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Budapest University of Technology and Economics

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Thermal issues in electronics:

measurement, modelling, special devices

PhD Thesis Booklet

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Ernő Kollár, BUTE-DED, 2013.

INTRODUCTION

In the past 12 years I have continued to participate separately's closely related to semiconductor device thermal problems of research and development works carried out in the Department, which simultaneously help to provide a wide and sometimes I get in-depth knowledge. My research fields may be far apart stand each other for an external observer, but according to the problems and solutions these are closely related. The thesis title is more revealing of the relationship, rather than the fields: examination of the heat conductivity measuring of printed circuit boards, planning and some applications of the heat-flux sensor array, and multi-physical analysis of the OLEDs (Organic Light Emitting Diode).

RESEARCH BACKGROUND AND OBJECTIVES

Correction of the heat conductivity measuring of printed circuit boards

Background: The gradual integration of electronic devices increases the dissipation density in the components. The local heat path can be an increasingly important role in the removing of the unnecessary heat. In the case of some electronic equipment (see racks) you have to find a solution to the cooling problems inside of the chasses. That’s why the printed circuit boards usually are used as cooling surface. However, the local layer structure and layout of the board has effect on the heat conductivity. Due to the problem is complex, only the thermal simulation programs can get a clear picture of the temperature components. Despite of some of the environmental effects are neglected the modelling of the PCB board requires lot of preparation and simulation time. It has been desired to develop a faster, measurement technique traceable method. Before the new millennium on the Department began the experimental measurements, based on the transient measurement technique developed for contact and non-contact thermal conductivity measurement methods.

In the first case a power transistor provides the forcing and sensing, and in the second case a CO_2 laser and an infrared camera do the same task. My thesis presents the results of simulation and measurement experiments of non-contact and non-destructive method.

Heat-flux mapping on cooling surface of semiconductor devices

Heat flow measurement we are curious to how much heat per unit time passing through a known interface. If you review the application fields of heat-flux sensor, you can find them in a variety of places. You will meet them in the industry as sensor of the blast furnaces, boilers, furnaces, and control systems. These sensors allow the efficiency of the fabrication processes, their automation and their safety. In the agriculture it is applied to measure the evapotranspiration. The architects use it to measure the thermal insulation of the walls. In medicine it is used to the diagnosis of certain diseases. In the fire-proof it is applied to check the fire and heat protection. There are some special, interdisciplinary fields as Heat and fire resistant clothing, cold water wetsuit, flight suits, spacesuits. If you need the knowledge of heat-flux on devices you should derive it indirectly from the material properties, the geometry, the temperature difference. In the case of simple structure as one side heated cooper rod in vacuum, (in fact is not a real 1D heat transfer due to the convection and radiation), It does not seem too complicated. But in the case of micro-processor which has more than 100 pins, the heat-flux calculation requires a computer simulation program. Unfortunately, the sensor manufacturers didn't have sensor to match to this application, that's why it was needed to develop a new heat-flux sensor. A well designed sensor can help to validate and accurate the simulation program and devices models. Before my research, wasn't created heat-flux sensor by the Department. My dissertation shows the sensor fabrication, calibration and some application.

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9. P. Maák, T. Takács, A. Barócsi, **E. Kollár**, P. Richter: Thermal behavior of acousto-optic devices: effects of ultrasound absorption and transducer losses, submitted to Ultrasonics (2007)

10. Székely V, Török S, **Kollár E**: Improvements of the variable thermal resistance. In: Proceedings of the 13th International Workshop on THERMal INvestigations of ICs and Microstructures (THERMINIC'07). Budapest, Magyarország, 2007.09.17-2007.09.19. (13)pp. 180-183.

Unrelated Publications

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2. S. Ress, **E. Kollár**: Comparison of Various Thermal Transient Measurements on a Benchmark Package, 6th THERMINIC Workshop, 24-27 September 2000, Budapest, Hungary, pp. 120-123.

3. M Rencz, V Székely, **E Kollár**: Measuring dynamic thermal multiport parameters of IC packages. In:Proceedings of the 6th International Workshop on THERMal INvestigations of ICs and Systems (THERMINIC'00). Budapest, Magyarország, 2000.09.24-2000.09.27. pp. 244-250.

4. **Kollár Ernő**: A Celeron 600 MHz-es processzor és hűtőbordájának vizsgálata termovíziós kamerával és termikus tranziensmérővel. HÍRADÁSTECHNIKA 58: pp. 27-31. (2003)

5. Farkas G, Poppe A, **Kollár E**, Stehouwer P: Dynamic Compact Models of Cooling Mounts for Fast Board Level Design. In: Proceedings of the 19th IEEE Semiconductor Thermal Measurement and Management Symposium (SEMI-THERM'03). San Jose, Amerikai Egyesült Államok, 2003.03.11-2003.03.13. pp. 255-262.

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7. P. Maák, T. Takács, A. Barócsi, **E. Kollár**, V. Szekely, P. Richter: Refractive Index Nonuniformities in Acousto-optic Devices due to Heat Production by Ultrasound, Opt. Comm. 226, 419-425 (2006)

Multi-physical analysis of the OLEDs

The overall objective of Fast2Light is to develop novel, cost-effective, high-throughput, roll-to-roll, large area deposition processes for fabricating light-emitting polymer-OLED foils for intelligent lighting applications. The scope of the project comprises all of the layers that are part of an OLED lighting foil. The project aims to strengthen the leading position of the European Lighting Industry by enabling new technologies and market possibilities. Furthermore, these new sustainable disruptive technologies will create long-term European manufacturing jobs due to their high degree of technical novelty and specialization. Finally, the intellectual property generated in new process and product domains will protect these advances from Asian and US competition. Before the project, the Department haven't built up on either theoretical or practical knowledge of organic semiconductors, but it had knowledge of inorganic LEDs. Our aim was the gaining of knowledge about organic semiconductors.

APPLIED METHODS

Correction of the heat conductivity measuring of printed circuit boards

I have estimated the heat conduction of boards by summing elementary layer thickness weighted elementary heat conductions. I have investigated by analytic method based on modified Bessel-functions the change of temperature distribution of given thickness and low heat conduction homogeneous boards by the shunting effect of the ambient air. The Heat Transfer Coefficient (HTC) was considered 6 … 14 W/m2K.

I have investigated the boards by the SunReD thermal field solver based on successive network reduction which applies finite differences method. I have made thermal DC and thermal transient simulations on the boards. The simulation results were evaluated by the T3Ster-Master [ ] evaluating software and by my own algorithm. I have determined the heat conduction increase caused by the air of 0.026 W/mK heat conductivity compared to vacuum by the so-called integral structure function gained from te simulation. I have made board and measuring equipment simulations by the FloTHERM computational fluid dynamics software. I havecompared the result of the different simulation methods. I have made thermal transient measurements on patterned and unpatterned printed wiring boards in air and in vacuum. By considering the effect of air I have developed and applied correction method(s). I have compared the results with the simulation results.

Heat-flux mapping on cooling surface of semiconductor devices

I have estimated the sensitivity and border frequency of the 100 mm^2 active surface Al-Si-Al sandwich structure heat flux sensor at the upper and lower limit of the planned temperature range. I have measured the 100 mm^2 active surface experimental heat flux sensor. As an experiment I have designed and made a 3 × 3 matrix arranged sensor to verify the possibility of determining the two-dimensional distribution of heat flux between the heating surface and heating equipment of a power device. By the experiences I have designed, made and measured a 6×7 cell sensor. By examples applied in electronics I have demonstrated the work of the sensor. By thermal transient measurement method I have made transient heat flux maps. I have realised that the ohmic resistance of sensor cells is temperature dependent thus it can be used also to measure temperature maps. I have shown that the sensitivity difference of sensor cells caused by different temperature of the cells can be corrected by using the related heat flux and temperature maps. I have designed a 2×1 arranged, combined heat flux and temperature sensor for the static TIM (Thermal Interface Material) tester. I have proved the raison dieter of heat flux measurement in microelectronics by application examples.

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on THERMal INvestigation of ICs and Systems (THERMINIC'09). Leuven, Belgium, 2009.10.07-2009.10.09. pp. 121-123.

C.14. A. Poppe, L. Pohl, **E. Kollár**, Zs. Kohári, H. Lifka, C. Tanase: Methodology for thermal and electrical characterization of large area OLEDs., LED PROFESSIONAL REVIEW *:(13) pp. 15-20. (2009)

C.15. A. Poppe, L. Pohl, **E. Kollár**, Zs. Kohári, H. Lifka, C. Tanase: Methodology for thermal and electrical characterization of large area OLEDs., In: Proceedings of the 25th IEEE Semiconductor Thermal Measurement and Management Symposium (SEMI-THERM'09). San Jose, Amerikai Egyesült Államok, 2009.03.15-2009.03.19. pp. 38-44.

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C.12. **E. Kollár**, I. Zólomy, A. Poppe: Electro-thermal modeling of large-surface OLED, In: Tarik BOUROUINA, Bernard COURTOIS, Reza GHODSSI,Jean Michel KARAM, Aurelio SOMA, Hsiharng YANG (szerk.) Proceedings of the Symposium on Design, Test, Integration and Packaging of MEMS/MOEMS (DTIP'09). Rome, Olaszország, 2009.04.01-2009.04.03. pp. 239-242.

C.13. **Ernő Kollár**, Gusztáv Hantos: Electro-termal modeling of different LEP-thickness white OLEDs. In: Proceedings of the 15th International Workshop

Multi-physical analysis of the OLEDs

In the last part of my dissertation I have studied the lighting purposes OLEDs. These I have carried out multi-physical analysis on these devices. I have studied the current, the voltage, the temperature, the light emission and the thickness of Light Emitting Polymer in same time. I have created device model both the forward and the reverse region form the measuring results. I have studied and modelled the spot defects on the OLED surface in both the optical and infrared ranges. I have performed device and spot defect simulations. These models are verified. I have carried out long term examinations. I concluded that the instruments used can be applied to the previously prepared model, the model parameters change over time of the correlation. I have compared the different lateral sized OLED structures. I have measured surface potential distribution on OLEDs. The measuring, the modelling, the defects and the different OLED constructions will help to plan and manufacture organic devices in the Department clean-room laboratory. I have estimated and found that you couldn’t have measure the heat conductivity and heat capacity of the organic semicondutors of the project due to the time resolution of the present thermal transient tester. I have measured surface potential distribution on OLEDs. I have found that ITO layer can reduce the potential difference between the organic layer in lateral direction.

NEW SCIENTFIC RESULTS (THESES)

T1.1. I have created an algorithm for decreasing the subjective error of evaluation for helping determining the local heat conduction values of printed wiring boards based on the evaluation of the temperature response of power step derived so-called structure function (λ-finder algorithm). The algorithm investigates the steepness change of a tight, symmetrical environment of a given point of the integral structure function consisting of discrete elements. I have determined the following heat conductance values for the whole range:

$$\lambda_n(R_{th}) = \frac{1}{4\pi \cdot w} \cdot \frac{\ln\left(\frac{C_{th(+n)}}{C_{th(-n)}}\right)}{R_{th(+n)} - R_{th(-n)}} ,$$

where w is the board thickness and n in R_{th} and C_{th} indexing means the n smaple later (+n) and n sample earlier (-n) R_{th} and C_{th} values (n = 1…20).
I have determined the following $\lambda_m(R_{th})$ average local heat conductance values and $\delta_m(R_{th})$ relative dispersion values:

$$\overline{\lambda}_m(R_{th}) = \frac{1}{m}\sum_{n=1}^{m}\lambda_n(R_{th}) ,$$

$$\delta_m(R_{th}) = \frac{1}{\overline{\lambda}_m(R_{th})}\sqrt{\frac{\sum_{n=1}^{m}\left(\lambda_n(R_{th}) - \overline{\lambda}_m(R_{th})\right)^2}{(m-1)}} ,$$

where m = 5, 10, 15, 20.
The R_{th} where $\delta_m(R_{th})$ functions together provide the smallest minimum is where $\lambda_m(R_{th})$ value gives the effective heat conductance. [C: 4]

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J.7. **Ernő Kollár**, László Pohl, András Poppe, Zsolt Kohári: Nonlinear electro-thermal and light output modeling and simulation of OLEDs. PERIODICA POLYTECHNICA-ELECTRICAL ENGINEERING (2011)

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C.1. M. Rencz, **E. Kollár**, A. Poppe, S. Ress: Evaulation issues of thermal measurements based on the structure function, 9th THERMINIC Workshop, Aix-en-Provence, France, 24-26 September 2003, pp. 219-224.

C.2. M. Rencz, A. Poppe, **E. Kollár**, S. Ress, V. Székely, B.Courtois: Increasing the accuracy of structure function based evaluation of thermal transient measurements, Proceedings of ITHERM 2004, June 1-4, Las Vegas, NV, USA, pp 85-90.

C.3. M. Rencz, A. Poppe, **E. Kollár**, S. Ress, V. Székely, B. Courtois: A procedure to correct the error in the structure function based thermal measuring methods, Proceedings of the XXth SEMI-THERM Symposium, March 9-11, 2004, San Jose, CA, USA, pp 92-98.

C.4. **E. Kollár**, V. Székely: Reducing the possibility of subjective error in the determination of the structure-function-based effective thermal conductivity of PCBs, 12th International Workshop on THERMAL INVESTIGATIONS of ICs and SYSTEMS 27-29 September 2006, Nice,Côte d'Azur, France, pp 28-32.

C.5. V. Székely, M. Rencz, **E. Kollár**, J. Mizsei: Heat-flux sensor for the thermal measurement of IC packages, 8th THERMINIC Workshop, Madrid, 1-4 Oct. 2002, pp. 83-88.

T3. thesis:
In the near future we would like to fabricate organic semiconductors in our clean-room laboratory. We have gained lot of experiment on OLED issues due to the measuring. It can be useful for further R&D. We would like to share our experiment for the students.

PUBLICATIONS

Related Publications

Journal Papers

J.1. M. Rencz, A. Poppe, **E. Kollár**, S. Ress, V. Székely: Increasing the accuracy of structure function based thermal material parameter measurements, IEEE Transactions on Components and Packaging Technology, Vol. 28, NO.1, March 2005, pp. 51-57.

J.2. M. Rencz, **E. Kollár**, V. Székely: Heat flux sensor to support transient hermal characterisation of IC packages, Sensors and Actuators, A. Physical, Vol. 116/2 pp 284-292, 2004.

J.3. V. Székely, **E. Kollár**, G. Somlay, P. G. Szabó, M. Rencz: Design of a Static TIM Tester. JOURNAL OF ELECTRONIC PACKAGING 132:(1) 9 p. Paper 011001. (2010).

J.4. Székely Vladimír, **Kollár Ernő**, Somlay Gergely, Szabó Péter Gábor, Juhász László, Rencz Márta,Vass-Várnai András: Statikus TIM teszter tervezése, HÍRADÁSTECHNIKA LXVI:(1) pp. 37-46. (2011)

J.5. László Pohl, **Ernő Kollár**, András Poppe, Zsolt Kohári: Nonlinear electrothermal modeling and field-simulation of OLEDs for lighting applications I: algorithmic fundamentals. MICROELECTRONICS JOURNAL 43: Paper Article in press. (2011)

J.6. Zsolt Kohári, **Ernő Kollár**, László Pohl, András Poppe: Nonlinear electrothermal modeling and field-simulation of OLEDs for lighting applications II:

T1.2. I have created correction curves by applying the thermal transient measurement for measuring in the air. I have found at measuring of the printed circuit boards that shunt effect of the air can be correctable, and the application of vacuum is not necessary. I have found that the radius of the isothermal ring of the measuring structure had an optimum.

I have found by analysis, that in the case of given thickness weak thermal conductivity material the radius of the isothermal ring is upper limited by the shunt effect of the air and the uncertainty in estimating of the heat transfer coefficient. I have created correction curves to correct the shunt effect of the air. I have found from the limits of the measuring that in the case of given thickness good thermal conductivity material the radius of the isothermal ring is under limited by the temperature resolution and the maximum dissipation of the heater transistor. I have proved by measuring that the console of the heater transistor behaves as parasitic heat path, and its correction is possible. I have calculated the recommended heat conductivity range of the applied isothermal ring. The results can be used to optimize the measuring structure and the reduction of measuring error. [J: 1, C:1-4]

T2.1. I have created an new, Al-Si thermocouple, three masks technology, heat-flux sensor array for microelectronical applications. The sensor is based on the gradient principle, it is formed from p-type silicon wafer, both sides of Si / Al contacts behave as thermocouples. These measure the temperature difference between the two sides, that is proportional to the heat-flux. I have made it able to measure heat-flux distribution by the matrix arrangement of contacts on one of the sides. I have realized the 6 × 7 array arrangement pilot sensor, which had 2,5 × 2,5 mm cells. I have compared to theoretical calculation and measured results and I have verified it between 5 and 95 °C temperature range. [J:2, C:5-9]

T2.2. I have examined the temperature depending of the heat-flux sensor sensitivity by measuring. I have gained the next result at Al-Si contacts, 356 µm sensor thickness, and 6,25 mm^2 sensor surface:

$$\gamma_{heatflux}(T = 0^\circ C) = \left(500{,}6 + 1{,}287 \frac{1}{^\circ C}\right)\frac{\mu V}{W}$$

The temperature depending of the heat-flux sensor sensitivity (T = 0 ºC):

+0,002 57 1/ºC ± 10 %

[J:2, C:5-9]

T2.3. I recognized that the ohmic resistance of sensor cells is temperature dependent thus it can be used also to measure temperature maps. The matrix sensor array also can use to temperature mapping. I have found the temperature dependence of ohmic resistance of sensor:

$$\gamma_{ohmic\ resi\tan ce}(T = 0^\circ C) = +0{,}87 \frac{\%}{^\circ C} \pm 2\%$$

I have presented that the temperature dependence of the heat-flux sensitivity of sensor can be corrected by temperature map. [J:, C:6-8]

T2.4. I have planned a combined heat-flux/temperature sensors for a TIM (Thermal Interface Material) tester. These sensors are the one of the most important part of the TIM tester. The temperature drop on the TIMs can be measured so far more accurate than by sensor pair aided way. [J:3,4, C:10]

T3.1. I have created a temperature depend OLED circuit modell, which can handle in same time the current, the voltage, the temperature, the light emission and the thickness of Light Emitting Polymer.

$$I(T, d_{LEP}) = \overline{T} \cdot \overline{\overline{B}} \cdot \overline{d_{LEP}} \cdot U^{\overline{T} \cdot \overline{\overline{M}} \cdot \overline{d_{LEP}}}$$

$$\Phi_E / \Phi_V (T, d_{LEP}) = \overline{T} \cdot \overline{\overline{M_\Phi}} \cdot \overline{d_{LEP}} \cdot I + \overline{T} \cdot \overline{\overline{B_\Phi}} \cdot \overline{d_{LEP}}$$

On given OLED structure I have defined by measuring the elements of the quadratic matrix. [J:5-7, C:11-18]

T3.2. I have recognized, that the spot defects in the OLED's LEP layer can be modelled by ohmic resistance. I have presented the device behavior in the case of low, middle and high impedance spots.
Around the defect I have verified the temperature distribution by infrared camera quantitative way, and the luminous intensity distribution by digital camera qualitatively way. [J: 5, 6,7, C:11-18]

PRACTICAL APPLICATION OF THE RESULTS

<u>T1. thesis:</u>

The knowledge of heat transfer in disk-like material is important around the high power devices. The research results help the measurement and these decrease the measuring errors. The results may be used to thermal optimization of the applied structure and reduce systematic errors.

<u>T2. thesis:</u>

The sensor was built in an equipment, which was developed to measure the thermal properties of TIMs. The results can allow the more accurate examination of thermal properties of TIMs which have smaller specific heat resistance than conventional materials TIMs. These materials are very important between cooling surface of the high dissipation devices and the cooling mount. The matrix array arrangement sensor can be used typical of research and development: thermal characterization of special devices, dynamic thermal compact modelling, thermal verification.