Multiphysics Analysis of Infra Red Bolometer

J. Thomas[1], J.S. Crompton[1]*and K.C. Koppenhoefer[1]
[1]AltaSim Technologies, Columbus, OH

*Corresponding author: 130 East Wilson Bridge Road, Suite 140, Columbus, OH 43085, jeff@altasimtechnologies.com

Abstract: Bolometers are used in a number of applications including night vision cameras, astronomy, and particle physics to measure the power of incident electromagnetic radiation. The general principle of operation is that a strip of conducting material is exposed to incident electromagnetic radiation, energy is absorbed and the temperature of the material rises. The resulting reduction in electron mobility manifests itself as a reduced electrical conductivity. With a bias current already flowing through the strip the reference potential is known and any change in conductivity causes a change in the reference potential which can be related to the amount of incident electromagnetic radiation. To explore the effect of bolometer designs on detection of incident electromagnetic radiation, a computational model of a bolometer was developed using COMSOL Multiphysics ®.

Keywords: bolometer, parametric design, radiation detection, sensor, sensitivity

1. Introduction

Bolometers are designed to detect incident radiation. Depending on the rate of change in the absorbing material's electrical resistance with temperature and specifics of the bolometer design, temperature changes less than 0.0001°C can be detected for good designs. This paper describes the development of a parameterized computational model of a bolometer in COMSOL Multiphysics to aid the improvement of the sensitivity of these bolometers.

The principal of operation for bolometers is shown in Figure 1. As radiation hits a conducting absorber that is insulated thermally from the rest of the unit, the temperature of the absorber rises relative to the rest of the unit. The absorber is mounted to a dielectric material which serves the dual function of a heat sink and an electrical insulator. The electrical conductivity of the absorber changes with temperature change and the current flow of a bias current is altered and detected by a voltmeter. This change in voltage is related to the power of the incident radiation thereby enabling the device to function as a sensor.

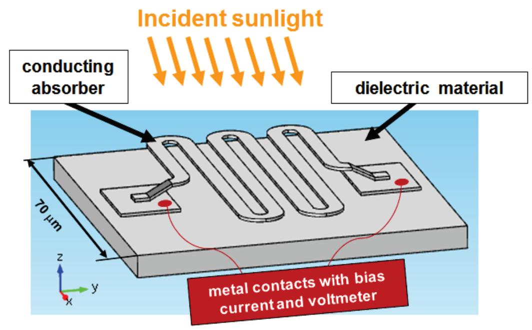

Figure 1. Bolometer model geometry and materials showing incident radiation.

2. Use of COMSOL Multiphysics

The functioning of these devices is based on three main physical phenomena: radiation through the ambient environment, heat transfer within the solid parts and conservation of electric currents. Because of the multiphysics nature of the device, COMSOL Multiphysics is well-suited for modeling, testing, and designing these devices. Additionally, when the incident electromagnetic radiation is associated with sunlight the external radiation source can be defined via the solar position option in which the direction and intensity of the sun's incident radiation is based on the latitude and longitude position on the Earth, the date, and the time. This helpful feature is available within the Heat Transfer Module.

2.1 Governing Equations and Boundary Conditions

For modeling the actual bolometer, the heat transfer and electric currents equations are coupled together and solved simultaneously because of their intimately coupled nature. The bi-directional couplings are:

1. The electrical conductivity: σ, is temperature dependent
2. The resistive heating, Q, is a function of the voltage gradient; this is also known as Joule heating

Figure 2 shows schematically how the equations are linked; the heating term, Q, also includes a contribution from the incident light on the top boundary of the strip which drives the functioning of the device.

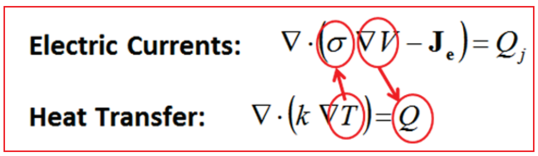

Figure 2. Governing equations with schematic of multiphysics couplings.

The solver set-up within COMSOL is able to solve these sets of equations simultaneously (using either the Fully Coupled solution approach or the Segregated solution approach a.k.a. the Partitioned approach).

For convenience and to test realistic sunlight conditions, the incident radiation heating term can be simulated using the solar source position functionality within the external radiation heat source available with the Heat Transfer Module. For the purposes of this technology study, a uniform normal heating term of 100 W/m^2 is applied as a smoothed ramp function that ramps for 0 to 100 over a time duration of 0.1 seconds as shown in Figure 3. See Section 4 for proposed future studies for changes in the light source.

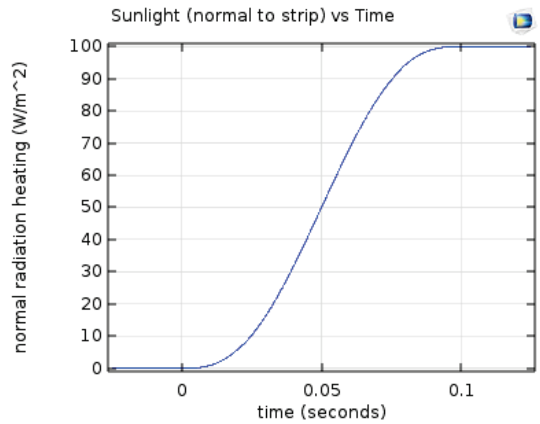

Figure 3. Radiation heating as a function of time

The temperature at the bottom boundary of the device is fixed at an operating temperature of 25[K]. A convective heat flux of 3 W/(m^2*K) is applied to all other boundaries to approximate a small cooling effect due to the cooled air within a bolometer package. Depending on the material selection of the strip material, some bolometers may be able to operate at room temperature. For the copper material selection, cryogenic temperatures are needed for maximum sensitivity (See Section 2.3).

One of the contact strips is grounded in an electric sense and the other contact has a specified bias current equal to 100 μA to fully define Ohm's law for electric currents. The dielectric base material is insulating electrically.

2.2 Parametrized Geometry

Good bolometer design seeks to maximize the sensitivity of these devices. Research has shown a number of design parameters can have an effect on sensitivity including the strip spacing, surface area of the strip, aspect ratio of the strip, material selection, as well as the operating temperature of the bolometer. The loft feature available with the COMSOL Multiphysics v5.1 Design Module add-on enables the parametrization of the strip spacing parameter defined in Figure 4.

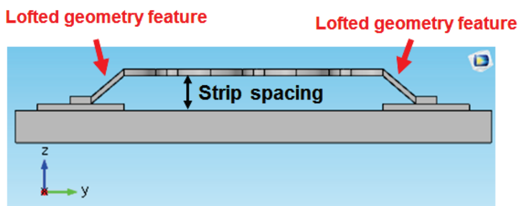

Figure 4. Geometry side-view with lofted geometry feature enabling automatic parametrization of strip spacing and computation of sensitivity with respect to strip spacing.

2.3 Material Selection

Bolometers show greatest sensitivity when operating in a regime in which the absorbing strip material shows a strong dependence of conductivity to temperature. Depending on the material chosen for the absorbing strip, some bolometers may be more sensitive when operated at cryogenic temperatures. The results shown here are for a copper material with temperature dependent material properties available under the COMSOL Material Library which shows a strong dependence of conductivity to temperature in the 10-50 K range (see Figure 5). This bolometer is most sensitive when the operating temperatures are kept within this range. In contrast, specialty materials that are conductivity-sensitive at room temperatures are also available.

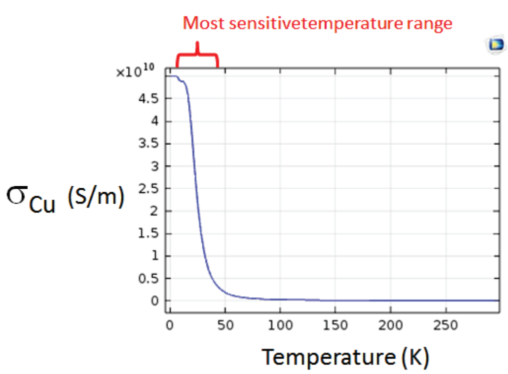

Figure 5. Governing equations with schematic of multiphysics couplings.

2.4 Meshing

The default COMSOL physics-controlled mesh was used to generate a free tetrahedral mesh. A custom meshing sequence was deemed unnecessary for this technology demonstration. A custom meshing sequence could be developed for more efficient analyses for specific applications. Figure 6 shows a representative mesh for a strip spacing of 0.048 m.

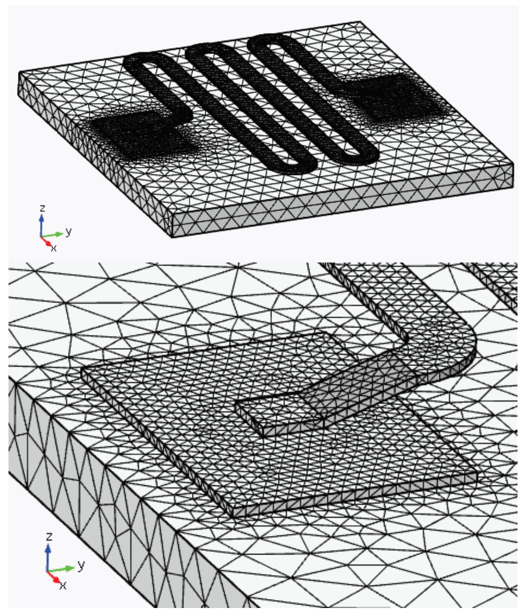

Figure 6. Tetrahedral mesh for strip spacing of 0.048 m.

2.5 Solution Approach

The default solver set-up with COMSOL for the coupled electric currents and thermal problem is the Segregated solver approach (single simultaneous step) with an iterative linear system solver used to solve the current sub-step and a direct solver used for the thermal sub-step. Relative and absolute tolerances are specified to allow for converged results within 1% allowed error in the numerical solution. The time dependent solver uses the BDF method to step in time for total duration of 0.2 seconds. As mentioned before, the heating term is ramped over 0.1 seconds from a value of 0 to 100 W/m^2. The time parametric auxiliary sweep function with the solver is was used to sweep for different operating temperatures to confirm maximum sensitivity at an operating temperature of 25 K. The Parametric Sweep of the strip spacing geometry parameter is set-up to automatically sweep time dependent solutions for the different geometry configurations and store results with a single solution file for post-processing of all design options.

3. Results and Discussion

Representative results are presented below for temperature (Figure 7), current flow (Figure 8), and the change in voltage due to the sun's heating off the top boundary of the strip (Figure 9) at time of 0.2 seconds.

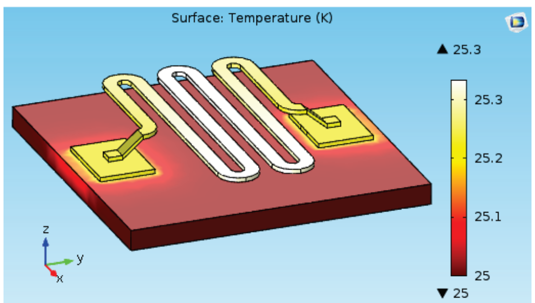

Figure 7. Temperature contour plot at 0.2 seconds.

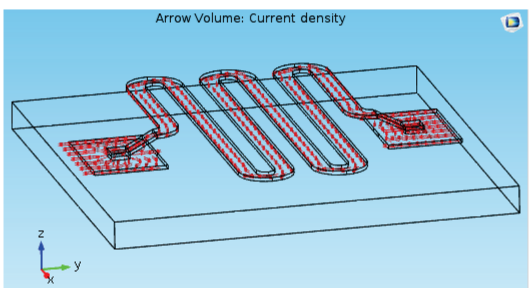

Figure 8. Current flow at 0.2 seconds.

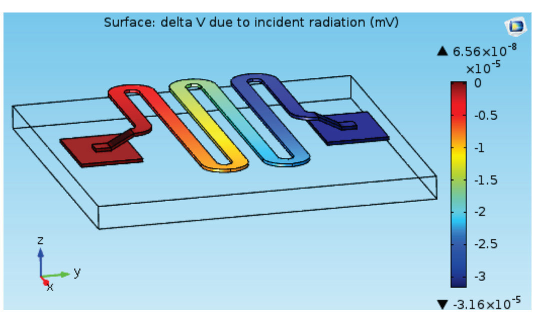

Figure 9. Change in Voltage due to incident radiation at 0.2 seconds.

An important design parameter for bolometers is sensitivity, *S*, defined as change in voltage divided by amount of incident light wattage absorbed:

$$S = \frac{dV_{voltmeter}}{dW_{absorbed}}.$$

As mentioned before, good bolometer design seeks to maximize this sensitivity. A parametric sweep was performed for a series of strip spacing values. The effect of strip spacing can be seen in Figure 10, with increasing space between the mounting board and the serpentine absorber the sensitivity of the bolometer increases. This phenomenon is consistent with the operation of the device that seeks to establish the conducting absorber as a thermal isolator. (Sensitivity is normalized by initial voltage drop because the voltage drop changes when the length of the serpentine geometry changes due to the change in the strip spacing.)

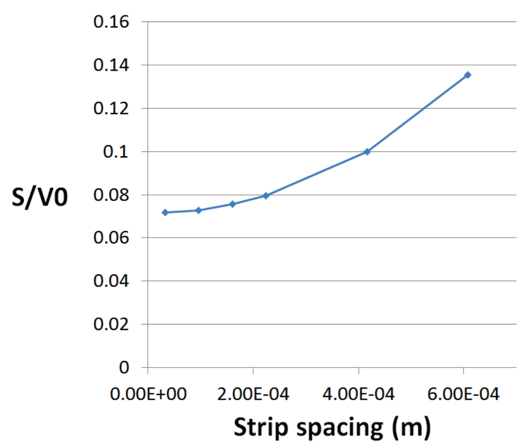

Figure 10. Strip spacing

4. Further Research

Extensions of studies of this type have been used to develop customized bolometer designs to meet the requirements of specific applications. Further use of this particular model could explore the effect of other important design parameters on the sensitivity of the bolometer and be used to develop a custom solution for additional specific applications. Important parameters to be studied include serpentine geometry (particularly aspect ratio), strip material selection, bias current magnitude, and incident radiation power to be detected. Additionally, the effect of realistic, non-normal radiation patterns could be tested using the Solar Position functionality.

5. References

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