Advance Journal of Food Science and Technology 9(9): 711-716, 2015
DOI: 10.19026/ajfst.9.1765
ISSN: 2042-4868; e-ISSN: 2042-4876

Submitted: April 14, 2015 Accepted: May 10, 2015 Published: September 15, 2015

Research Article

Research on Responsivity of Microbolometer in Food Temperature Prediction by System-level Collaborative Simulation Method

Chao Chen, Ma Jiafeng, Zhou Yun and Zheng Xing
State Key Laboratory of Electronic Thin Films and Integrated Devices, University of Electronic Science and Technology of China, Chengdu, Sichuan 610054, China

Abstract: In this study, an 320×240 are fabricated according to the design to verify the system-level co-simulation results. Due to the complexity of microbolometer in food temperature prediction heat-transfer structure, thermoelectric characteristics could't be simulated in the same design platform with the design of its Read-Out Integrated Circuit (ROIC) which is monolithically integrated with the heat-transfer structure. The purpose of coordinated simulation is to find out a coordinated analysis method between microbolometer in food temperature prediction and its Read-Out Integrated Circuit (ROIC). Input and output characteristics of microbolometer in food temperature prediction was obtained. Responsivity of the heat-transfer model is analyzed based on the results of system-level collaborative simulation. Test values of responsivity matched the known design results of simulation well.

Keywords: Collaborative simulation, food temperature prediction, heat-transfer models, microbolometer

INTRODUCTION

Microbolometer in food temperature prediction type uncooled infrared focal plane arrays (UIRFPAs) are widely used in security rescue and food temperature application due to its low cost, light weight, superior reliability, small size, low power consumption and room temperature operating (Li *et al*., 2011). As detect pixel of UIRFPAs, microbolometer in food temperature prediction has a heat-transfer structure which thermally isolated from substrate. Temperature of the heat-transfer structure increased when it absorbs IR radiation power and resultings in a chang of the resistance. ROIC which is monolithically integrated with the heat-transfer structure provides a plus bias to microbolometer in food temperature prediction and then resistance change can be read out and processed as a change in electrical signal.

Traditionally, design of heat-transfer structure is starting with mechanical Computer Aided Design (CAD) tools. Thermoelectric behavior of microbolometer in food temperature prediction is analyzed via the Finite Element Method (FEM) (Han *et al*., 2009; Kucuk *et al*., 2011; Senveli *et al*., 2011), theoretical calculation (Topaloglu *et al*., 2007; Topaloglu *et al*., 2010; Han *et al*., 2011), sub-circuit heat-transfer model (Raghvendra *et al*., 2010) or PSPICE heat-transfer model analysis (Raghvendra *et al*., 2012). There are no straight-forward link between simulate thermoelectric behavior of microbolometer in food temperature prediction and ROIC. In recent years, collaborative or system-level simulation method for Micro-Electro-Mechanical System (MEMS) device and IC designs in the same simulation environment are introduced (Bechtold *et al*., 2005; Schlegel *et al*., 2006; Peter *et al*., 2012). Multi-domain, multi-language system-level heat-transfer modeling of MEMS accelerometer sensor (Ahmed *et al*., 2011), DLP (Gunar *et al*., 2010), High Acceleration Linear Motors (Graham *et al*., 2009), gyroscope (Gerold *et al*., 2010), CMOS image sensors (Blanco-Filgueira *et al*., 2012) and X-ray imager had been implemented (Hansen *et al*., 2010). For UIRFPAs, there has no link between the design of its heat-transfer structure and ROIC and result in a very long design cycles and very high cost.

In this study, collaborative simulation of microbolometer in food temperature prediction based on Verilog-AMS reduced-order macro-heat-transfer model is introduced. It prefers a fast, efficient design method which allow the designer take entire mems monolithic integrated device components of microbolometer in food temperature prediction including the heat-transfer structure, ROIC into account.

MATERIALS AND METHODS

Method of collaborative simulation: Collaborative simulation of microbolometer in food temperature

Corresponding Author: Chao Chen, State Key Laboratory of Electronic Thin Films and Integrated Devices, University of Electronic Science and Technology of China, Chengdu, Sichuan 610054, China

prediction is discussed by using FEA method and VHDL-AMS hardware language. VHDL-AMS language supports multi-domain, mixed-signal heat-transfer modeling capabilities needed for system-level heat-transfer modeling of MEMS-based systems. 3D heat-transfer structure of a VO2 microbolometer in food temperature prediction is heat-transfer modeling. Thermal Time Constant (TTC), thermal capacitance, thermal conductance and resistance of microbolometer in food temperature prediction are obtained by FEA and theoretical calculations. Equivalent circuit of microbolometer in food temperature prediction heat-transfer model is established based on the parameter metioned above. By using Verilog-AMS hardware language, equivalent circuit is described as reduced-order macro-heat-transfer model of microbolometer in food temperature prediction. Then this macro-heat-transfer model is compiled and defined in cadence to form a mems IP library unit of microbolometer in food temperature prediction. It offers the possibility of COMS-MEMS collaborative simulation for UIRFPAs. Finally, collaborative simulation of microbolometer in food temperature prediction and ROIC is accomplished. Collaborative simulation flow shown in this study shown in Fig. 1.

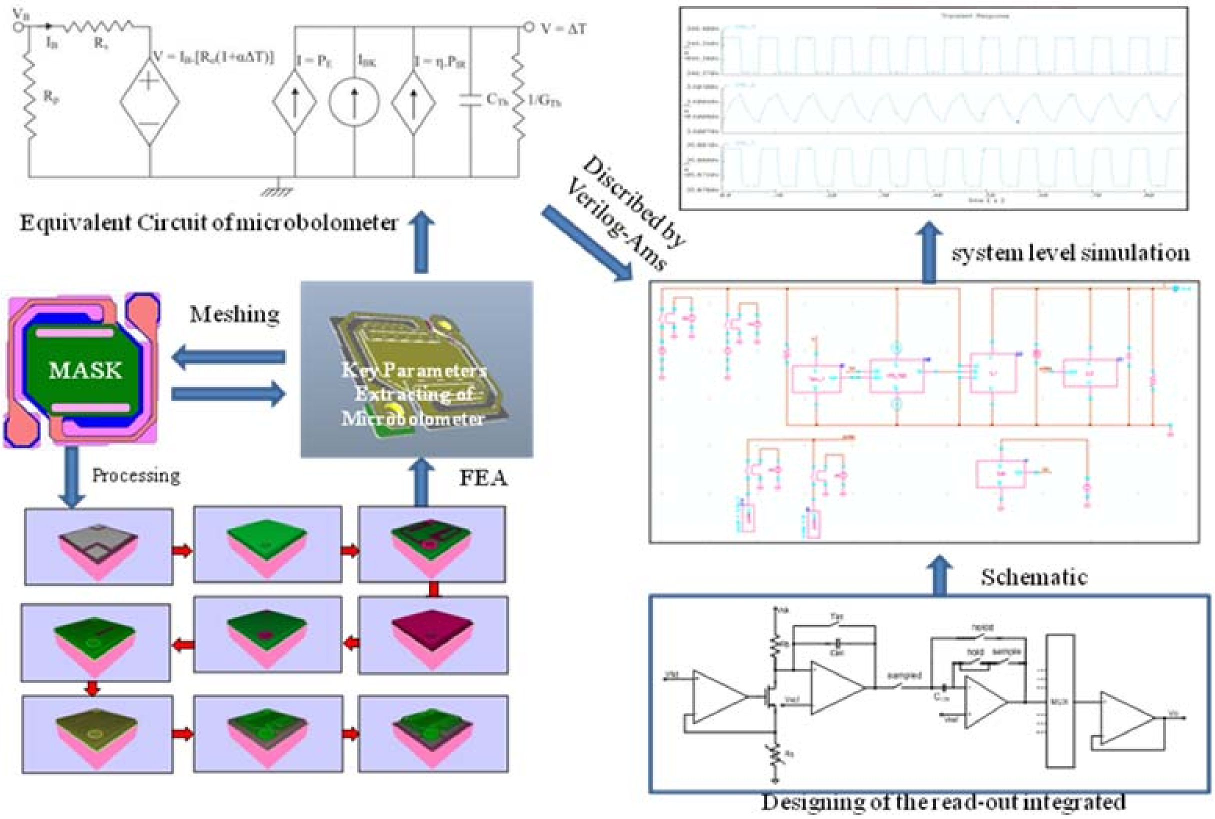


Fig. 1: Collaborative simulation flow-chart

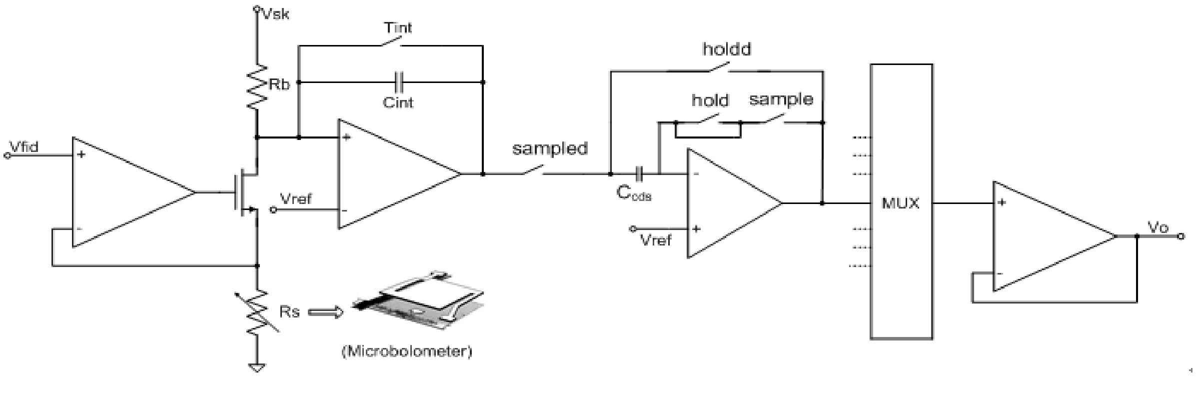
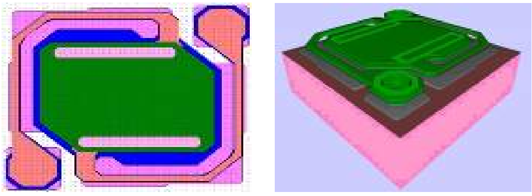
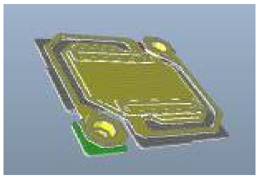


Fig. 2: Schematics of the read-out integrated microbolometer in food temperature prediction circuit



(a) Masbk (b) 3-D heat-transfer model



(c) FEA mesh heat-transfer model

Fig. 3: Mask and heat-transfer model of microbolometer in food temperature prediction

Read-out integrated circuit: Figure 2 shows the schematics of ROIC. Rs presented heat-transfer microbolometer in food temperature prediction which change under infrared irradiation. Vref, Vsk, Vfid, Tint and Cint are the reference voltage, blind pixel bias voltage, bias voltage, integrated time and integrated capacitance respectively: Rb is the resistance of the blind pixel, which is constant and did not change under infrared irradiation;

The output voltage V_0 is given by Eq. (10):

$$V_o = V_{ref} - \frac{T_{\text{int}}\left(\frac{V_{sk}-V_{ref}}{R_b} - \frac{V_{fid}}{R_s}\right)}{C_{\text{int}}} \tag{1}$$

Then sensitivity is a key parameter of microbolometer in food temperature prediction which is defined as the output voltage divided by the incident radiant power (Kruse and Skatrud, 1997) can be expressed as Eq. (2):

$$S_v = \frac{\partial V_o}{\partial P} = \frac{\alpha \cdot \eta \cdot V_{fid} \cdot T_{\text{int}}}{\sqrt{G_{eff}^2 + \omega^2 C^2} \cdot R_s \cdot C_{\text{int}}} \tag{2}$$

where,

α = The temperature coefficient of resistance

η = The IR absorption coefficient of the microbolometer in food temperature prediction

V_{fid} = Bias voltage of microbolometer in food temperature prediction

Tint = Integration time

G_{eff} = Effective thermal conductance

ω = Modulation frequency

C = Thermal capacitance

R_S = Resistance of microbolometer in food temperature prediction

C_{int} = Integration capacitance

Effective thermal conductance, thermal capacitance and R_s of microbolometer in food temperature prediction had significant impact on performance as well as parameters of ROCI. During system level simulation, all these aspects should be take into.

3D heat-transfer modeling: 3-D heat-transfer model of a VO2 microbolometer in food temperature prediction is established by using Intellisuite MEMS software. Mask of microbolometer in food temperature prediction is design which shown in Fig. 3. All of the membranes and structures of a microbolometer in food temperature prediction are heat-transfer modelled as shown in Fig. 4. In this accurate three-dimensional

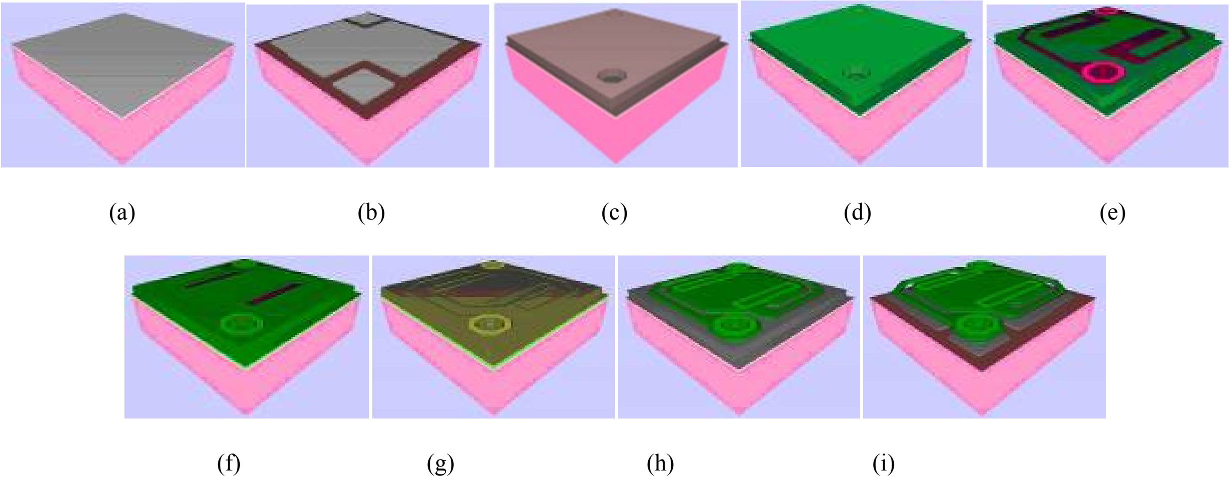


Fig. 4: Fabrication process of microbolometer in food temperature prediction; (a): Sputtering aluminum reflector; (b): Etching aluminum reflector; (c): Etching the sacrificial layer; (d): Sputtering and Etching support layer; (e): Sputtering and Etching electrode; (f): Sputtering and Etching passivation layer; (g): Sputtering and Etching sensitive resistant layer; (h): Sputtering and Etching absorbing layer; (i): Releasing sacrificial layer

Table 1: Microbolometer in food temperature prediction: Key sizes

Property	Size
Pixel pitch	37 µm
Width of structural layer (Si_3N_4)	1.1 µm
Thickness of structural layer (Si_3N_4)	200 nm
Width of the interconnecting metal (NiCr)	0.9 µm
Thickness of the interconnecting metal (NiCr)	50 nm
Thickness of the interconnecting metal VO_2	60 nm
Thickness of passivation layer (Si_3N_4)	70 nm
Vacuum cavity height	2 µm

Table 2: Microbolometer in food temperature prediction material properties

Material	Thermal conductivity (W/cm·K)	Heat capacity (J/kg·K)	Density (g/cm^3)	Resistivity (Ω·cm)
Si_3N_4	0.02	3.33	2.3	1×10^{15}
NiCr	0.3	3.92	8.5	1
VO_2	0.05	5.00	4.34	1×10^{-4}

heat-transfer model, the heat-transfer structure, support layer, sensitive resistance layer, passivation layer, absorbing layer, electrode and vacuum cavity, are established which guarantee a accurate result of finite element analysis.

And then Electronic, dynamic thermoelectric field-coupling finite element analysis and theoretical calculations are used to obtain the thermal capacity, effective thermal conductance and resistance of the heat-transfer model. Key sizes of the heat-transfer model in Table 1. The sensitive membrane is made of VO2 with a Temperature Coefficient of Resistance (TCR) of -0.023%.

The material properties of each layer are defined according to the actual process parameters of their materials. The material properties used for the FEA are listed in Table 2.

The thermal conductance is usually estimated by solving Fourier's first law of conduction and is approximate given by Eq. (4) (Kruse and Skatrud, 1997):

$$G \approx 2\sum_{i=1}^{n}\frac{k_i A_i}{l_i} \tag{4}$$

where, n is the number of parallel layers forming arms, k_i, A_i and l_i are the thermal conductance, cross-sectional area and length of thermal conductance of the i^{th} layer of the region of the arms, respectively. While the effective conductance of a microbolometer in food temperature prediction G_{eff}, affects the performance of the device (Kruse and Skatrud, 1997) and is given by Eq. (5):

$$G_{eff} = G - \left.\tfrac{\partial P}{\partial T}\right|_{T_S} = G - \frac{V_{fid}^2}{R_s}\alpha \tag{5}$$

where,

V = A bias voltage

R_s = The resistance of the microbolometer in food temperature prediction

α = TCR of sensitive membrane

Then the effective TTC, τ_{eff}, can be solved with Eq. (6):

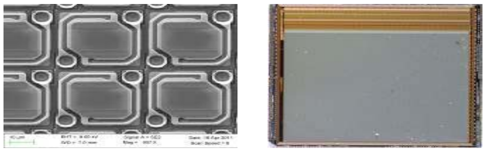
The thermal capacitance C of the microbolometer in food temperature prediction which can be expressed as Eq. (6) (Kruse and Skatrud, 1997):

$$C = \sum_{i=1}^{n} V_i c_i \rho_i \tag{6}$$

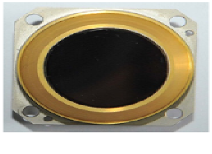
where, n is number of parallel layers forming the microbolometer in food temperature prediction, V_i, C_i and ρ_i are the volume, heat capacity and density of the i^{th} layer of each region of the microbolometer in food temperature prediction, respectively.

Another important parameter should be introduced before FEA. The effective TTC which is a measurement of the time required for the thermistor to respond to a change in the ambient temperature. The technical definition of TTC is the time required for a thermistor to change 63.2% of the total difference between its initial and final body temperature when subjected to a step function change in temperature, under zero power conditions (Kruse and Skatrud, 1997). It is also given by:

$$\tau_{eff} = \frac{C}{G_{eff}} \tag{7}$$



(a) SEM (b) UIRFPAs (320×240)



(c) IR Detector

Fig. 5: Microbolometer in food temperature prediction as manufactured and as used

RESULTS AND DISCUSSION

Experimental verfication and description: A 320×240 UIRFPs with pixels measuring 37×37 μm^2 is fabricated according to the design undertaken previously which shows in Fig. 3 and Table 1. A Scanning Electron Micrograph (SEM) of the product is shown in Fig. 5a. Figure 5b is overview ROIC with microbolometer in food temperature prediction array. Figure 5c is the IR detector.

The responsivity of this 320×240 microbolometer in food temperature prediction is 7.42×10^6 V/W. The deviation between the measured and simulated responsivity1.1% which is as expected.

CONCLUSION

In this study, a system level coordinated simulation is introduced which to find out a coordinated analysis method between microbolometer in food temperature prediction and its Read-Out Integrated Circuit (ROIC). Structure design of microbolometer in food temperature prediction has making connections with ROIC design which are accomplished in cadence. FEA of the three-dimensional heat-transfer microbolometer in food temperature prediction heat-transfer model is used to obtain key parameters of microbolometer in food temperature prediction. A equipment circuit of microbolometer in food temperature prediction which containing key parameters is established and described by Verilog-AMS language. Then the equipment circuit is compiled and definited in cadence. Responsivity is obtained by collaborative simulation between microbolometer in food temperature prediction and ROIC and it is under experimental verification. This collaborative simulation method offered a fast, low cost and efficient means of microbolometer in food temperature prediction design and fabrication.

ACKNOWLEDGMENT

This study was supported by the National Natural Science Foundation of China (Grant No. 61235006) and the National Natural Science Foundation of China (Grant No. 61421002).

REFERENCES

Ahmed, R., A. Florence, D. Norbert *et al*., 2011. A behavioral heat-transfer model of MEMS convective accelerometers for the evaluation of design and calibration strategies at system level. J. Electron. Test., 27(3): 411-423.

Bechtold, T., G. Schrag and L. Feng, 2005. Enabling technologies for system-level simulation of MEMS. Proceeding of the 14th International Conference on Thermal, Mechanical and Multi-Physics Simulation and Experiments in Microelectronics and Microsystems. Wroclaw, April 14-17, pp: 1-6.

Blanco-Filgueira, B., P. Lopez and J.B. Roldan, 2012. A Verilog-AMS photodiode heat-transfer model including lateral effects. Microelectr. J., 43: 980-984.

Gerold, S., L. Gunar, R. Stephane and B. Stephen, 2010. Novel 3D heat-transfer modeling methods for virtual fabrication and EDA compatible design of MEMS via parametric libraries. J. Micromech. Microeng., 20(6): 1-15.

Graham, D., B. Igor and T. Krishna, 2009. Heat-transfer modeling and simulation in support of system level design for high acceleration linear motors. P. IEEE, 97(11): 1818-1830.

Gunar, L., R. Stephane and C. Jean-Francois, 2010. A novel heat-transfer modelling methodology for MEMS with IC applied to a DLP mirror array. Proceeding of the IEEE Conference Publications, Hardware and Software Implementation and Control of Distributed MEMS. Besan, June 28-29, pp: 24-31.

Han, S., C.H. Chun, C.S. Han *et al*., 2009. Coupled physics analyses of VOx-based, three-level microbolometer in food temperature prediction. Electron. Mater. Lett., 5(2): 63-65.

Han, S., C.H. Chun, C.S. Han *et al*., 2011. Parameterized simulation program with integrated circuit emphasis heat-transfer modeling of two-level microbolometer in food temperature prediction. J. Electr. Eng. Technol., 6(2): 270-274.

Hansen, K., M. Randall, S. Schleitzer and C. Gutt, 2010. System-level simulation of a X-ray imager with nonlinear gain and per-pixel digitizer: XPCS case study. Nucl. Instrum. Meth. A, 65(2): 323-333.

Kruse, P.W. and D.D. Skatrud, 1997. Uncooled Infrared Imaging Arrays and Systems. Academic Press, San Diego, pp: 47-58.

Kucuk, S.E., M. Yusuf Tanrikulu and T. Akin, 2011. A detailed analysis for the absorption coefficient of multilevel uncooled infrared detectors. Proceeding of SPIE 8012, Infrared Technology and Applications XXXVII, Orlando, May 20, 80121R: 1-8.

Li, C., C.J. Han and G. Skidmore, 2011. Overview of DRS uncooled VOx infrared detector development. Opt. Eng., 50(6): 0610171-0610177.

Peter, Schneider, P., C. Bayer, K. Einwich and A. Kohler, 2012. System level simulation-a core method for efficient design of MEMS and mechatronic systems. Proceeding of the 9th International Multi-Conference on Systems, Sygnals and Devices. Chemnitz, March 20-23, pp: 1-6.

Raghvendra, R.S., Saxena, A. Panwar *et al*., 2010. A sub-circuit heat-transfer model of a microbolometer in food temperature prediction IR detector and its experimental validation. Sensor. Actuat. A-Phys., 171: 138-145.

Raghvendra, S.S., P. Arun, S.K. Semwal *et al*., 2012. PSPICE circuit simulation of microbolometer in food temperature prediction infrared detectors with noise sources. Infrared Phys. Techn., 55(6): 527-532.

Schlegel, M., F. Bennini, J. Mehner, G. Herrmann, D. Muller *et al*., 2006. Analyzing and simulation of MEMS in VHDL-AMS based on reduced-order FE heat-transfer models. IEEE Sens. J., 5(5): 1019-1026.

Senveli, S.U., M.Y. Tanrikulu and T. Akin, 2011. A thermal conductance optimization and measurement approach for uncooled microbolometer in food temperature predictions. Proceeding of the SPIE, Infrared Technology and Applications XXXVII, Orlando, May 20, 80121T: 1-10.

Topaloglu, N., P.M. Nieva, M. Yavuz *et al*., 2007. A novel method for estimating the thermal conductance of uncooled microbolometer in food temperature prediction pixels. Proceeding of the IEEE International Symposium on Industrial Electronics. Vigo, June 4-7, pp: 1554-1558.

Topaloglu, N., P. Nieva, M. Yavuz and J.P. Huissoon, 2010. Heat-transfer modeling of thermal conductance in an uncooled microbolometer in food temperature prediction pixel. Sensor. Actuat. A-Phys, 157(2): 235-245.