MEETING HIGH-SPEED COMMUNICATIONS ENERGY DEMANDS THROUGH SIMULATION

Simulation-driven design is employed at Bell Labs Research to meet the energy demands of exponentially growing data networks and reduce the operational energy costs of the telecommunications network.

By **DEXTER JOHNSON**

ENERGY DEMANDS ARE becoming a bottleneck across multiple industries. From reducing the energy costs associated with operating a building to maintaining the exponential growth of high-speed networks, energy considerations are critical to success. Significantly improved energy efficiency is driving researchers at Bell Labs to design and implement new technologies in a scalable and energy-efficient way.

Bell Labs is the research arm of Alcatel-Lucent and is one of the world's foremost technology research institutes. Bell Labs Alcatel-Lucent founded the GreenTouch consortium, a leading organization for researchers dedicated to reducing the carbon footprint of information and communications technology (ICT) devices, platforms, and networks. The goal of GreenTouch is to deliver and demonstrate key components needed to increase network energy efficiency by a factor of 1000 compared with 2010 levels.

The Thermal Management and Energy Harvesting Research Group at Bell Labs (Dublin, Ireland) leads Alcatel-Lucent's longer-term research into electronics cooling and energy-harvesting technology development. It has developed two new energy-saving approaches that promise significant savings.

One research project is targeting between 50 and 70 percent energy reduction by improving the thermal management surrounding the photonic systems by means of which laser light transmits data through our networks. Meanwhile, another team has developed an entirely new approach to the harvesting of energy from ambient vibrations that generates up to 11 times more power than current approaches and is used to power wireless sensors for monitoring the energy usage of large facilities.

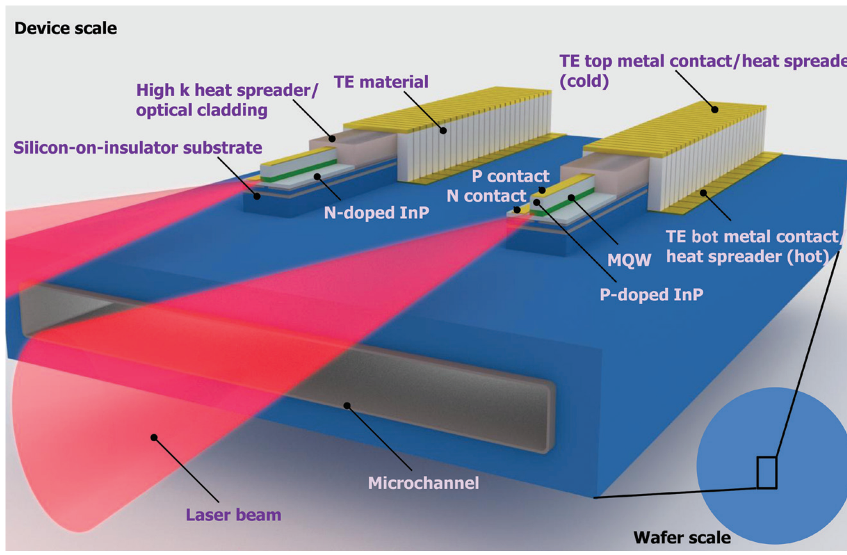

FIGURE 1: Schematic of the thermally integrated photonics system (TIPS) architecture, which includes microthermoelectric and microfluidic components.

» USING SIMULATION TO MEET DATA TRAFFIC DEMAND WITH PHOTONICS COOLING

THE EXPLOSION IN data traffic in the last few years is causing an immense strain on the current network, which was designed for low cost and coverage rather than energy efficiency. Energy management is becoming a major obstacle to the deployment of next-generation telecommunication products.

To address this issue, the Thermal Management team investigates all aspects of electronics and photonics cooling. The research team is realizing benefits that affect product performance by employing multiphysics simulation at multiple length scales—from the micrometer scale to the macro level.

To find efficiencies at the micrometer scale, Bell Labs has turned to COMSOL Multiphysics® to model potential approaches for cooling photonic devices that rely on the thermoelectric effect. Thermoelectric

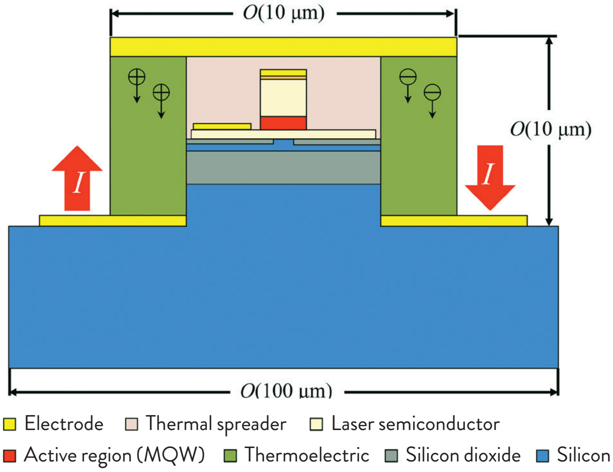

FIGURE 2: Cross-section schematic of laser architecture with integrated μTEC (not to scale).

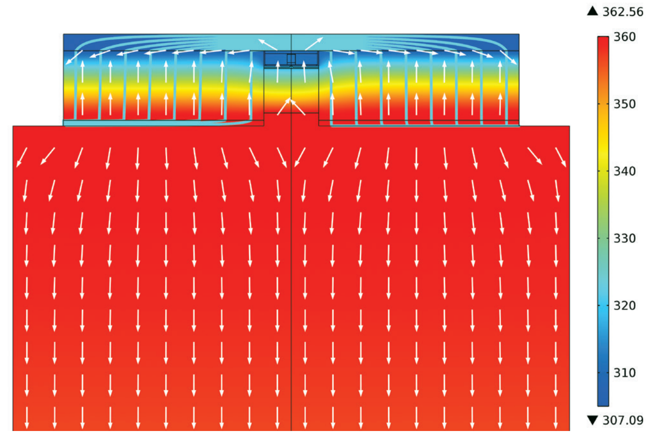

FIGURE 3: Multiphysics simulation of a laser with an integrated μTEC where temperature (surface plot), current density (streamlines), and heat flux (surface arrows) are shown.

materials are those in which a temperature difference is created when an electric current is supplied to the material, resulting in one side of the material heating up and the other side cooling down to provide heat pumping against an adverse temperature gradient. This effect can be employed to provide high-precision temperature control of photonics devices and forms one of the core building blocks within a novel architecture called a thermally integrated photonics system (TIPS), as depicted conceptually in Figure 1. Using the TIPS architecture, the team has simulated the electrical, optical, and thermal performance of new laser devices with the integrated microthermoelectric coolers (μTECs), as shown in Figure 2. Such μTECs have the potential to be applied in telecommunication laser devices that require cooling to maintain their design output wavelength, output optical power, and data transmission rates. Simulation results from COMSOL Multiphysics are shown in Figure 3 and help optimize the system design. The challenges in cooling photonics devices include precise temperature control, extremely high local heat fluxes, and micrometer-size features that need to be cooled. In particular, the research team investigated how precise temperature control and refrigeration are maintained in these systems through μTECs that are integrated with semiconductor laser architectures.

"COMSOL is the best simulation software solution for simultaneously solving all the physical processes associated with advanced photonic integrated circuits," says Shenghui Lei, one of the Bell Labs team members looking at photonics cooling. "The reason for this is that thermoelectric effects—Peltier, Thomson, and Seebeck—and the resulting temperature and electrical fields are all coupled within the same simulation environment, COMSOL. This provides deeper physical insight into the problem."

Another key COMSOL functionality is the link between COMSOL and MATLAB® through the LiveLink™ interface. This link lets the team accelerate the design phase by accurately modeling different parts of the package with design rules in MATLAB®.

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> **—SHENGHUI LEI, BELL LABS**

"If we look at the length scales of typical lasers used in photonics devices, you are talking about micrometers to tens of micrometers," says Ryan Enright, TIPS technical lead at Bell Labs. "However, laser performance is coupled from that scale all the way up the thermal chain until you get to the ambient air on the board. Solving complicated multiphysics problems across multiple length scales is computationally expensive. So we value the functionality of being able to use COMSOL and MATLAB® together to provide insight into the role of system design on laser performance in a computationally efficient way."

Domhnaill Hernon, Research Activity Lead at Alcatel-Lucent, further explains that, beyond just capturing the thermal behavior of integrated thermoelectrics, by carefully validating simulations against experimental device performance data it's also possible to more precisely determine the region of

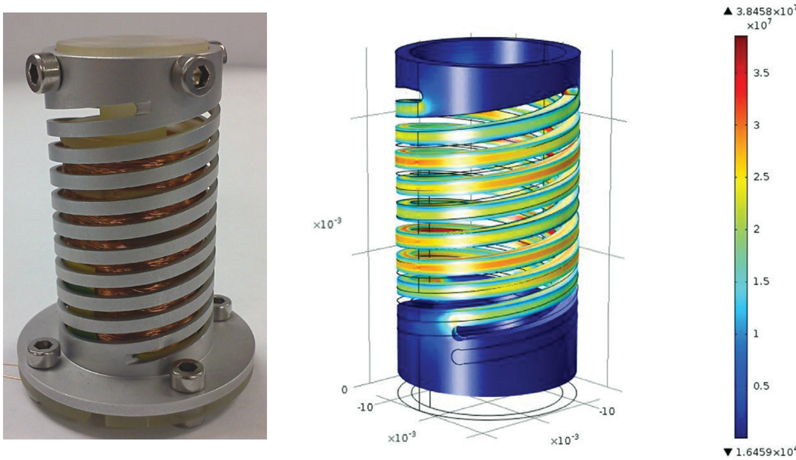

FIGURE 4: Left: Prototype of novel machined-spring energy harvester. Right: Simulation of the energy harvester, showing von Mises stress.

the laser device that caused the heat generation in the first place.

"It's the capability of accurately modeling the heat generation source and then coupling that to the device- and system-level cooling solutions where we see the power of COMSOL," says Hernon.

» OPTIMIZING A NEW ENERGY-HARVESTING DEVICE

PHOTONICS COOLING IS not the only way that Bell Labs is addressing energy concerns. Simulation is also enabling wireless sensors to be powered autonomously, reducing the need to frequently replace batteries in a network. Large-scale commercial deployments of wireless sensors have been hindered by costs associated with battery replacements.

The Bell Labs Energy Harvesting team developed a solution that efficiently converts ambient vibrations from motors, AC, HVAC, and so on to useful energy. In this way, a wireless sensor can potentially be powered indefinitely. Energy-harvesting technology can be employed in many different ways with low-power wireless sensors in applications ranging from monitoring energy usage in large facilities to enabling the large-scale sensor deployments of the future Internet of Things (IoT).

The energy-harvesting devices

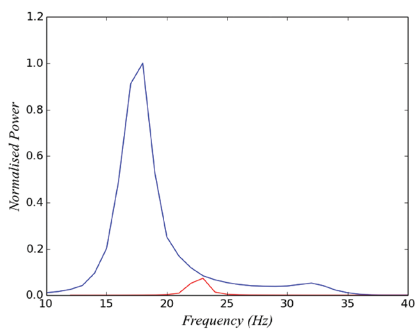

FIGURE 5: The figure compares the Bell Labs design (blue line) with a similar state-of-the-art single-mass system (red line). The multiple-mass system designed by Bell Labs has 11 times greater peak energy.

designed at Bell Labs operate by converting vibrations into electricity thanks to electromagnetic induction. Traditionally, energy harvesters consist of a single magnet that moves inside a coil, thus inducing a current.

The team employed simple physical principles: the conservation of momentum and velocity amplification. The design they developed uses multiple masses, or what is called multiple degrees of freedom, and can significantly amplify the velocity of the smallest mass in the system. This novel energy-harvesting device is now being investigated, as it is more efficient at converting ambient vibrations into electrical current than similar technology that does not employ the multiple-degree-of-freedom approach.

COMSOL is used for modeling the magnetic, electrical, and structural behavior of this system. See Figure 4, left for a picture of the energy harvester prototype and Figure 4, right for simulation results.

"We are using COMSOL to examine the electromagnetic coupling and the magnetic field distribution," says Ronan Frizzell, the lead researcher on this topic. "We've used the parametric sweep capabilities of COMSOL to optimize the system configuration and better understand the system dynamics."

A parametric sweep allows for the understanding of how the performance of the system is affected if you change one of its components, such as a spring or a magnet orientation. Figure 5 shows experimental results for the novel energy-harvesting device whose design process made use of COMSOL to achieve an enhanced understanding of the system dynamics involved.

"Reasonably quickly we can go through a parametric sweep, and by that I mean looking at structural, electrical, and magnetic parameters that are important to the system and how they couple together and affect each other," says Hernon. "That's very important. We don't look at them separately, but we use COMSOL to look at them in a coupled way. It's important for optimizing the system for real-life deployment."

While these technologies are not yet in commercial use, Hernon and his colleagues are confident they are getting a level of accuracy in the models for these new technologies that could only have been reached before by using much more time-consuming and laborious methods. At this pace of development, Hernon believes that the new thermoelectric cooling methods and innovative energy-harvesting devices should see commercial use in as little as five years. ◎