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Applications of infrared thermography in electronics research

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Abstract:

In the course of time, power densities in electronics have been continuously growing. Since excessive dissipated power leads to elevated temperatures affecting on functionality, usability, and reliability of electronic device, interest to thermal phenomena occurring in this specific frame of reference has respectively increased in order to enable enhancing the thermal quality of products. One considerable tool to facilitate this work is infrared thermography. In this paper, some not yet so common applications of infrared imaging in electronics thermal management related research are concisely described with examples.

1. Introduction

An electronic device always produces waste heat, and in time its amount has drastically and continuously increased. This trend is depicted from a few last years' time in Fig. 1, which shows the recent power dissipation levels for laptop microprocessors. The figures for 1998 and 1999 are estimates from year 1997 – the reality (PIII) is even harsher. When simultaneously the physical dimensions at all levels of electronics, from chips to cabinets, are rapidly contracting, the ability to handle the dissipated energy so that the temperature all over the system remains acceptable becomes more and more essential.

In order to manage this challenging task, one has to know thoroughly the thermal phenomena and related factors appearing in electronics environment. Unfortunately, in reality this aim is complicated by the fact that often the rigorous analytical treatment of the real device, where all three heat transfer modes are considerable, may prove extremely difficult if possible at all. This emphasizes the significance of precise numerical simulations, taking advantage of adequate simplifications, and complementary experimental measurements to verify their validity.

Infrared (IR) thermography is a natural selection for one such evaluation tool. It has been utilized in thermal management of electronics for some time [1, 2], and the application rate is growing deducing from the number of publications. As a 2-D imaging technique, infrared thermography enables a straightforward and fast way to map the entire temperature distribution on whole area of interest in one go. Taking into account the sometimes unexpected thermal behavior of electronics, this may be a very advantageous feature comparing with traditional point-measurement techniques such as thermocouples. In addition, IR camera enables both capturing of single frames or, when required, recording entire image sequences to study time-dependent phenomena.

For long, the typical application of thermography in electronics has mostly been plain inspection of design prototype or final products for possibly overheating components or otherwise problematic areas ('hot spots'), or fault detection and localisation when the product has been returned for service. In these duties, the technique has clearly demonstrated its power to save considerable costs.

Quintessential problems appearing in IR imaging of electronics and limiting the applicability of the method are varying emissivities and inaccessibility of samples in operational use. These issues can be at least partially compensated by using such means

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as emissivity equalization, IR transparent windows, and temporal backwards extrapolation of true temperatures.

In addition to these fundamental issues, a few other from the thermal management research point of view interesting approaches are described below with illustrating quantitative examples. Such issues are heat transfer studies from heat source to its environment, validation of computational fluid dynamics (CFD) calculations, verification of thermal design of real products, mapping the temperature distributions in research demonstrators, effect of accruing impurities on thermal performance of electronics, required IR imaging procedures in various measurement cases, direct microscopic imaging of operational dies, and operational visualization of advanced cooling techniques.

2. Examination of demonstrator units

An often useful method to experimentally study and predict the thermal behaviour and related heat transfer mechanisms in sometimes very complicated real electronic devices is to design a simplified mock-up demonstrator unit, in which all the inessential electronic and mechanical complications are removed but which is thermally similar to the original set-up. In this way the real device can be emulated in well-controlled environment and the effect of design variables can be easily tested. Simultaneously, the numerical model will usually be drastically simplified.

An example of measuring such a demonstrator is shown in Figure 2, where Fig. 2 a) depicts a numerical CFD simulation of the demonstrator temperature distribution and Fig. 2 b) shows the actual temperatures measured with an IR camera. Frequently, like also in this case, the CFD results may easily underestimate the true temperatures. Thus, the experimental verification of the calculations is always necessary.

3. Visualisation of heat transfer and cooling devices

Also the impact of additional cooling methods such as minifans, microjets, heat sinks, enhanced heat transfer routes, and heat pipes (HPs) on thermal behaviour of the source can often be easily examined by using IR thermography.

As an example, Fig. 3 depicts a flat, oscillating [3] aluminium HP compared with a similar Al slab. A heat pipe is a heat transfer device based on cyclic evaporation and condensation of working fluid at opposite ends of an evacuated tube, and an oscillating HP is a rather novel specific HP type under eager research at the moment.

Both samples were heated resistively from one end and the other end was set to fixed temperature with a cold plate. In this application, the HP turned out to be superior heat transfer device, staying practically adiabatic between the evaporator and the condenser. At 40 W load, the gradient is approximately ¼ times smaller and the hot end temperature 16° C less compared to the readings on the Al slab excited with only 10 Watts.

In addition, we have studied the pulsating behaviour, starting point of operation, and the operational limits of the oscillating heat pipes using IR thermography. Entire heat transfer routes utilising traditional HPs, effects of highly conductive and phase-change materials, heat distribution on heat sinks etc. have as well been examined.

4. IR imaging of electronics inside enclosures and emissivity correction

Maybe the most limiting problem of using IR thermography is that the practical devices in their operational environment of use are located inside enclosures, thus disabling direct thermal imaging. Test results obtained elsewhere cannot give the full picture of the sample. Two possibilities to avoid the problem are 1) to replace part of the enclosure with IR transparent material or 2) to extrapolate the earlier temperature backwards in time after revealing the sample from its chassis and thus changing the measurement circumstance.

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Although useful, the methods have their restrictions as reported previously [4, 5]. Both flexible (such as LDPE film) and solid (ZnSe, for instance) window materials are able to provide reliable results when appropriately calibrated with thermocouples and transparency function of the camera properly adjusted. However, in applications in which the window material constitutes an important heat transfer route or is exposed to stress the solid option is preferred. The extrapolation, for its part, may lead to considerable underestimations of operational temperatures especially if the sample has to be moved for imaging when its is subjected to forced convection by draught.

Another unfavorable feature of electronics objects is varying emissivity, which makes the estimation of real temperatures tedious. Although emissivity correction algorithms based on reference images captured in known temperature may often facilitate the measurements, the practice has shown that covering the sample with a layer of known emissivity provides most reliable results.

5. Reference printed wired board platform

In addition to above-mentioned case-specific demonstrators, often a more generic, well-controlled platform maybe comprising some product range-specific features is very practical for reference purposes. We have constructed such a PWB representing the most essential thermographic features from telecommunication electronics point of view. It has proven quite useful in such applications as performance comparisons of IR imaging set-ups, procedures and operators, introducing thermography to beginning or occasional operators, studying factors influencing the measurement results and their accuracy, examining the hardware independent phenomena like deposition of impurities on thermally interesting surfaces, and comparison of numerical simulations to measurement results. The reference platform has also considerably facilitated creating company-wide guidelines to produce common practice and commensurate reports.

6. Investigation of exposed silicon chips

Certain component packaging techniques enable direct imaging of operating dies or in some cases they may be exposed if desired. However, such difficulties as microscopic structural details, IR transparency and reflectance of silicon, inadequate spatial resolution, and low emissivity of both Si and metallisations immediately arise.

In Figure 4, a microscopic infrared image of a RF power amplifier mounted in ceramic air-cavity package is shown. In addition to defining the run-time thermal behaviour of the chip, the experimental data were used to validate the component-level numerical simulations and to study the applicability of microscopic IR method. The comparison against the simulation values indicates that the quantitative spatial resolution of the IR camera at which accurate temperature values can be obtained is too coarse to pick up the fine structure and real maximum temperature of the component. On the other hand, it also alludes that the simulations may underestimate the lateral heat diffusion in the component.

7. Heat conduction in PWBs

Usually the most important heat transfer route from the heat source is conduction from the chip via the package to the PWB. In the example depicted in Fig. 5, steady state thermal performance of an isolated SO-8 package is experimentally characterised on five thermal test PWBs [6]. The study includes three FR4 and two insulated metal substrate (IMS) standard test PWBs, each displaying a different internal structure and effective thermal conductivity. Temperature line profiles over the test component in each case were recorded with an IR camera.

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The study clearly illustrates the sensitivity of component operating temperature to the PWB construction. The case temperatures of the component can drop even 45 °C at this standardised and thus representative measurement arrangement. The decrease of PWB surface temperature is as obvious, which is an important factor since in practice the board is fully equipped and the different components interact thermally via the PWB.

8. Conclusions

As seen, infrared thermography is a versatile and powerful instrument to apply both in thermal design work of electronics and in studying the specific thermal phenomena taking place in such applications. However, there are also dangers in using IR cameras of which both operators and all users of the obtained data must be aware of. Especially emissivity variations may easily misguide less experienced operators, who often have no actual IR training but are experts in other areas such as electronics design.

At all electronics assembly levels, combination of recording the actual chip temperatures, imaging the temperature distribution with IR camera, and verifying the measurement with reference thermocouples mounted in strategic locations provides a rather reliable measurement data. Keeping all the effective factors in mind, infrared camera certainly is an inestimable tool for electronics thermal management – not only in fault detection, but also in providing quantitative research data required to manufacture thermally more advanced products.

Acknowledgements

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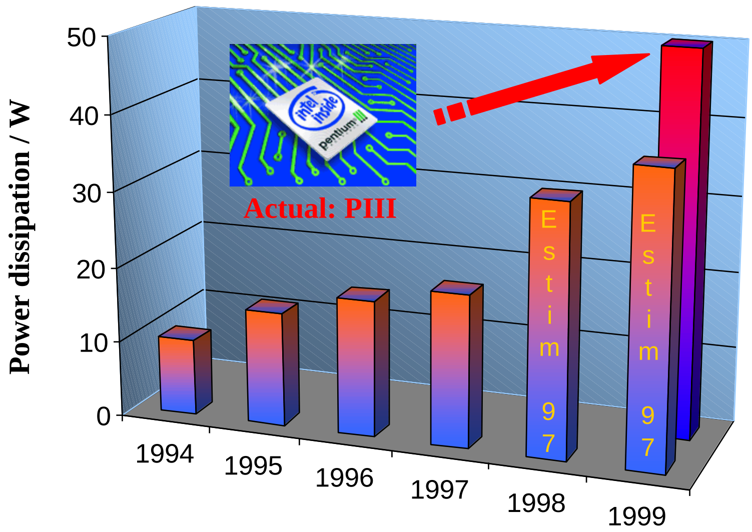

Figure 1: *Recent trend of laptop processor dissipation power level. Figures for 1998 and 1999 are estimations from year 1997; the actual dissipation of Pentium III is even higher. (Source: Intel Corp.)*

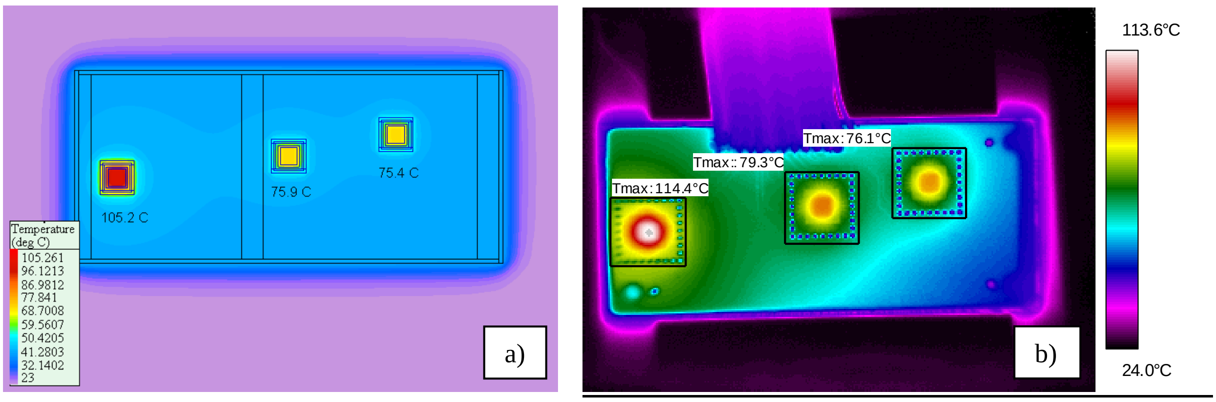

Figure 2: *a) A numerical simulation, and b) An infrared image of a demonstrator device. Infrared measurement reveals deviation compared to simulation values*.

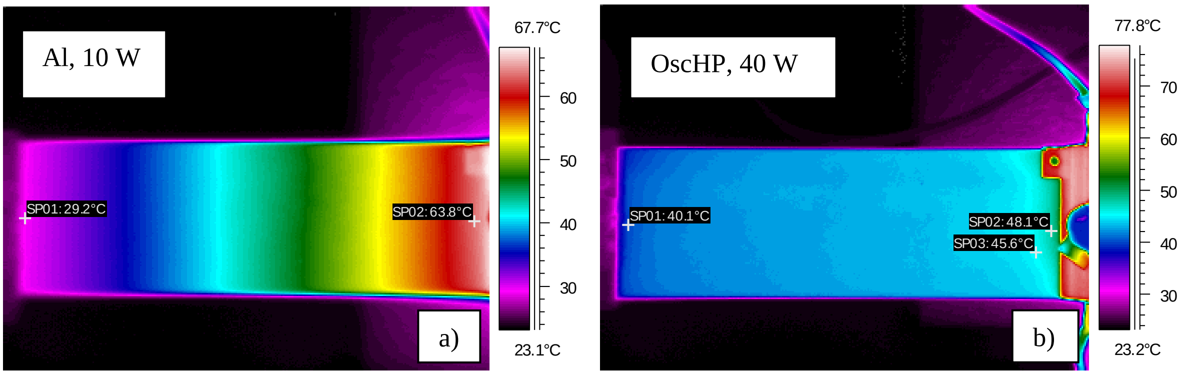

Figure 3: *a) Temperature distribution in an Al slab excited with 10 W, and b) Distribution in an oscillating heat pipe with 40 W. Gradients are 35 °C and 8 °C and the evaporator temperatures 64 °C and 48 °C, respectively.*

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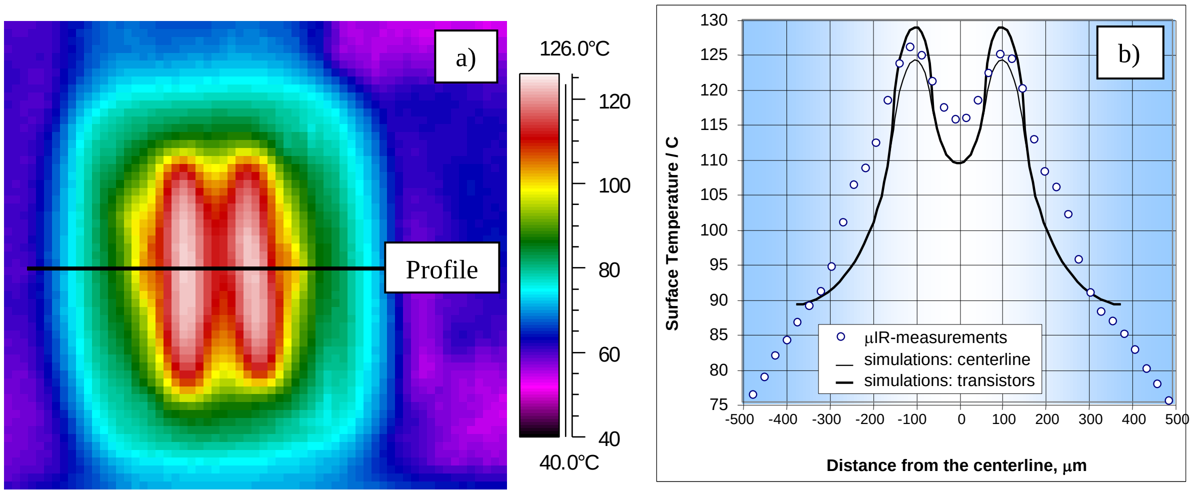

Figure 4: *a) An IR microscopic image of an exposed power component, and b) Corresponding simulation. The image width in a) is 1.5 mm. The simulation results indicate inadequate IFOV for accurate temperature measurement.*

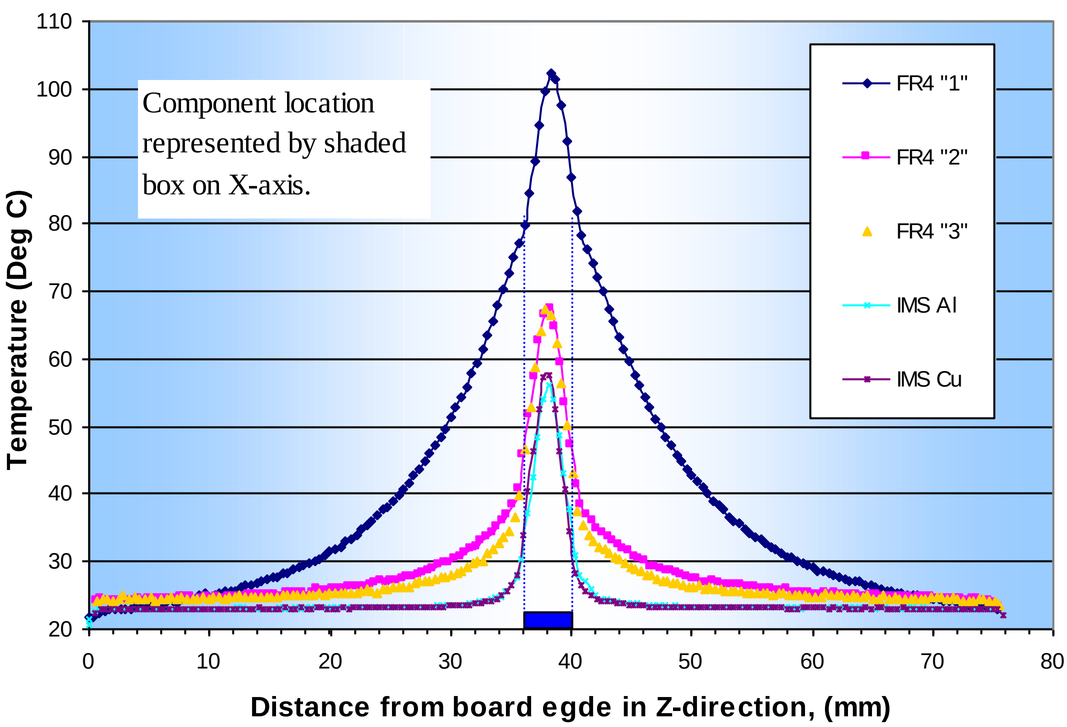

Figure 5: *A study of heat diffusion from component to PWB. The profile measurements are performed with an IR camera, and the effect of different PWB types is obvious: component case temperatures drop several tens of degrees.*