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RESEARCH ARTICLE OPEN ACCESS

HEAT TRANSFER IN ELECTRONIC DEVICES

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ABSTRACT

Modern micro equipment is characterized by a reduction in the mass and dimensions of their elements which requires increased reliability. This requires a systematic approach to objective data on their thermal regimes, in order to adopt more accurate design and technological solutions for operation with temperature distribution using the finite difference method.

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INTRODUCTION

Thefinite difference methodknowing the boundary conditions we obtain systems of equations in extreme differences for the nodes.The result is the required temperature field at all internal points of the network.Using the finite difference method, give examples of thermal analysis of stationary temperature fields of microelectronic devices with the finite difference method.

HEAT TRANSFER

The heat transfer passing only in the direction of the x-axis is determined by Fourier's law:

$$q = kA\frac{dt}{dx}$$

q – the heat flow in the direction of the axis x;
A -the face of the cross section through which the heat passes.
$\frac{dt}{dx}$– the temperature gradient along the axis$x$;
k – the coefficient of thermal conductivity, which is different for different substances and determining their physical properties..

Using the finite difference method, we consider different cases of the two-dimensional problem of thermal conductivity in a square network ($\Delta x = \Delta y$)

The nodes are located inside the two-dimensional solid body:

d– thickness of the body,
k – thermal conductivity coefficient.

The energy balance of Fourier's Law is:

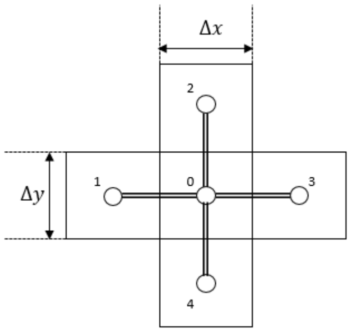


Fig.1.

$$q_{1\to 0} + q_{2\to 0} + q_{3\to 0} + q_{4\to 0} = 0$$

$$k\Delta y d\frac{(T_1 - T_0)}{\Delta x} + k\Delta x d\frac{(T_2 - T_0)}{\Delta y} + k\Delta y d\frac{(T_3 - T_0)}{\Delta x} + k\Delta x d\frac{(T_4 - T_0)}{\Delta y} = 0$$

$$T_1 + T_2 + T_3 + T_4 - 4T_0 = 0$$

Energy balance for a node at the boundary of a solid body with the environment. The temperature of the environment isT_∞ and the coefficient of convective heat transfer from the environment to solid body is h_c.

The energy balance for node **0** is:

$$q_{1\to 0} + q_{2\to 0} + q_{3\to 0} + q_{\infty\to 0} = 0$$

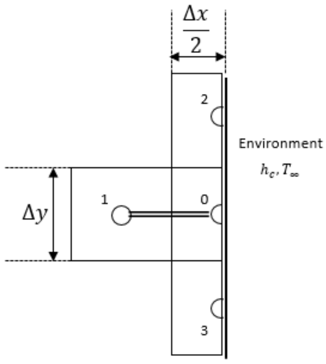


Fig. 2

The first three terms show the conductive heat flow, and the last one - Newton's law of convective heat flow:

$$k\Delta y d\frac{T_1 - T_0}{\Delta x} + k\frac{\Delta x}{2}d\frac{T_2 - T_0}{\Delta y} + k\frac{\Delta x}{2}d\frac{T_3 - T_0}{\Delta y} + h_c\Delta y d(T_\infty - T_0) = 0 \;\Rightarrow$$

$$\Rightarrow \frac{1}{2}T_2 + \frac{1}{2}T_3 + T_1 + \frac{h_c\Delta y}{k}T_\infty - \left[2 + \frac{h_c\Delta y}{k}\right]T_0 = 0$$

$\frac{1}{2}T_2 + \frac{1}{2}T_3 + T_1 - T_0 = 0$ (Fig. 3)

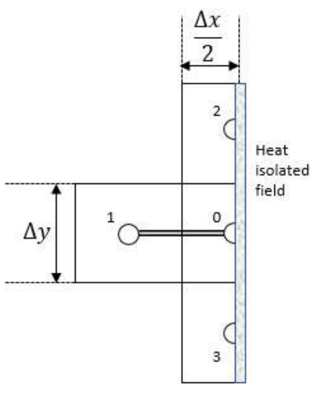


Fig. 3.

$\frac{1}{2}T_1 + \frac{1}{2}T_2 + \frac{h_c\Delta y}{k}T_\infty - \left(1 + \frac{h_c\Delta y}{k}\right)T_0 = 0$ (Fig. 4)

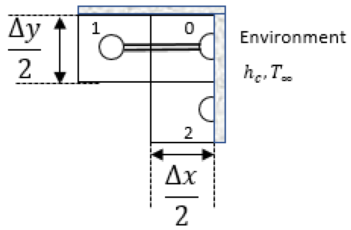


Fig. 4.

$\frac{1}{2}T_1 + \frac{1}{2}T_4 - 3T_0 + \frac{h_c\Delta x}{k}T_\infty - \frac{h_c\Delta x}{k}T_0 = 0$ (Fig. 5)

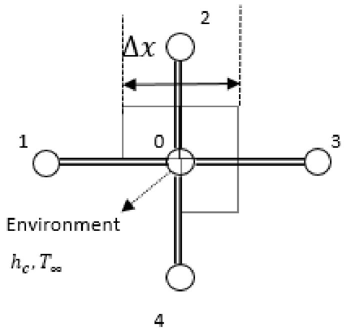


Fig. 5.

$T_1 + T_2 - 2T_0 + \frac{\Delta x}{k}(T_\infty - T_0)(h_{c_1} + h_{c_2}) = 0$ (Fig. 6)

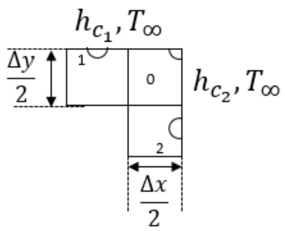
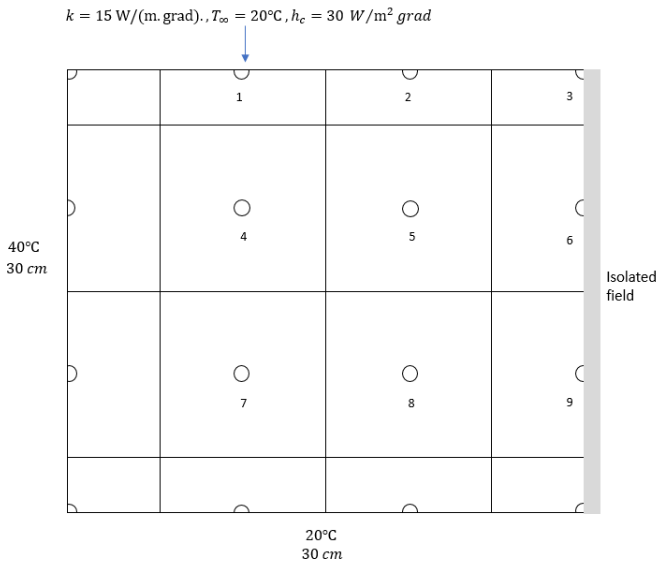


Fig. 6.

Example 1: Calculation of the temperature in the 9 nodes of a solid body.

Calculate the stationary distribution of temperature in the 9 knots of a solid body shown in the following figure.Both surfaces are isothermal, the third - thermally insulated and the fourth one has convective heat transfer.



$\Delta x = \Delta y = 0{,}1\ m \qquad \frac{h_c \Delta x}{k} = \frac{30\ .\ 0{,}1}{15} = 0{,}2$

Node ①:

$$\frac{\Delta y}{2}\frac{40 - T_1}{\Delta x} + \frac{\Delta y}{2}\frac{T_2 - T_1}{\Delta x} + \Delta x\frac{T_4 - T_1}{\Delta y} + \frac{h_c \Delta x}{k}(T_\infty - T_1) = 0$$
$$\frac{40}{2} + \frac{1}{2}T_1 + \frac{1}{2}T_2 - \frac{1}{2}T_1 + T_4 - T_1 + \frac{30\ .\ 0{,}1}{15}(20 - T_1) = 0 \quad .|10$$
$$200 + 5T_2 - 20T_1 + 10T_4 + 40 - 2T_1 = 0$$
① $:22T_1 - 5T_2 - 10T_4 = 240$

Node ②:

$$\frac{\Delta y}{2}\frac{T_1 - T_2}{\Delta x} + \frac{\Delta y}{2}\frac{T_3 - T_2}{\Delta x} + \Delta x\frac{T_5 - T_2}{\Delta y} + \frac{h_c \Delta x}{k}(T_\infty - T_2) = 0$$
$$\frac{1}{2}T_1 - \frac{1}{2}T_2 + \frac{1}{2}T_3 - \frac{1}{2}T_2 + T_5 - T_2 + \frac{30\ .\ 0{,}1}{15}(20 - T_2) = 0 \quad .|10$$
② $:\ 5T_1 - 22T_2 + 5T_3 + 10T_5 = -40$

Node ③:

$$\frac{\Delta y}{2}\frac{T_2 - T_3}{\Delta x} + \frac{\Delta x}{2}\frac{T_6 - T_3}{\Delta y} + \frac{h_c}{k}\frac{\Delta x}{2}(T_\infty - T_3) = 0$$
$$\frac{1}{2}T_2 - \frac{1}{2}T_3 + \frac{1}{2}T_6 - \frac{1}{2}T_3 + \frac{30\ .\ 0{,}1}{15.2}(20 - T_3) = 0 \quad .|10$$

③ $:\ 5T_2 - 11T_3 + 5T_6 = -20$

Node ④:

$$\Delta y\frac{40 - T_4}{\Delta x} + \Delta x\frac{T_1 - T_4}{\Delta y} + \Delta y\frac{T_5 - T_4}{\Delta x} + \Delta x\frac{T_7 - T_4}{\Delta y} = 0$$
$$40 - T_4 + T_1 - T_4 + T_5 - T_4 + T_7 - T_4 = 0$$

④ $:\qquad T_1 - 4T_4 + T_5 + T_7 = -40$

Node ⑤:

$$\Delta y\frac{T_4 - T_5}{\Delta x} + \Delta x\frac{T_2 - T_5}{\Delta y} + \Delta y\frac{T_6 - T_5}{\Delta x} + \Delta x\frac{T_8 - T_5}{\Delta y} = 0$$

⑤ $:\qquad T_2 + T_4 - 4T_5 + T_6 + T_8 = 0$

Node ⑥:

$$\Delta y\frac{T_5 - T_6}{\Delta x} + \frac{\Delta x}{2}\frac{T_9 - T_6}{\Delta y} + \frac{\Delta x}{2}\frac{T_3 - T_6}{\Delta y} = 0 \quad .|2$$
$$2T_5 - 4T_6 + T_9 + T_3 = 0$$

⑥ $:T_3 + 2T_5 - 4T_6 + T_9 = 0$

Node ⑦:

$$\Delta y\frac{40 - T_7}{\Delta x} + \Delta y\frac{T_8 - T_7}{\Delta x} + \Delta x\frac{20 - T_7}{\Delta y} + \Delta x\frac{T_4 - T_7}{\Delta y} = 0$$
$$40 - T_7 + T_8 - T_7 + 20 - T_7 + T_4 - T_7 = 0$$

⑦ $:\qquad T_4 - 4T_7 + T_8 = -60$

Node ⑧:

$$\Delta y\frac{T_7-T_8}{\Delta x}+\Delta x\frac{T_5-T_8}{\Delta y}+\Delta y\frac{T_9-T_8}{\Delta x}+\Delta x\frac{20-T_8}{\Delta y}=0$$
$$T_7-T_8+T_5-T_8+T_9-T_8+20-T_8=0$$

⑧ : $T_5+T_7-4T_8+T_9=-20$

Node ⑨:

$$\Delta y\frac{T_8-T_9}{\Delta x}+\frac{\Delta x}{2}\frac{T_6-T_9}{\Delta y}+\frac{\Delta x}{2}\frac{20-T_9}{\Delta y}=0$$
$$T_8-T_9+\frac{1}{2}T_6-\frac{1}{2}T_9+10-\frac{1}{2}T_9=0\quad .|2$$

⑨ : $T_6+2T_8-4T_9=-20$

For all nodes we have:

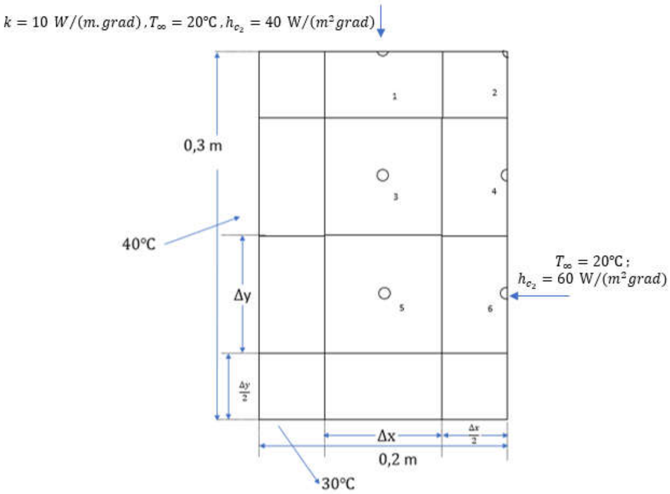
① : $22T_1-5T_2-10T_4=240$
② : $5T_1-22T_2+5T_3+10T_5=-40$
③ : $5T_2-11T_3+5T_6=-20$
④ : $T_1-4T_4+T_5+T_7=-40$
⑤ : $T_2+T_4-4T_5+T_6+T_8=0$
⑥ : $T_3+2T_5-4T_6+T_9=0$
⑦ : $T_4-4T_7+T_8=-60$
⑧ : $T_5+T_7-4T_8+T_9=-20$
⑨ : $T_6+2T_8-4T_9=-20$

The solution of system of equations is:

$T_1=31{,}03$; $T_2=28{,}04$; $T_3=26{,}82$; $T_4=32{,}45$; $T_5=28{,}25$; $T_6=26{,}96$; $T_7=29{,}50$; $T_8=25{,}57$; $T_9=24{,}53$

Example 2. Two adjacent walls of the two-dimensional solid body with a thickness ***d***,the cross section of which is shown in the figure, have constant temperatures of 40 □ and 30 □, and for the other two flows convection heat transfer.

Calculate the stationary distribution in the 6 nodes ($\Delta x=\Delta y=0{,}1m$):



For node ①we apply the law of Fourier and Newton:

$$\frac{\Delta y}{2}\frac{40-T_1}{\Delta x}+\frac{\Delta y}{2}\frac{T_2-T_1}{\Delta x}+\Delta x\frac{T_3-T_1}{\Delta y}+\frac{h_{c_1}\Delta x}{k}(T_\infty-T_1)=0$$
$$20-\frac{1}{2}T_1+\frac{1}{2}T_2-\frac{1}{2}T_1+T_3-T_1+\frac{40}{10}.0{,}1(20-T_1)=0$$

① : $5T_2+10T_3-24T_1=-280$

Node ②:

$$\frac{\Delta y}{2}\frac{T_1-T_2}{\Delta x}+\frac{\Delta x}{2}\frac{T_4-T_2}{\Delta y}+\frac{h_{c_1}}{k}\frac{\Delta x}{2}(T_\infty-T_2)+\frac{h_{c_2}}{k}\frac{\Delta y}{2}(T_\infty-T_2)=0$$

$$\frac{1}{2}T_1-\frac{1}{2}T_2+\frac{1}{2}T_4-\frac{1}{2}T_2+\frac{40\,.\,0{,}1}{10\,.\,2}(20-\ T_2)+\frac{60\,.\,0{,}1}{10.2}(20-T_2)=0$$

②: $T_1+T_4-3T_2+20=0$

For the rest of the nodes we have:

Node ③:$T_1-4T_3+T_4+T_5=-40$
Node ④:$5T_2+10T_3-26T_4+5T_6=-120$
Node ⑤:$T_3-4T_5+T_6=-70$
Node ⑥:$5T_4+10T_5-26T_6=-270$

The solution of system of equations is:

$T_1=30{,}80$; $T_2=26{,}17$; $T_3=32{,}83$; $T_4=27{,}72$; $T_5=32{,}79$; $T_6=28{,}33$

CONCLUSION

With these numerical methods the calculated temperatures in the calculation network give an analysis on temperature fields of the microelectronic device.

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