UNDERSTANDING BRILLOUIN OPTOMECHANICAL INTERACTION WITH MULTIPHYSICS MODELING

Researchers from the University of Campinas and Corning use electromagnetics and solid mechanics analysis to investigate a different kind of coupling: how photoelastics and moving boundary effects work together to enhance or suppress Brillouin scattering in waveguides, optical fibers, and other nanophotonic structures.

By **BRIANNE CHRISTOPHER**

OPTICAL WAVEGUIDES HAVE CHANGED a lot since the 1970s. The waveguides were larger then, and scientists had just discovered that, especially for optical fibers, photoelastic effects were important in a design. With the introduction of the field of optomechanics, the moving boundaries of the waveguides also needed to be taken into account. Researchers realized that there was a complex interplay between both effects that could be tweaked to either increase or downplay Brillouin scattering effects in a design. Brillouin scattering is the interaction between light and the material waves in a medium, named after Léon Brillouin. A research group from the University of Campinas and Corning has been using multiphysics simulation to investigate this coupled effect and how it can be used to optimize nanophotonic structures.

» A TALE OF TWO EFFECTS

BRILLOUIN OPTOMECHANICAL INTERACTION involves a coupling between two effects. First, there is the moving boundary effect, in which just the boundary or geometry of the device is considered. In general, the moving boundary effect comes into play, for instance, when making a waveguide thinner. The photoelastic effect, on the other hand, considers the materials involved. Here, it is the refractive index in the waveguide that is modified due to elastic strain in the material.

Think about the design of a tapered optical fiber. Every time you perturb the geometry, it affects the Brillouin optomechanical scattering occurring in the design. This is the moving boundary effect. The photoelastic effect considers the materials of which the fiber is made, which also affects the interaction.

» TO ENHANCE OR SUPPRESS: THAT IS THE QUESTION

WHEN ACCOUNTING FOR BRILLOUIN SCATTERING in an optomechanical design, you often want to either enhance or suppress the effect. For example, in a regular optical fiber, Brillouin scattering is an impairment in communication systems that causes a lot of light to scatter backward instead of propagate forward. This could mean that little to no light travels through the fiber from its input source. Examples where this is an important design consideration include regular fibers and accelerometers (Figure 1).

So, when would you want to enhance Brillouin scattering effects? One example is on integrated waveguides. For instance, you can manipulate the mechanical interactions in these waveguides to create a narrow-bandwidth laser, or use Brillouin scattering to specify frequencies and wavelength channels for an exceptionally accurate filter.

At the Photonics Research Center in the University of Campinas and Corning Research & Development Corporation, professors Gustavo Wiederhecker, Paulo

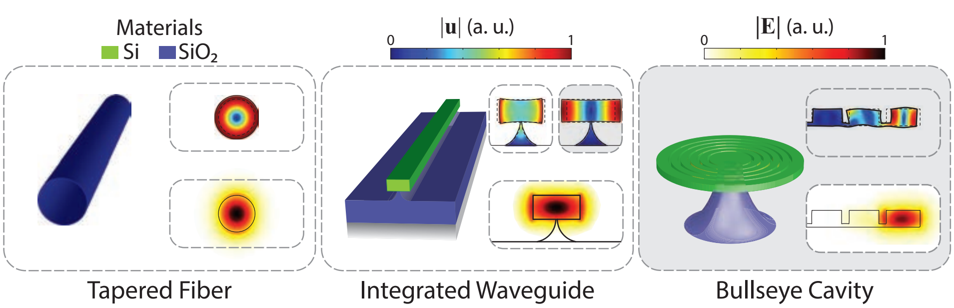

Figure 1. A COMSOL Multiphysics® model of Brillouin scattering in a nanophonic structure, including a tapered fiber (left), integrated waveguide (center), and bulls-eye cavity (right).

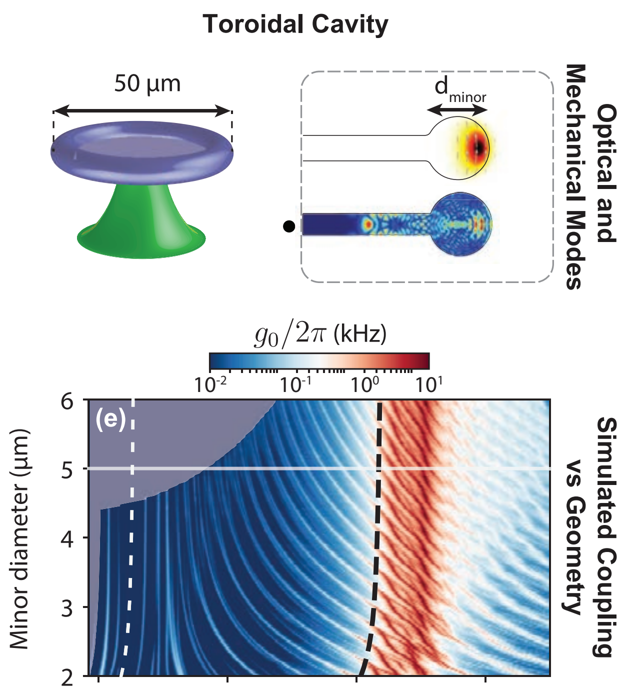

Figure 2. Top: A full example of the use of COMSOL Multiphysics. A model for the toroidal cavity is used to simulate both the optical and mechanical modes. Bottom: The coupling between these two modes is then simulated for a series of different geometries.

Dainese, and Thiago Alegre aimed to understand the coupling between boundaries and materials that causes Brillouin optomechanical interaction. One of their main goals was to understand the coupling of the photoelastic effect and moving boundary effect in nanophotonic structures to set up more effective (or, in some cases, ineffective) couplings, depending on whether the device calls for enhanced or suppressed Brillouin scattering.

MULTIPHYSICS SIMULATION OF BRILLOUIN OPTOMECHANICS

HOW DID THE TEAM from the University of Campinas gain a deeper understanding of this complex interplay? One way is through the use of multiphysics simulation. The team used the COMSOL Multiphysics® software to model the coupling of photoelastic and moving boundary effects, and the resulting Brillouin scattering, in nanophotonic structures. They started with 2D simulations that are both easy to simulate and good observatory examples. "2D models are very quick to solve," says Alegre. They started with simple examples, like a single silica rod, and integrated both electromagnetics and solid mechanics physics into their analyses — eventually building up to fully integrated nanophotonic structures (Figure 2). The team then used their simulation results to calculate the overlap integrals between optical and mechanical fields, one of the main aspects of Brillouin scattering. "Once you have access to these integrals, you can understand and plot optomechanical integrands, which is very helpful," says Alegre. "COMSOL Multiphysics® is one of the only software [products] that gives us access to this type of analysis."

The University of Campinas team found a few features of the COMSOL® software particularly useful, the first being the multiphysics capabilities. Solving for both photoelastic and moving boundary effects in the same study makes it easy to integrate them, compared to solving for one physics, exporting the results, going back and solving for the other, and so on.

Another helpful tool is the user interface (UI) in general. "Using the interface in COMSOL® is very nice," says Alegre, adding that after running a simulation, "right away, we have the relevant coupling coefficient right in the user interface."

> *"Using the interface in COMSOL® is very nice. Right away, we have the relevant coupling coefficient right in the user interface."*
>
> **—THIAGO ALEGRE, UNIVERSITY OF CAMPINAS**

The team also enjoys that postprocessing features are available directly in the UI. "With any other software, you have to write postprocessing code along with all of the integrals," says Alegre. COMSOL Multiphysics, on the other hand, includes postprocessing as part of the modeling workflow.

GUIDING LIGHT TOWARD FUTURE RESEARCH

AS FOR FUTURE RESEARCH, the University of Campinas team plans to explore the effect of different materials on the optomechanical coupling as well as look into the hybrid integration of materials in nanophotonics. They also plan to investigate different geometries for the design of better waveguides, seeking good candidates for Brillouin scattering devices.

In addition, as the home base of their research is an academic institution, the team is also thinking about how to inspire and involve the next generation of nanophotonics researchers, namely, their students. To do so, the team created a data repository to go along with their Brillouin scattering project, "Brillouin optomechanics in nanophonic structures," APL Photonics 4, 071101 (2019). The repository includes their models and codes, which students can use to change the geometry of a waveguide or cavity. By seeing Brillouin optomechanical interaction in real time, students can potentially develop some bright ideas of their own. ◎