Using demand-controlled ventilation at large facilities such as CEA-MINATEC can help significantly cut energy costs.

Optimization Slashes Energy Consumption in Silicon-Based MEMS CO_2 Detectors

Demand-controlled ventilation, where incoming air is brought into buildings based on actual occupancy, relies heavily on CO_2 sensors. Modeling is helping to make them smaller and less expensive.

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Adequate ventilation with outdoor air is essential for occupants living or working in buildings. In fact, building codes require that a minimum amount of fresh air be provided to ensure adequate air quality because inadequate fresh air can have detrimental effects on building occupants and reduce their productivity. To comply with regulations that require certain levels of fresh air, ventilation systems have traditionally drawn in air at a fixed rate based on an assumed occupancy, and generally more fresh air enters buildings than is necessary. This results in higher energy consumption and costs because the incoming air must be heated in the winter and cooled in the summer.

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In the last decade, there has been a strong trend towards DCV (demand-controlled ventilation) systems based on CO_2 sensors. These monitor actual occupancy levels and air quality so that the ventilation system draws in only the amount of fresh air actually needed. Studies have found that such methods can often drop energy consumption associated with ventilation by more than half compared to a fixed rate of air intake.

Low-Cost CO_2 Sensors

One key to the widespread use of this technology is low-cost CO_2 sensors. One group working on this task is the Optics Department of CEA-MINATEC, an international center for micro and nanotechnologies with 2400 researchers; it is part of CEA, a French government-funded technological research organization. There researchers are working with an industrial partner to develop silicon-based MEMS CO_2 sensors that use optical detection. Such a sensor will run at very low current so that it can be left in a building for many years without the need to replace batteries. Such a sensor typically takes a reading five to ten times per hour, and a measurement requires only approximately 100 µJ of energy.

In addition, they should cost considerably less than conventional CO_2 sensors in use today, which generally sell for several hundred dollars each, and allow the widespread adoption of this technology.

The overall sensor functions in this way: first, a filament is heated to a specific temperature (650 °C) so it emits most of its infrared radiation near a specific wavelength, 4.2 µm. The ambient CO_2 absorbs much of this energy, and the remaining infrared radiation is detected to allow calculation of the amount of CO_2.

The Optimum Geometry

The current focus of our research based on COMSOL Multiphysics is finding the optimum geometry for an energy-efficient filament. This element is the sensor’s primary energy consumer and our goal was to optimize its design to consume as little power as possible. We are optimizing the design of the filament to avoid hot spots on the freestanding micro hotplate that

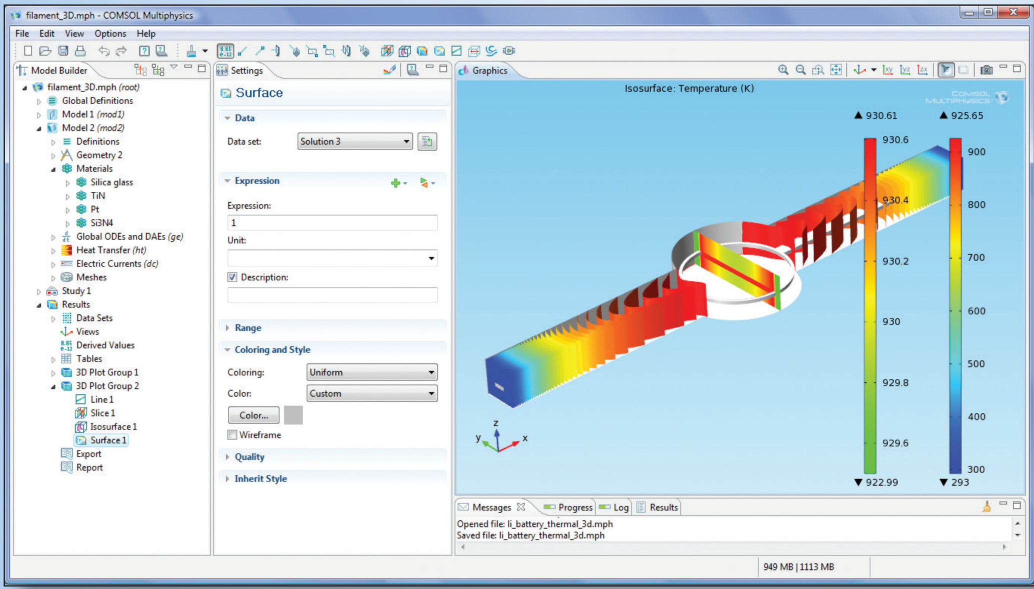

Figure 1. The image shows the temperature distribution throughout the sensor; temperature in the conductive tracks is visualized with isosurfaces (right colorbar), temperature in the filament is visualized using a sliceplot through the center of the filament (left colorbar).

is made of Si_3N_4/SiO_2 layers supporting TiN/Pt/TiN tracks.

In the sensor, the filament serving as the thermal source is located in a disc roughly 100 microns in diameter (Fig. 1). When raised to 650 °C, it emits most of its radiation near the desired wavelength of 4.2 µm. Because the wavelength is very sensitive to temperature, homogeneity of temperature across the entire filament is crucial. If we overheat the filament at some position, energy is wasted and the device could suffer failure in hot spots. If there are points in the filament with a temperature that is too low, it won't get energy at the required 4.2 µm. As for the width and relative locations of the three circular filaments' tracks, it is important to optimize these aspects. For instance, if a track is too thin, this radiative element won't emit at the right temperature.

The width of the arms is also important because the resistivity and thus current flow varies with the geometry. They must be wide enough to avoid Joule heating (which is desirable in the conductive tracks but not here), but they cannot be too wide or else the thermal resistivity drops and excess heat flows away.

2D Works Just as Well as 3D

For our studies, we initially created a 3D model, but for the optimization we chose to use a 2D simplification that is easier to set up and requires less computing resources (Fig. 2). In the 2D model we introduced an equivalent conductivity of the layers that doesn't account for thermal diffusion processes arising in the upper layer of the actual structure and it thus exaggerates the influence of the heating tracks. Even

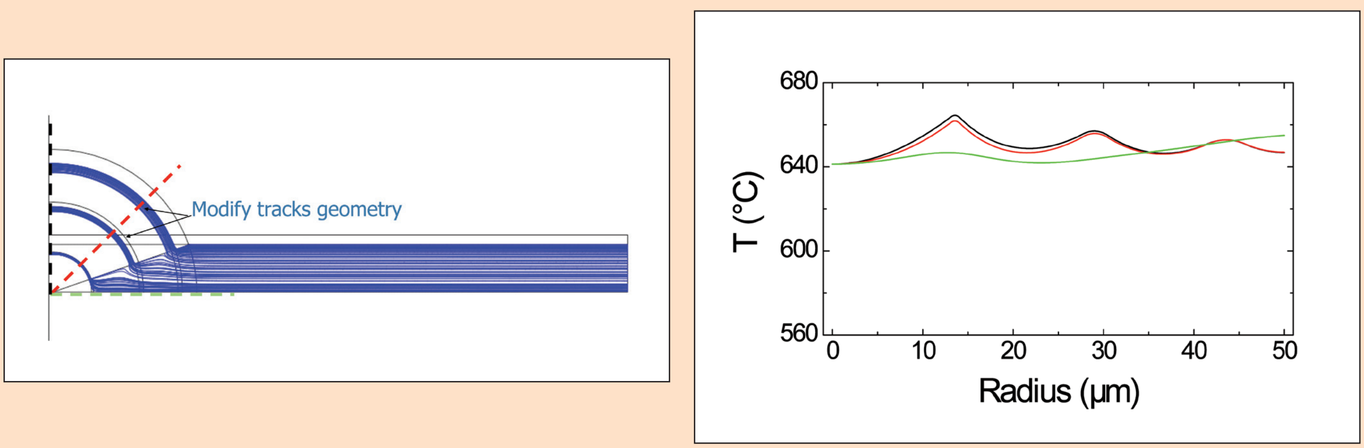

Fig. 2. Optimized track geometry obtained with the 2D optimization model; the temperature profile on the right corresponds to the location of the dashed lines. As desired, the temperature is very stable across the geometry.

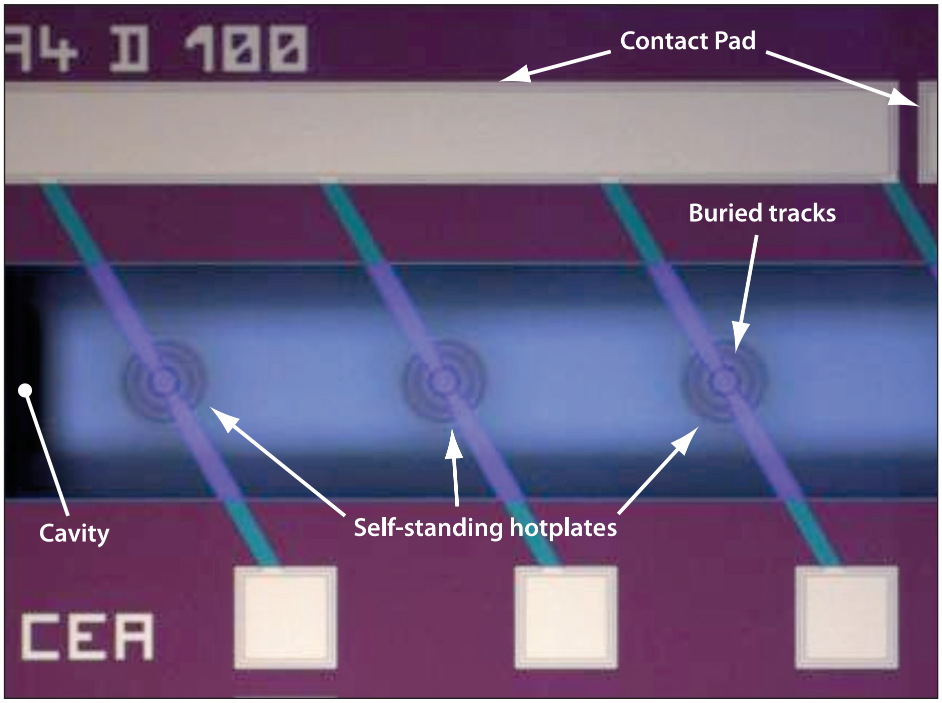

Figure 3: Photograph of the actual sensor. (Photo courtesy of CEA-MINATEC)

so, we found that the simplified approach provides a temperature profile comparable to the 3D model; when we plotted temperature for the desired point in the geometry for both cases, the value was essentially the same. This gave us the confidence to continue with the optimization using the 2D geometry.

Next we moved on to the optimization process itself. Here we had a number of parameters to work with: the positions of the three circular tracks, the widths of the two outer tracks (the inner track's width is imposed by lithography as well as process and performance requirements), and the thickness of the conductive tracks on both sides which determines their resistance and thus the proper voltage to apply.

To run this optimization, we turned to COMSOL's ALE (Arbitrary Lagrangian-Eulerian) method, which is an intermediate between the Lagrangian method (where the coordinate system follows the material as it deforms) and the Eulerian method (where the coordinate axes are fixed in space). ALE combines the best features of the two methods upon which it is based: it allows moving boundaries without the need for the mesh movement to follow the material. We found that through the optimization process and with prototypes (Fig. 3) that the temperature dispersion along the filaments has dropped from ±20 °C to ±10 °C; further, we have been able to cut energy consumption by at least a factor of two. Further, I have come to appreciate COMSOL's ability to allow engineers to perform applied physics, and thus I expect that the software will soon integrate geometric optimization without the need for the ALE method.

Moving Towards Commercialization

We are working with an industrial partner to commercialize this sensor technology, but we don't expect it to reach the market for a year or more. It depends on the success of many other sensor elements; for instance, the filter for detecting only the desired radiation is a key point. Here, too, we can use COMSOL to help us gain better understanding of the problems and how to solve them.

Choosing COMSOL for this study was an obvious choice for me. I've been a longtime user having started with very early versions, and I've used it enthusiastically for many projects. I'm doing physics not computations. I appreciate COMSOL's ability to test my vision and not the ability of my PC to do something. Among some recent projects were to model double-gate MOSFETs and to examine emerging techniques for increasing the capacity of optical storage devices. More than 50 people at MINATEC are involved in simulation, and plenty of them are turning to COMSOL. ■

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About the Author

Serge Gidon is a research physicist at the Optonics Department of MINATEC, which is an applied research laboratory of the French Atomic and Alternative Energy Commission (CEA) that is devoted to the development of micro- and nanotechnologies. He received an undergraduate degree in electro-technical engineering at the National College of Grenoble and a post-graduate diploma in optical instrumentation at the University of Grenoble. After 12 years working on large optical facilities at CEA, he joined LETI (one of the MINATEC labs) and for the last 16 years has participated in projects involving optical microsystems, micro lasers, bolometer images, data-storage discs and more recently optical sensors such as gas detectors.

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