Optimisation of Filament Geometry for Gas Sensor Application

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Abstract: Monitoring of indoor CO_2 concentration is of particular interest to detect room occupancy in order to optimise power consumptions of building. One technological approach is to use optical detection using specific absorption lines of CO_2 molecules in the infrared domain close to 4.2 µm. Key features for a wider use in public and private buildings are power consumption and price...
Such optical sensors include a detector, typically a micro-bolometer, an IR source – such as a hot filament – and a filter to select the interesting band in the black body spectrum of the emitter. All these components can be made in well known planar Si technology using MEMS approach. To fabricate a free-standing micro-hotplate, we chose Si_3N_4/SiO_2 as supporting layer and TiN/Pt/TiN for and heater layer.

Keywords: Optimisation, Electro-Thermal Model, Filament, Gas Sensor

1. 3D model

We designed the filament using COMSOL Multiphysics vers3.5a, considering electro-thermal models in which we exaggerate the z dimension for accuracy and restrict as much as we can domain by symmetry considerations, figures 1/a & b. To describe physical phenomena regulating heater behavior, we first developed a 3D model based on conductive and radiative thermal exchanges out of the micro-hotplate and taking in account the air convection as proposed by [1].

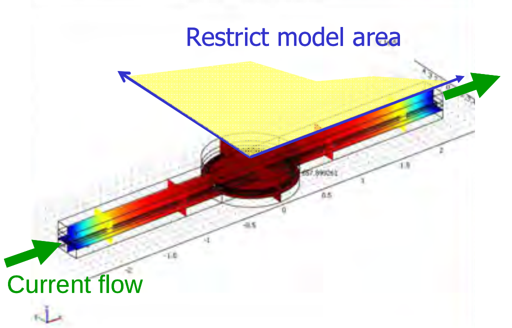

Figure 1/a. Filament appearance (z dimension magnified for better accuracy).

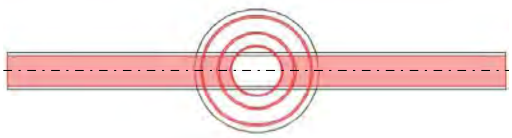

Figure 1/b. Filament conducting tracks shape (top view).

It gives an estimation of the temperature homogeneity depending on conductive tracks radius and width, figure 2. This model includes a ODE (Ordinary Differential Equation) that constrains the applied voltage ‘V0’ applied to the filament extremities, so that f(V0)=(T_probe-T_objective)=0. T_probe has been tested at the cross marks on figure 3. T_objective has been fixed to 650°C to fulfill technology consideration on the reliability.

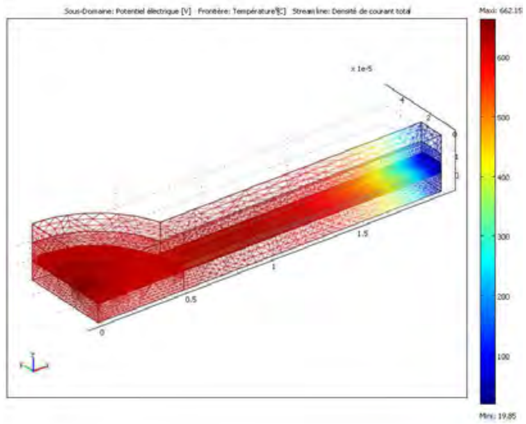

Figure 2. 3D model mesh imprint over temperature chart.

2. 2D model

Temperature homogeneity is requested to improve radiation efficiency while reducing consumption. Considering that we aim to optimise size and positions of the tracks to get best temperature homogeneity, we decided to downgrade the problem in a 2D model that will request less computing resources than the 3D one.
We introduce in this model, an equivalent conductivity of the overall layers considered them as being in parallel for the thermal and electrical conductivity considerations. This model can describe only the “front” thermal

losses of the structure and can't take in account for example thermal diffusing processes arising in the upper layer of the real structure, so that it emphasizes the local role of the heating tracks. As reported in figure 3, this approach gives a convincing temperature profile comparable to the 3D model.

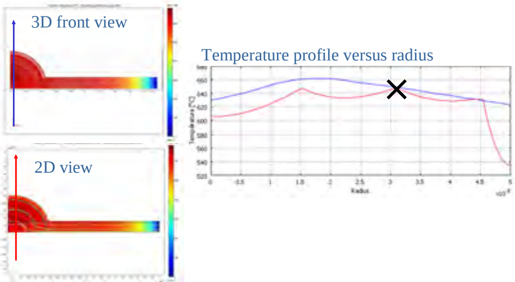

Figure 3. 2D model temperature profile (on a radius perpendicular to the filament length) compared to the 3D one. The cross marks the T_objective reference point.

3. Optimisation procedure

We introduced the optimisation procedure to get the lower temperature spreading on the radiating part of the filament modifying the conductive tracks geometry. To do so, we use COMSOL ALE module to modify the meshing with "Arbitrary Lagrangian Elements" and the Optimisation module. We used as variables the track radius and 2 over 3 of their widths (the third one – the inner and thinness, being considered as imposed by the lithography and technology process performances) and V0 the applied voltage to the filament. The function to minimize is the integral of $(T\text{-}T\_objective)^2$ on the circular radiating area.

Results of the optimisation show that the tracks are adequately distributed on the radiating area and that the largest is the thickest as presumed, figure 4/a. The temperature dispersion is lowered below ± 10°C, as shown in figure 4/b.

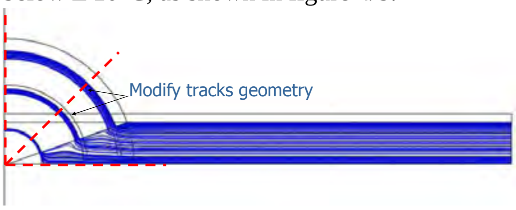

Figure 4/a. Optimized tracks geometry obtains with the 2D optimising model (dash lines show the cross sections considered for temperature profiles in figure 4/b).

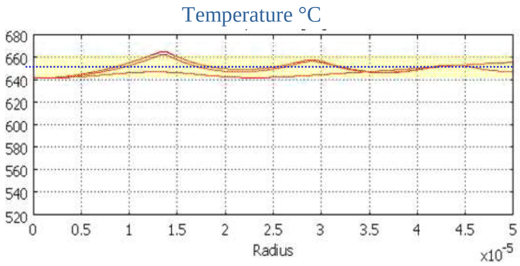

Figure 4/b. 2D model temperature profiles for different micro-hotplate cross sections (see figure 4/a).

4. Conclusions

We develop a 3D electro thermal model of the microfilament and a simplify 2D one to be able to do current tracks geometry optimisation using COMSOL Optimisation Module. We obtain good temperature uniformity on the radiating area and predict low consumption. The results of numerical modelling have been validated in real devices, as reported in figure 5.

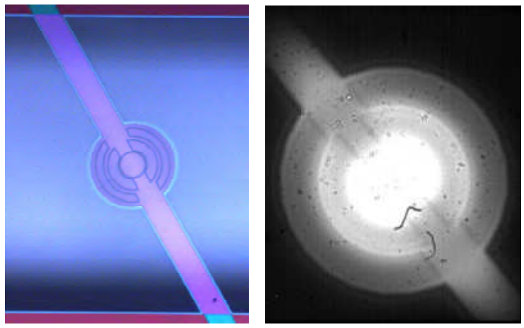

Figure 5. Microscopy images of the realized heated filament in optical (left) and IR (right) radiation domain (at 1.5µm wavelength).

5. References

1. E. Cozzani, "Material properties measurement and numerical simulation for Characterization of ultra-low-power consumption hotplates", Transducers & Eurosensors '07, 14th International Conference on Solid-State Sensors, Actuators and Microsystems, Lyon, France, June 10-14, 2007.