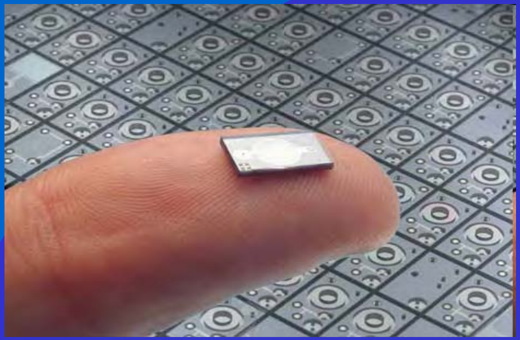
Presented at the COMSOL Conference 2010 India

2D Simulations and Electro-Thermal Analysis of Micro-Heater Designs Using COMSOL™ for Gas Sensor Applications

Presented By



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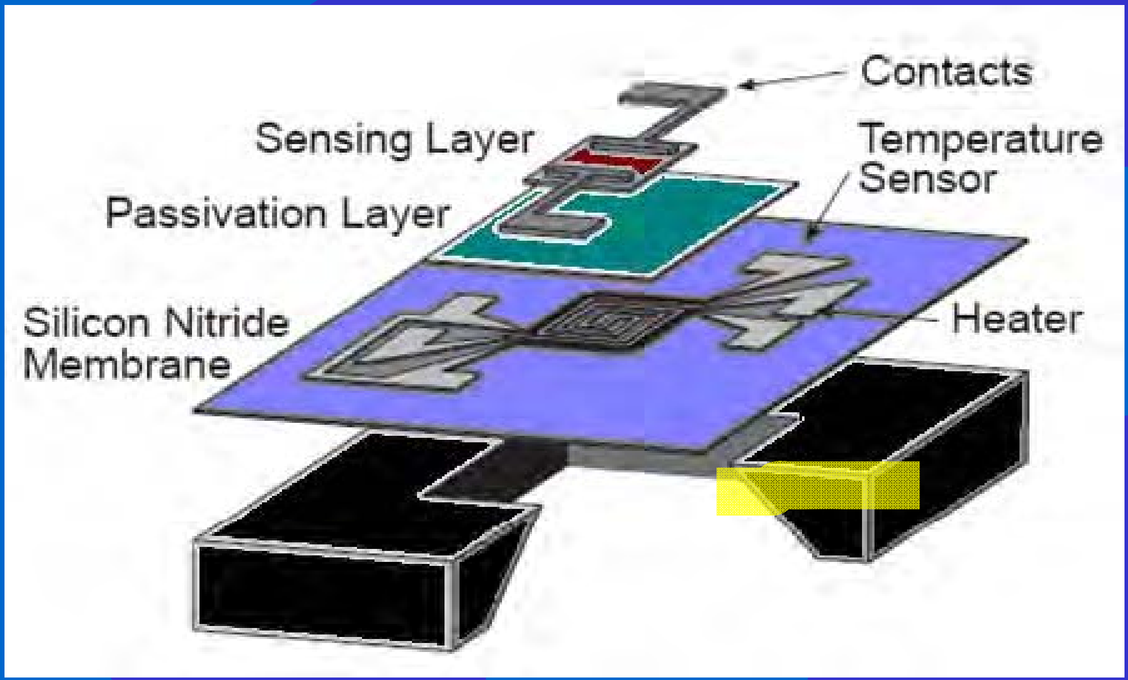
Integrated micro structure of a Gas sensor



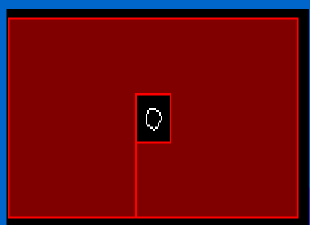
- Gas sensors are the devices which determine the information about the gas present and its concentration in an ambient gas atmosphere.
- Miniaturized gas sensors with a low power consumption for the detection of various gases such as CO,LPG and H_2 is very essential for a wide range of applications.
- The Micro-heater is the main component in gas sensors to make the sensing layer more sensitive and selective. Which is also a most power consuming part in gas sensors.
- Hence perfect design and fabrication of Micro-heater is an important aspect.

- Micro-heaters in gas sensors are basically resistive beams which can attain a temperature of 300^oC - 400^oC due to joule heating, when sufficient voltage is applied across them.

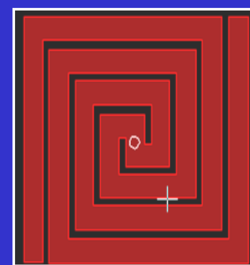
- The design of micro-heaters is optimized for…
  - low power consumption
  - low thermal mass
  - Better temperature uniformity across the device
  - enhanced thermal isolation from the surroundings

Micro-Heater patterns

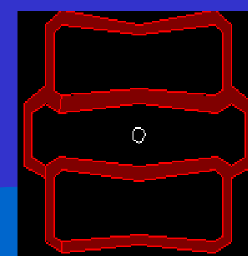
The Plane plate with central square hole



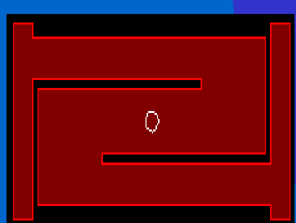
Double spiral



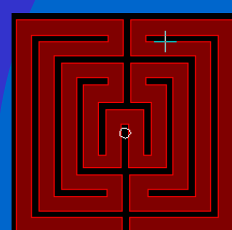
Honeycomb



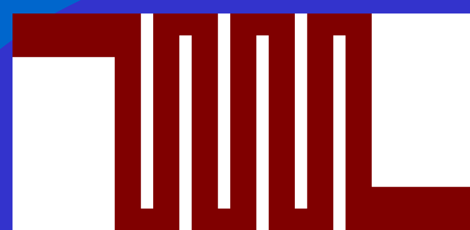
S-shape



Fan shape



Meander



Electro Thermal Mathematical modeling of microheater

- In Joule heating, the temperature increases due to the resistive heating from the electric current.
- The electric potential *V* is the solution variable in the Conductive Media DC application mode.
- The generated resistive heat *Q* is proportional to the square of the magnitude of the electric current density *J*.
- Current density, in turn, is proportional to the electric field, which equals the negative of the gradient of the potential *V*
- In our Simulations we assume the temperature and potential gradients in the z-direction (perpendicular to the heater plane) are small in comparison to the gradients in x-y plane. There by reducing the problems to two dimensions. This is a reasonable assumption given the relative dimensions of the structure; the thickness being much smaller than the length or width.

$$Q \propto |J|^2$$

$$Q = \frac{1}{\sigma}|J|^2 = \frac{1}{\sigma}|\sigma E|^2 = \sigma|\nabla V|^2$$

Over a range of temperatures the electric conductivity σ is a function of temperature T according to:

$$\sigma = \frac{\sigma_0}{1 + \alpha(T - T_0)}$$

where σ_0 is the conductivity at the reference temperature T_0. α is the temperature coefficient of resistivity, which describes how the resistivity varies with temperature. A typical value for platinum copper is 0.00385 per ^{o}C

- The coefficient of proportionality is the electric resistivity $\rho = 1/\sigma$, which is also the reciprocal of the temperature-dependent electric conductivity $\sigma = \sigma(T)$. Combining these facts gives the fully coupled relation.

- The equations have been solved under Dirichlet, Neumann, and mixed boundary conditions numerically using the Finite Element Method (FEM) when the Electro-Thermal module is selected in COMSOL^{TM}.

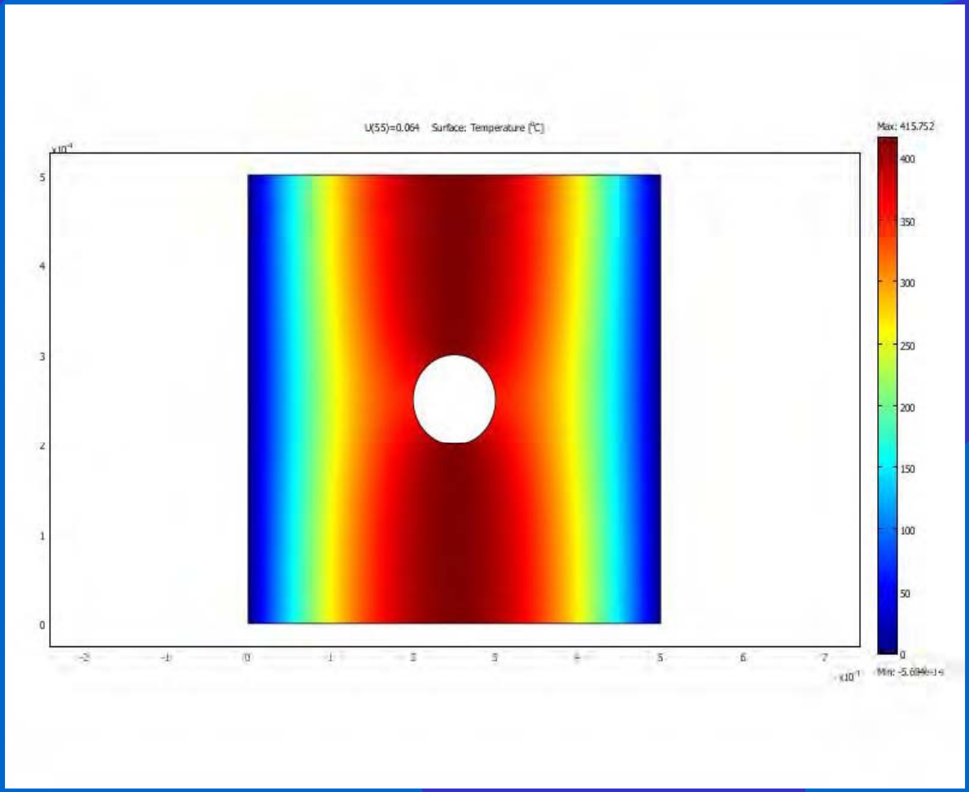
Meshing optimization

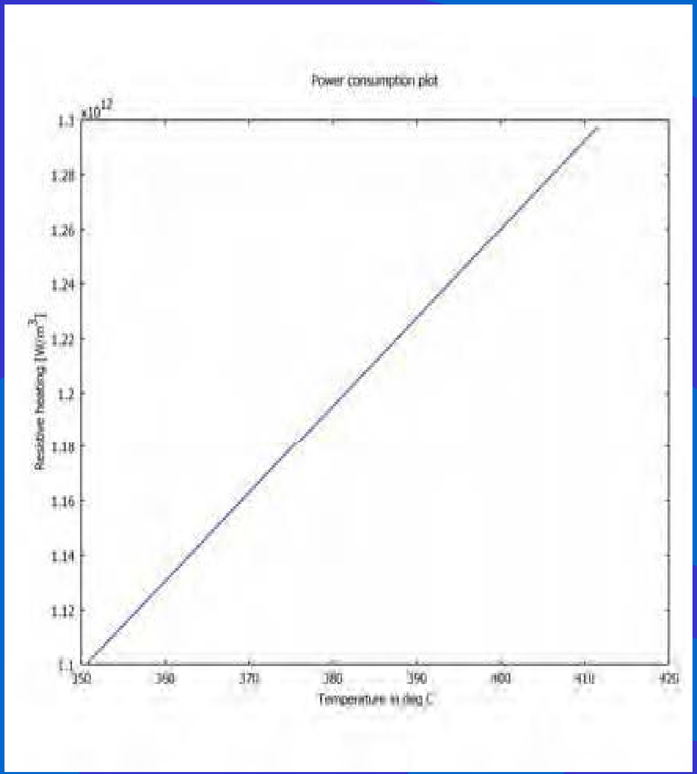
- The optimized meshing for the simulation is determined by performing an independent grid study to minimize the modeling error. When the change in the solution between subsequent stages of meshing refinement is considered to be negligible, the lower but still sufficient, mesh resolution is kept.

Material properties of layers used in the MEMS micro-Heater structure

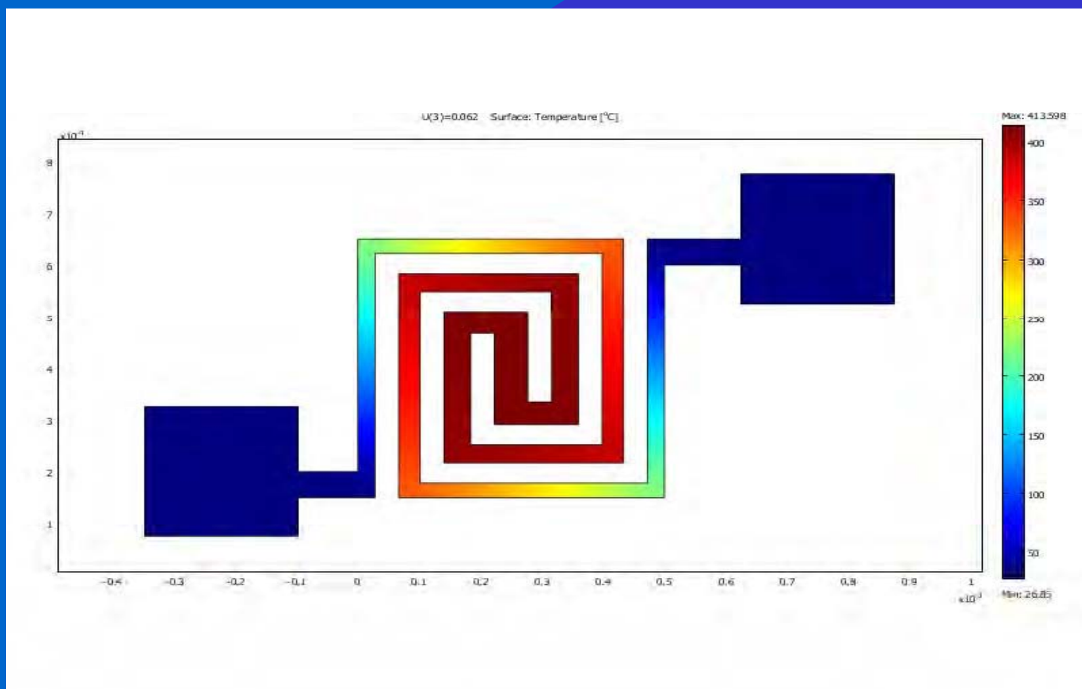
Material	**(Si)**	**(Si_xN_y)**	**(SiO_2)**	**(Pt)**
Thermal Conductivity (W/mK)	157	22	1.4	73
Young's Modulus (GPa)	190	290	73	170
Poisson's Ratio	0.17	0.24	0.20	0.39
Thermal expansion (1/K)	2.33e-6	2.33e-6	0.55e-6	8.9e-6
Density (kg/m^3)	2.32e3	3.1e3	2.2e3	2.145e4
Heat Capacity (J/kg^{o}C)	700	600-800	730	130

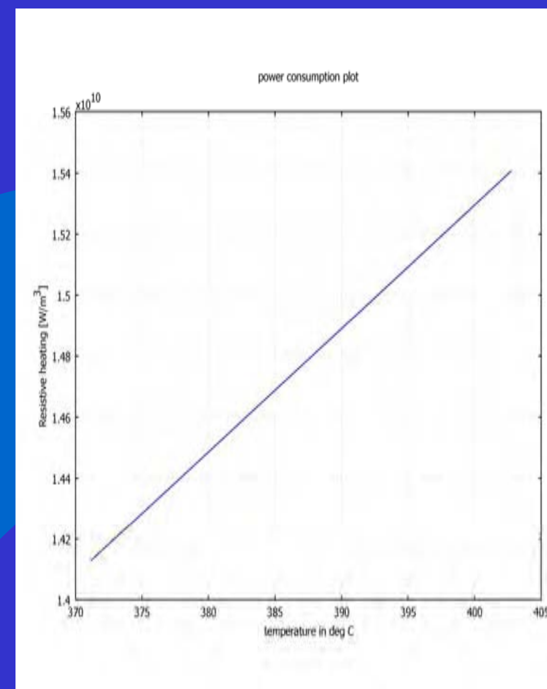
Square plate with center hole



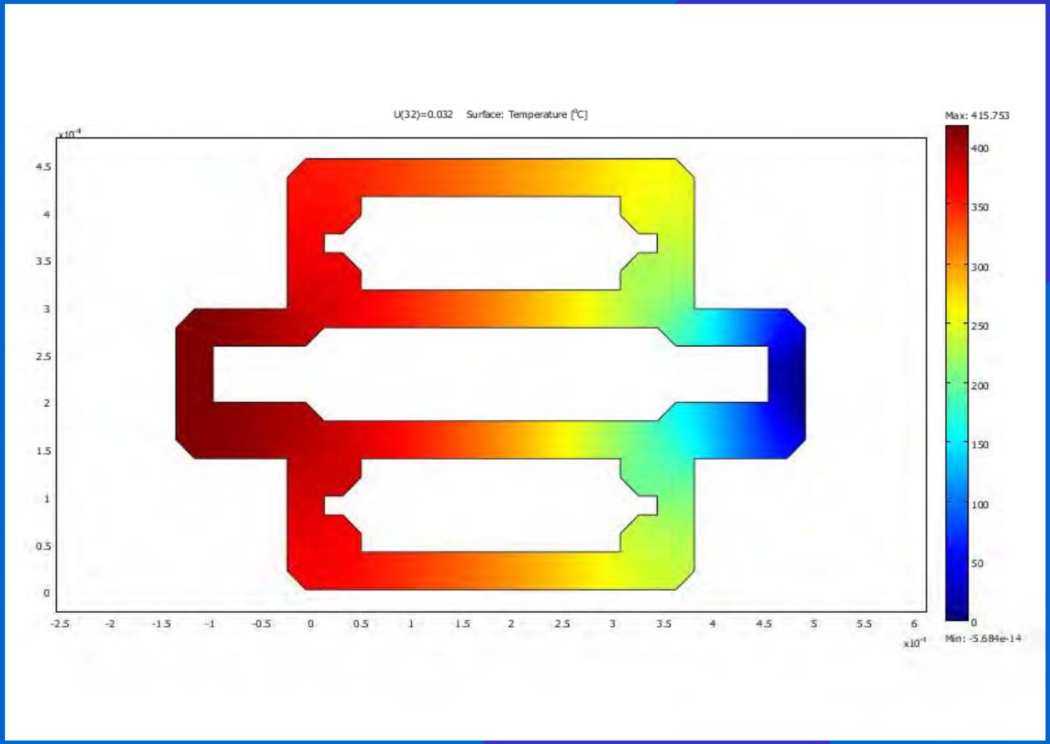


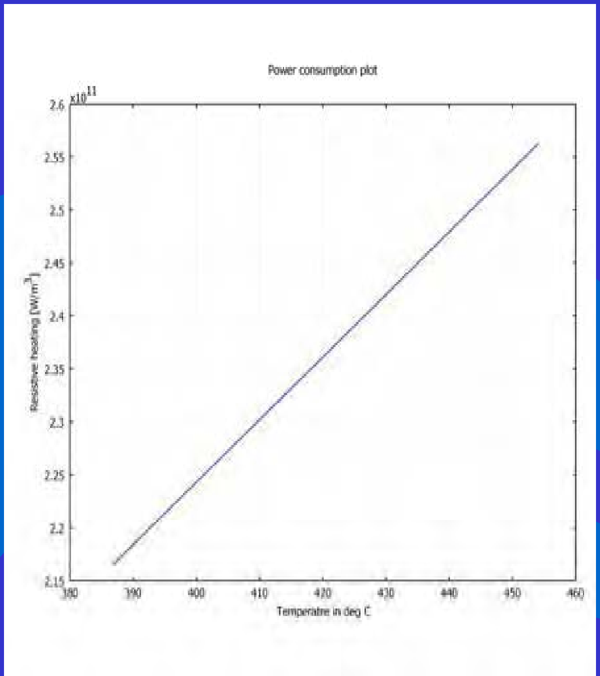
Double Spiral Shape



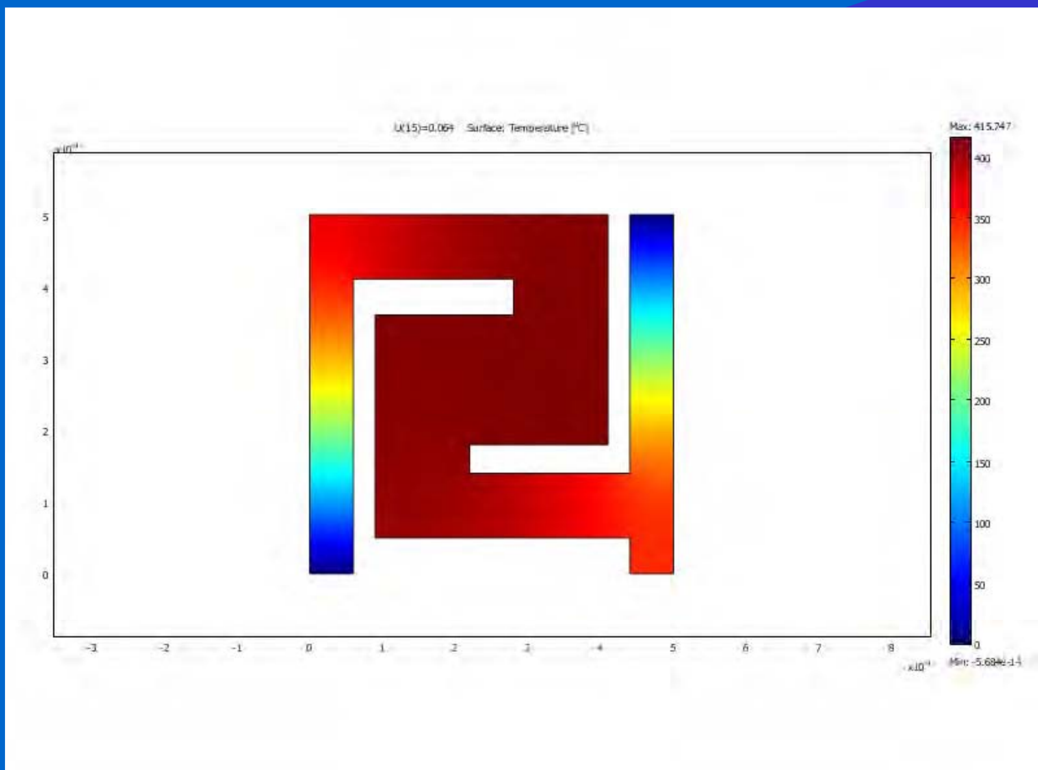


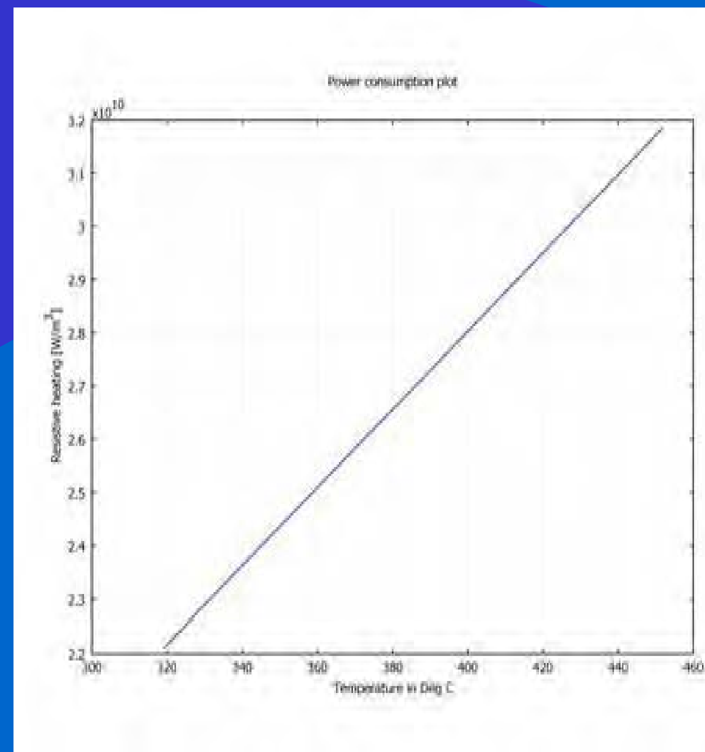
Honey Comb structure



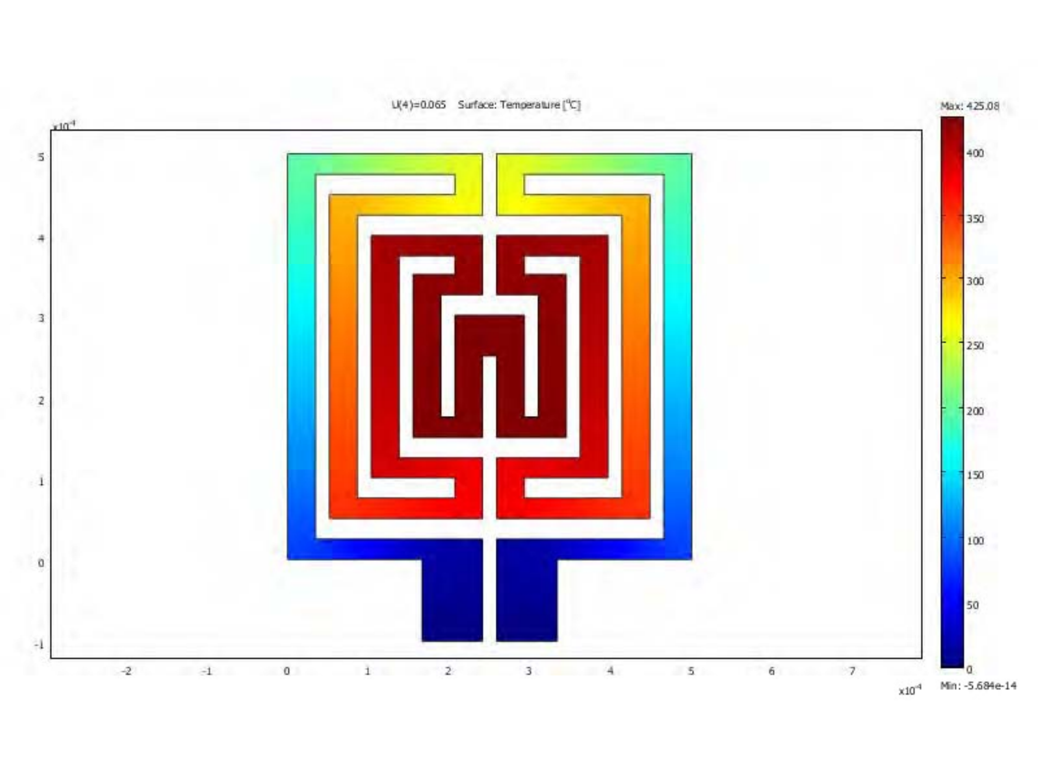


S-Shape structure

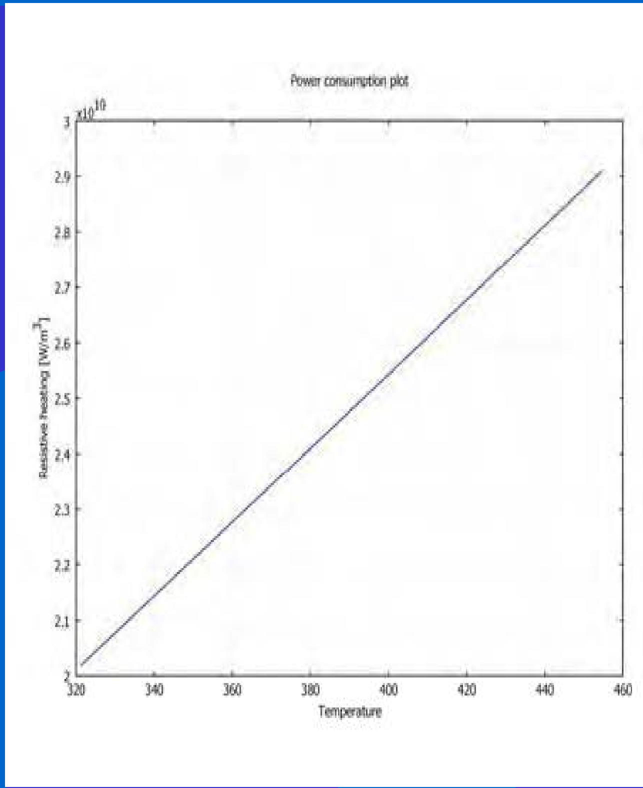




Fan shape

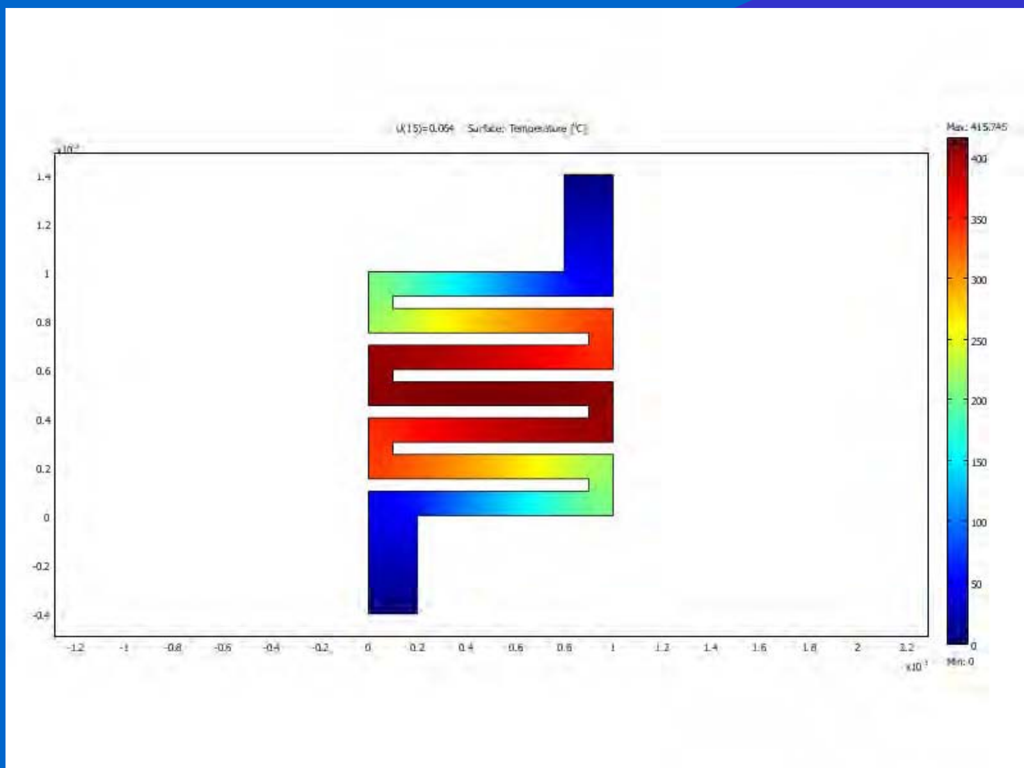


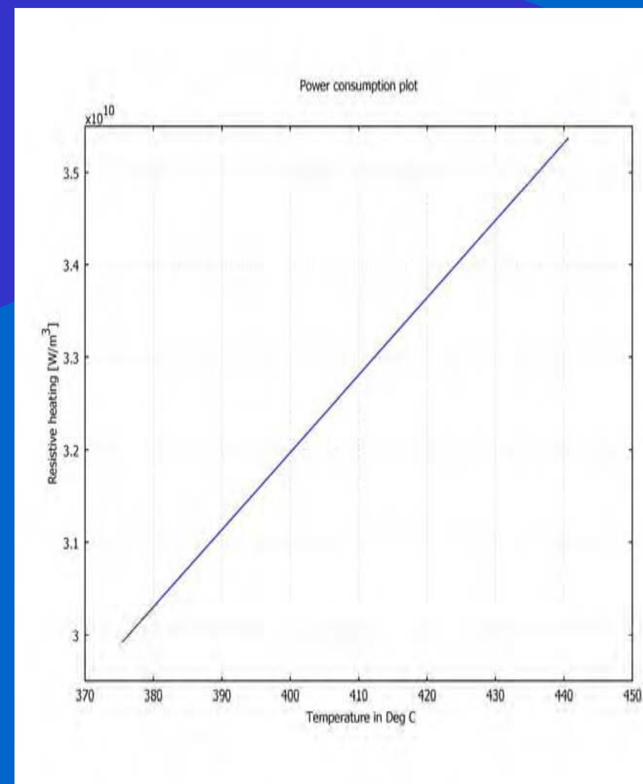
U(4)=0.065 Surface: Temperature [°C]
Max: 425.08
Min: -5.684e-14



Power consumption plot
Resistive heating [W/m^3]
Temperature

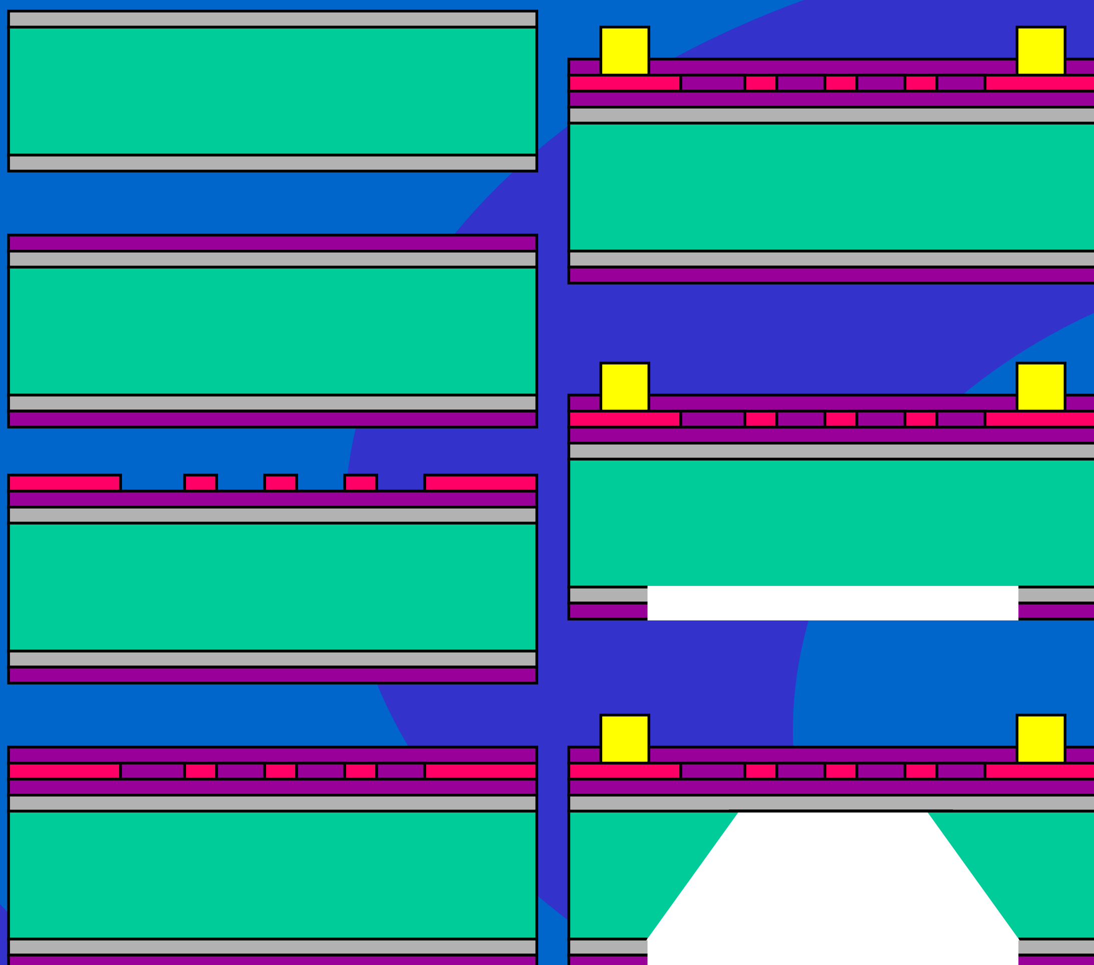
Meander structure

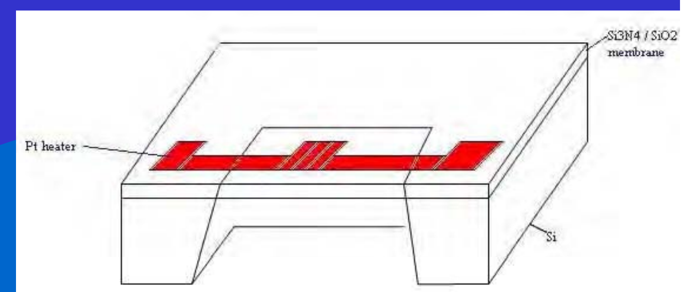




FABRICATION PROCESS STEPS

(1) Thermally grown SiO_2 on Si Substrate (2) Si_3N_4 deposition on top side (3) Pt heater deposition (4) Si_3N_4 deposition over Pt heater (5) contact pad open (6) back side window open (7) Backside etching using TMAH





Photograph of Gold wire bonded, packed micro-heater

SL.No	Heater pattern	Power consumption for 400 ^{O} C in mW
1.	Double Spiral	9.56
2.	Fan Shape	15.94
3.	S-Shape	17.50
4.	Meander pattern	20.00
5.	Honeycomb structure	140.63
6.	Square with center hole	787.50

- So taking (R= W i+1 / W i) as an important variable the double spiral pattern is designed within the area of 500µm X 500µm
- The pattern is fabricated with membrane at the back and tested for its heating profile

SEM image of Fabricated Micro-heater

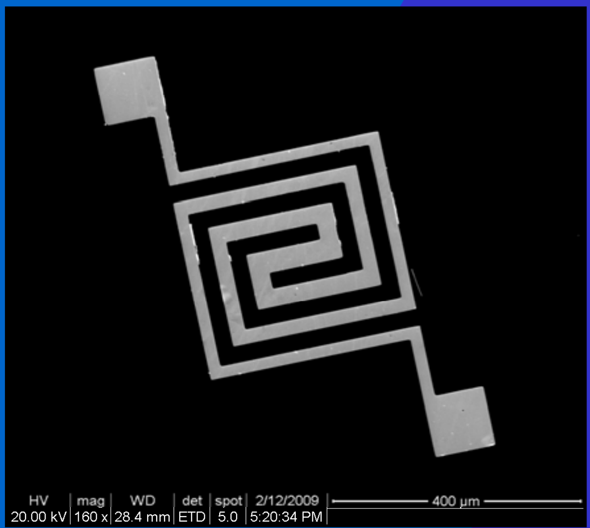
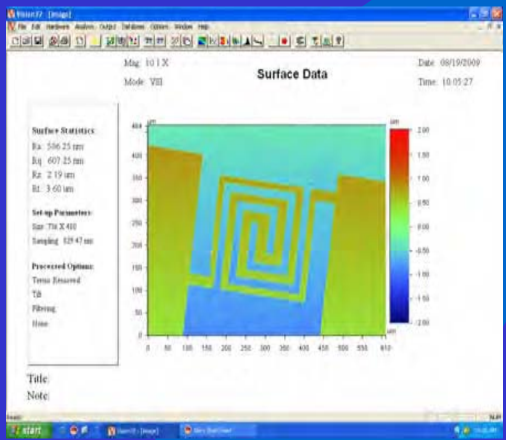
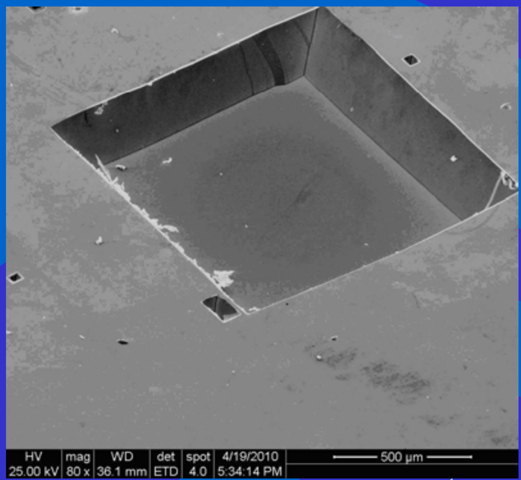


Image of Fabricated Micro-heater in Surface Profilometer



TMAH etched Membrane



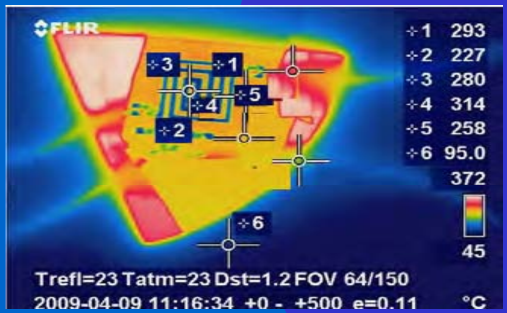
Gold Wire Bonded Heater

Thermal Imaging

- The ThermaCAM P65 delivers unmatched temperature measurement accuracy. A thermal sensitivity of 0.08°C results in clear noise-free images (320 x 240 pixels). A low thermal sensitivity not only offers you the possibility to see the smallest of temperature changes. It also means you get crisp, very detailed high-resolution images which cannot be obtained by less sensitive cameras.

How it Works?

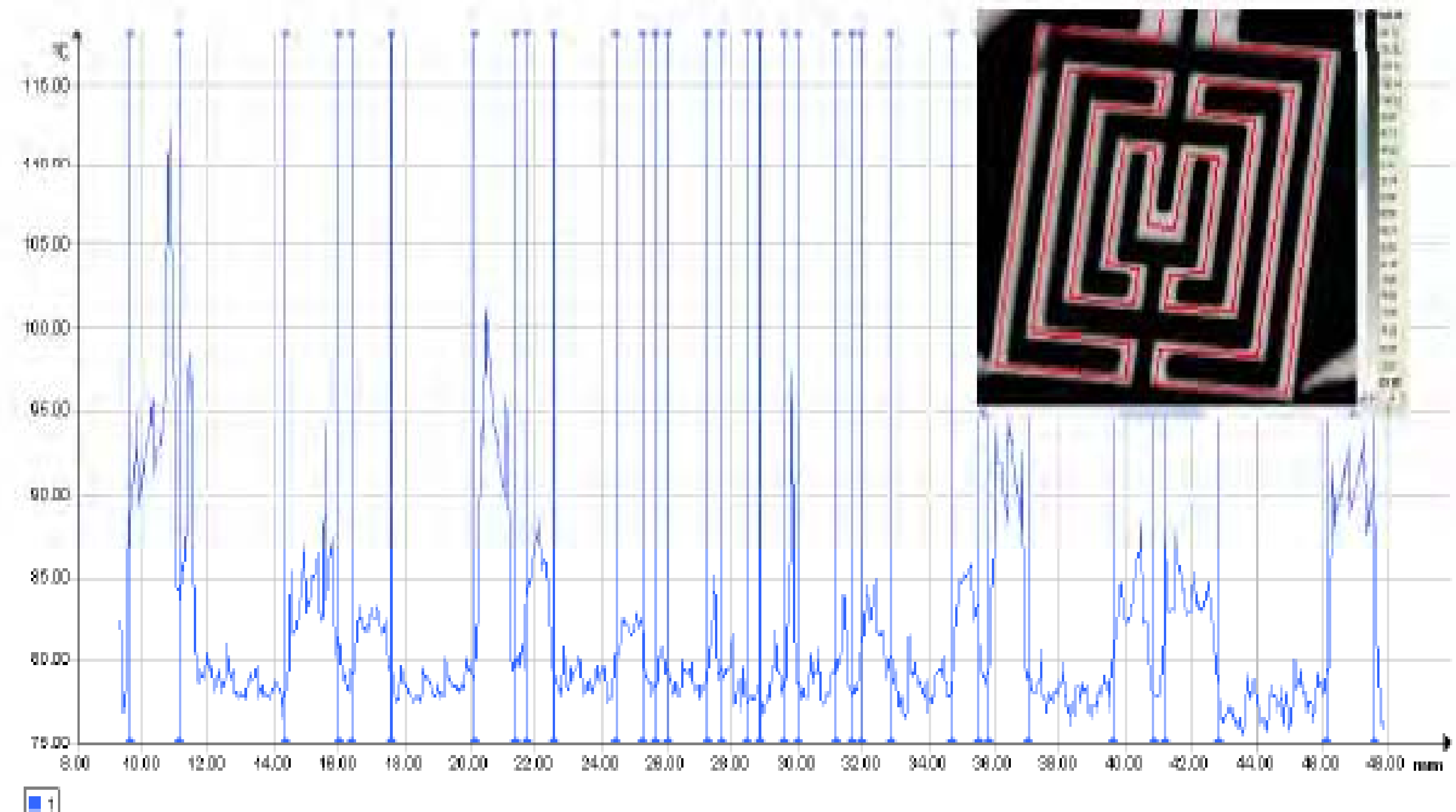
- The FLIR P65 uses an advanced, highly-sensitive detector for non-contact scanning across wide areas. Camera controls and software make it easy to quickly scan for emissivity and object temperature differencesdifferences that can signal trouble in building envelopes and infrastructure



FLIR thermal image @ 0.06V applied voltage.

ThermaCAM P65

Temperature change along the spiral



Thermal analysis of Micro-heater

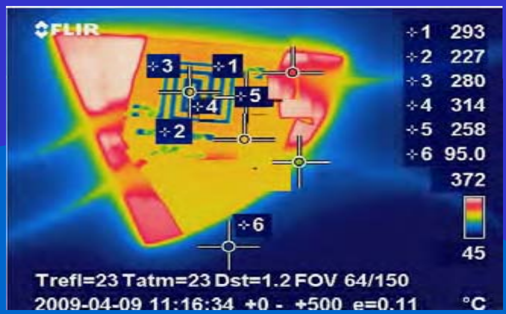
Practical Data

Resistance-temperature dependence for the determination of temperature (RT)

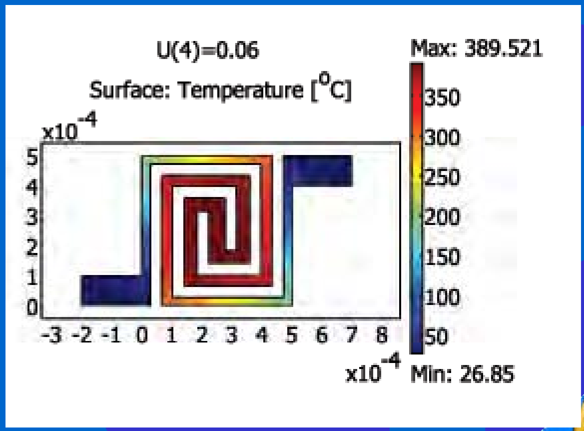
$$R_{sensor} = R_o(1+\alpha\,\Delta T)$$

- **Where**
- **$\Delta T = T_{sensor} - T_{amb}$**
- **Ro is the sensor resistance in ohms at T = T amb,**
- **α is Temperature coefficient of resistance (TCR) in $^oC^{-1}$**

FLIR thermal image @ 0.06V applied voltage.



voltage	temperature
0.020074	50.66
0.029974	101.32
0.040104	172.24
0.04976	253.29
0.060008	**377.12**
0.070045	506.58
0.079998	628.16



COMSOL simulated Result

Acknowledgements

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Thank you...
for your attention!