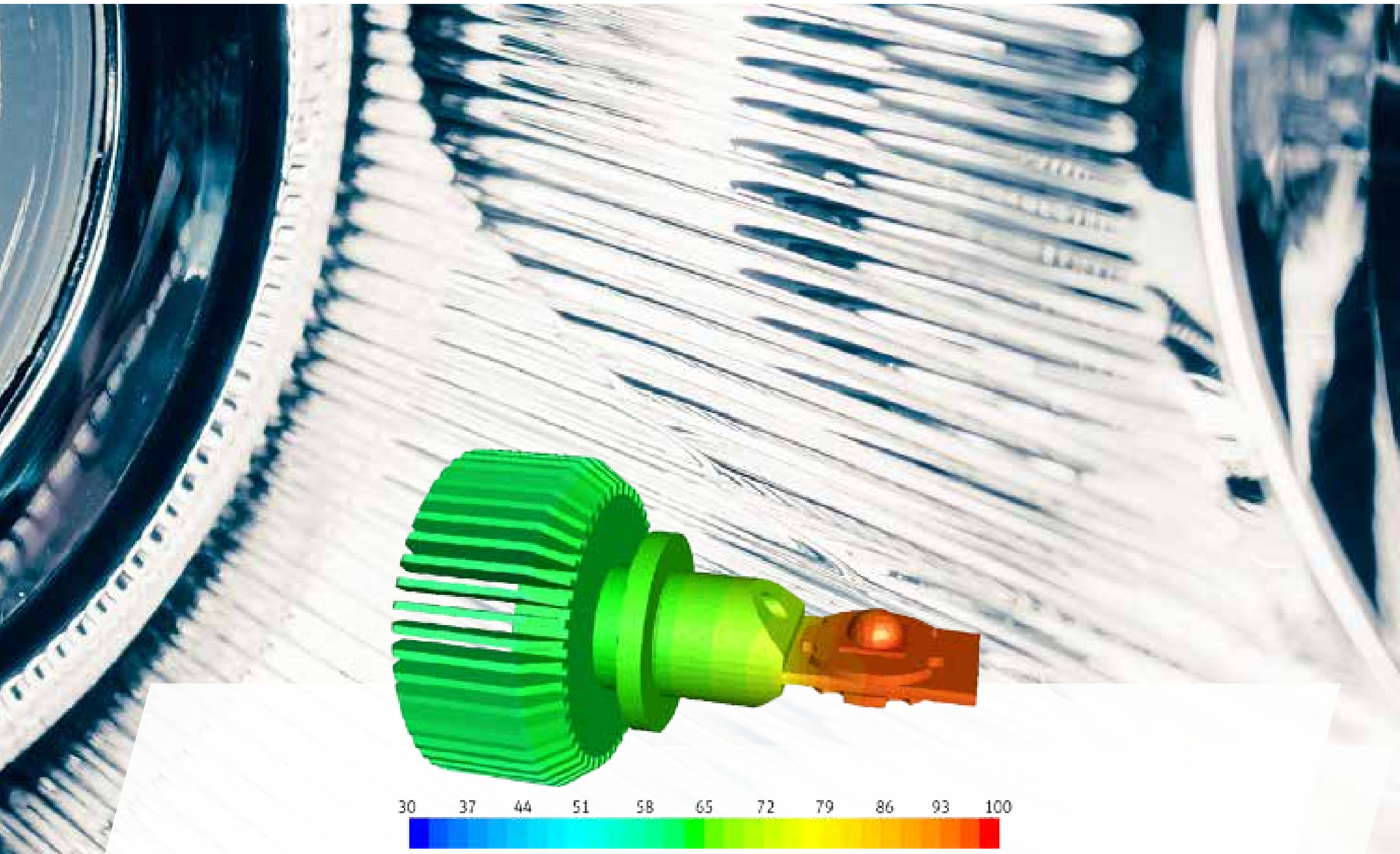


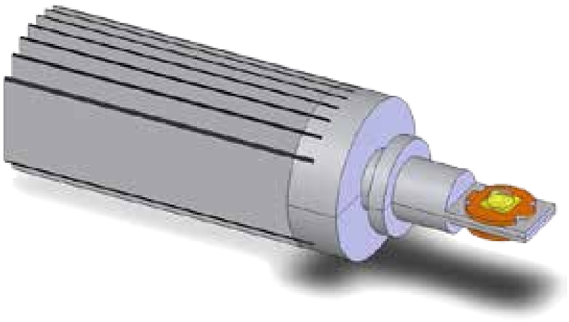
Aftermarket LED headlight that was used as a test case



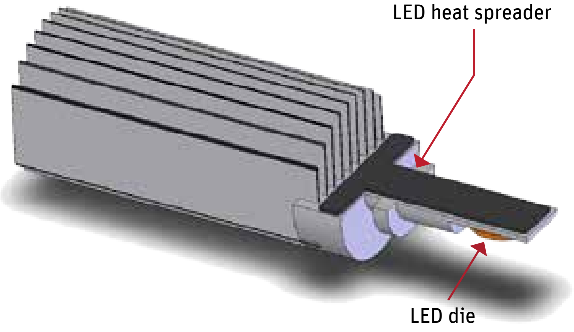
^ Simulation results for the original LED assembly design revealed bottlenecks in heat flow.

Light emitting diodes (LEDs) are increasingly being used as automotive headlights with an estimated 20 percent of cars expected to be equipped with them by 2020. Their low energy consumption improves energy efficiency while their small size provides greater freedom to produce stylish and innovative designs. The biggest obstacle to increased use of LEDs is thermal management. Typically, 70 percent of the energy is converted to heat. LEDs are also more sensitive to heat than alternative lighting technologies because, like other semiconductors, their junctions must be kept cool to operate properly. Most LED headlights use aluminum or copper heat sinks, and forced air or liquid cooling to dissipate heat.

Momentive Performance Materials (Momentive) has developed thermal pyrolytic graphite (TPG), a new material that provides four times the thermal conductivity of copper at one-fourth the weight. The high thermal conductivity of TPG comes from highly oriented graphite crystals in a layered structure. As a way to market this new material for automotive applications, Momentive set out to develop new heat sink designs that could improve the performance of current LED headlights. Building and testing a single prototype would take weeks of effort and many prototypes to optimize the design, but by leveraging the use of ANSYS Fluent computational fluid dynamics (CFD) software, Momentive engineers were able to accurately predict the performance of alternative thermal management designs in only 15 minutes. In a generic application, the engineers demonstrated through simulation that TPG could double the brightness of an LED with the same basic thermal management design. Alternatively, by eliminating a fan used for forced-air cooling, engineers could reduce thermal management costs and energy consumption, as well as improve the headlight reliability, all while maintaining the same brightness. The finalized designs were then prototyped, and the measured performance of the LED assemblies matched the simulation performance predictions.



^ LED assembly design modified to use TPG heat sink fins



^ Improved LED assembly design with TPG heat sink core and fins

SIMULATING THE ORIGINAL DESIGN

The diode junction temperature of an after-market LED headlight must be kept below 120 C. The original design cools the LED with a heat spreader, a heat sink base and fins, and an electric fan. Momentive engineers used ANSYS CFD to model all the components of the assembly and added the thermal conductivity of each component to the model. The heat input was estimated at 70 percent of the 30-watt total input power to the two LEDs and specified as a volumetric heat source in the LED chip. The model was simulated with a forced air flow of 3 cubic feet per minute. The simulation predicted an overall thermal resistance of 5.9 C/W. The device was also instrumented with thermocouples at the LED die, LED heat spreader, heat sink base, heat sink fins and light housing. The temperatures at each location as a function of input power were collected after the temperature reached equilibrium. Temperature profile predictions from simulation matched the experimental data, confirming the accuracy of the simulation.

IMPROVED FIN DESIGN

Based on the study of the baseline model, the heat sink fins and heat sink base were identified as the bottlenecks for heat flow. The next step was to modify the heat sink fins and base designs to improve thermal conduction and to validate their performances through CFD modeling. Momentive engineers changed the heat sink fin material in the model to a laminate consisting of a TPG core with a tin coating. As TPG is a soft material due to the weak van der Waals force between the graphene layers, it must typically be contained in some structural member. In this case, a thin tin coating was identified to protect the TPG material from moisture and abrasion, and to make it possible to reflow and solder TPG material directly to the aluminum base. The high thermal conductivity of the TPG material can spread the heat more uniformly across the entire fin structure, utilizing the fin surface more efficiently. The simulation results yielded a thermal resistance of 4.7 C/W, which was 20 percent less than the resistance of the baseline design.

> *“Changing the heat sink fins and base to a TPG-based material can allow a twofold increase of the input power to the LED, while doubling the brightness of the LED.”*

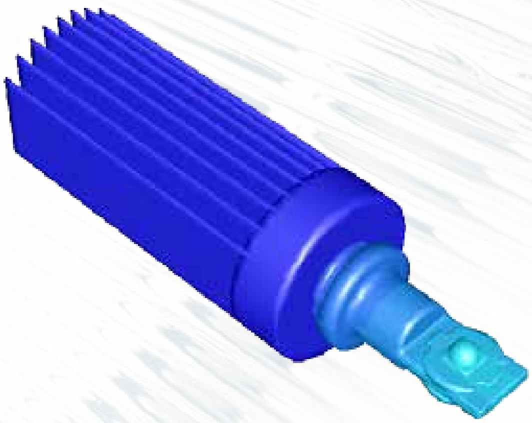
IMPROVED CORE DESIGN

Next, Momentive engineers looked at a design to facilitate heat flow through the narrow neck area of the heat sink base, beginning with replacement of this area with a T-shaped TPG tile brazed into an aluminum enclosure with a T-shaped cavity. High-temperature brazed joints between the metalized TPG material and aluminum enclosure components were specified to provide excellent thermal interfaces and high bonding strength, and to endure the downstream soldering temperatures that develop when the LED dies and TPG fins are attached. The simulation showed that the TPG heat sink base would reduce the temperature gradient along the narrow neck at the heat sink base and the heat sink fins, and increase the effective area dissipating heat to the air. Simulation results for the LED with a TPG heat sink core yielded an additional 29 percent reduction in thermal resistance with a nominal thermal resistance of 3.0 C/W. This is a total

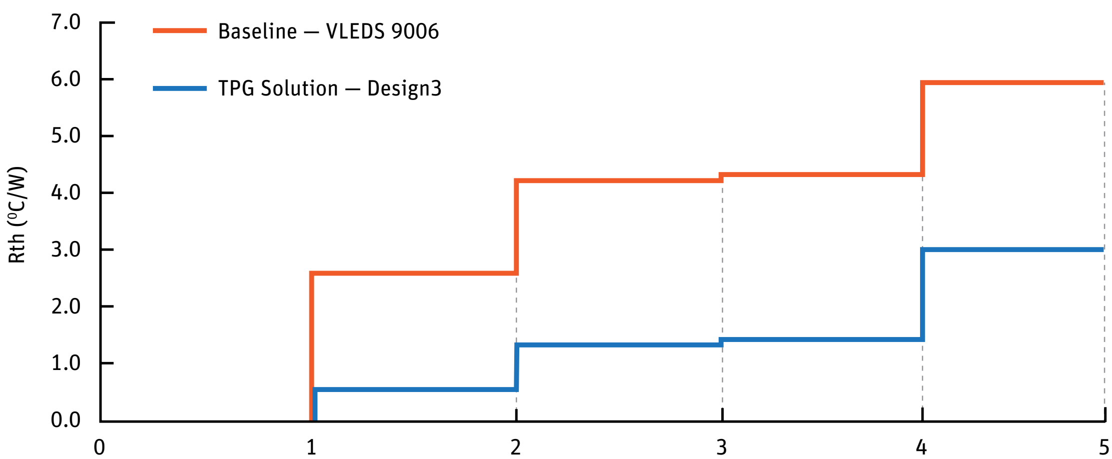
> *"Momentive engineers are making extensive use of simulation to demonstrate the benefits of TPG-based thermal management solutions and to reduce the number of product development cycles."*

reduction of 49 percent from the base design.

The simulation concluded that in this specific application, changing the heat sink fins and base to a TPG-based material would allow a twofold increase of the input power to the LED, while doubling the brightness of the LED without increasing the LED junction temperature, as compared to the baseline design. The simulation results were later confirmed by measurement of LED headlight prototypes that were built on the basis of the above designs. Further exploration showed that the headlight could be run at the existing 30-watt power level without the need for an electric fan, effectively reducing the cost, weight and energy consumption of the headlight, and increasing its reliability by eliminating a potential failure point. Going forward, Momentive engineers will be making extensive use of simulation to demonstrate the benefits of TPG-based thermal management solutions to customers in the automotive, aerospace, telecommunication and defense industries. Using simulation early in the design process is crucial for the energy efficiency and performance of all high-power electronics. Simulation can also demonstrate the benefits of improved designs to potential customers.



^ Simulation of LED headlight with TPG heat sink core and fins helped achieved 49 percent thermal resistance reduction.



^ Simulation results for LED with TPG heat sink core and fins show 49 percent reduction in thermal resistance and 104 percent additional power at equal temperatures (which matched physical measurement).

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