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

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Abstract: In this study, an 320×240 array 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 couldn’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 results in a change 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 to take entire mems monolithic integrated device components of microbolometer in food temperature prediction into account.

MATERIALS AND METHODS

Method of collaborative simulation: Collaborative simulation of microbolometer in food temperature prediction
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 parameters mentioned 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 UIRFPAAs. 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
The output voltage $V_o$ is given by Eq. (1):

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

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):

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

where,

- $\alpha$ = The temperature coefficient of resistance
- $\eta$ = The IR absorption coefficient of the microbolometer in food temperature prediction
- $V_{\text{fid}}$ = Bias voltage of microbolometer in food temperature prediction
- $T_{\text{int}}$ = Integration time
- $G_{\text{eff}}$ = Effective thermal conductance
- $\omega$ = Modulation frequency
- $C$ = Thermal capacitance
- $R_s$ = Resistance of microbolometer in food temperature prediction
- $C_{\text{int}}$ = 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 ROIC. During system level simulation, all these aspects should be taken 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...
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):

\[ G \approx 2 \sum_{i=1}^{n} \frac{k_i A_i}{l_i} \]

(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 \( G_{\text{eff}} \) affects the performance of the device (Kruse and Skatrud, 1997) and is given by Eq. (5):

\[ G_{\text{eff}} = G - \frac{\alpha V}{R_s} = G - \frac{V_{\text{ad}}^2}{R_s} \alpha \]

(5)

where,

\( V = \) A bias voltage
\( R_s = \) The resistance of the microbolometer in food temperature prediction
\( \alpha = \) TCR of sensitive membrane

Then the effective TTC, \( \tau_{\text{eff}} \), 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):

\[ C = \sum_{i=1}^{n} \frac{V_i C_i}{\rho_i} \]

(6)

where, \( n \) is number of parallel layers forming the microbolometer in food temperature prediction, \( V_i, C_i \) and \( \rho_i \) 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:

\[ \tau_{\text{eff}} = \frac{C}{G_{\text{eff}}} \]

(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 verification and description: A 320×240 UIRFPs with pixels measuring 37×37 μm² 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 7.42×10⁶ V/W. The deviation between the measured and simulated responsivity is 1.1% 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 defined 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.

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