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Infrared Thermography application to functional and failure analysis of electron devices and circuits

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ABSTRACT

In this paper the principal and more important application of Infrared Thermography are discussed. In particular the application of this experimental technique, both in its transient and steady-state mode of operation, are reported and illustrated through a broad set of experiments and examples. Functional application to the characterization of VLSI devices, application to the failure analysis of large area power devices, current monitoring in state-of-art heterojunction and organic devices prove the high potential of this technique.

1. Introduction

Among all the non-contact techniques used to monitor the operation of an electronic device or circuit, Infrared Thermography stands out thanks to many attractive features. Following the commercial market availability of high sensitive infrared sensors, nowadays the range of infrared (IR) cameras, that can be applied to characterize the temperature distribution across a semiconductor device, has increased considerably. As current flow within the volume of a semiconductor device generates heat according to the Joule's effect, temperature differences in the devices are inherently presents during its operation. Accordingly many papers relevant to the application of this technique field of characterization of electron devices have appeared and the flexibility of this tool has been proven [1–3].

IR cameras can be arranged to monitor temperature variation on packaged discrete devices, PCBs or for accurate on wafer characterization if assembled together with a standard wafer probe station. To this extent it is likely to foresee that it will become a more and more common inspection tool in research laboratories at almost any device production stage. In Fig. 1 a Karl Suss PM5 probe station custom equipped with a FLIR Merlin Mid-IR camera, for on wafer temperature measurement, is depicted.

In this paper, after a short review of the fundamental applications of IR Thermography to the monitoring of semiconductor devices, a wide range of examples will be reported to show its flexibility and usefulness. Before entering the details some background in IR Thermography is reported for readers' convenience.

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2. Infrared radiation

Usually the part of the electromagnetic spectrum involved in thermography study is located in the 1–10 μm range even if longer wavelengths ($\lambda > 10$ μm) are becoming attractive in recent instrumentation. This range is commonly referred to as Thermal Infrared. State-of-art IR cameras are made by arrays of sensors capable of detect IR radiation in these ranges and convert it into a digital signal. Usually the choice of the sensor is made according to its sensitivity if steady-state measurements are required, or by its speed if fast thermal transients need to be investigated, as it is usual case in the characterization of electron devices and circuits.

A black body in thermal equilibrium at a given temperature, emits electromagnetic radiation according to the Planck's law:

$$B(\nu, T) = \frac{2h\nu^3}{c^2} \frac{1}{e^{\frac{h\nu}{kT}} - 1}$$

where B is the spectral radiance, T is the absolute temperature of the black body, k is the Boltzmann constant, h is the Planck constant, and c is the speed of light. In Infrared Thermography it is common use to refer to the wavelength λ of the emitted radiation instead of its frequency ν.

3. Steady state and lock-in thermography

The dissipated heat in a semiconductor device subject to steady-state biasing condition can be characterized in terms of temperature distribution usually evaluated on the top surface of the device. To this aim, low-cost bolometric sensors can be used as the temperature differences are relevant and no special requirements regarding the camera frame rate or the sensor integration time are requested. One of the biggest issues in having temperature-calibrated images from radiometric data regards the different

Fig. 1. Probe station equipped with an IR camera for on wafer temperature mapping.

emissivity values of the materials usually employed on top surfaces of semiconductor devices. Even more important is the different temperature dependence of the emissivity for metals and dielectrics usually employed as a passivating layer. Although some compensation technique have appeared and also black painting of the device surface has been proposed but, as this additional layer changes the thermal behavior of the device under test (especially in transient measurements), the most robust and reliable solution to this issue is the off-line calibration of the IR setup by passive heating the device and subsequent calibration of the radiance data (see Fig. 2).

An example of what can be obtained with this approach is reported in Fig. 3 where the temperature distribution on a GaN HPA used for RF application is reported [4,5]. By inspecting the temperature map, it is possible to distinguish which part of the amplifier are in operation, i.e. the pre-amplifier on the left and the final stage on the right, and if current focalization phenomena appear. Quantitative information, such as the thermal resistance of

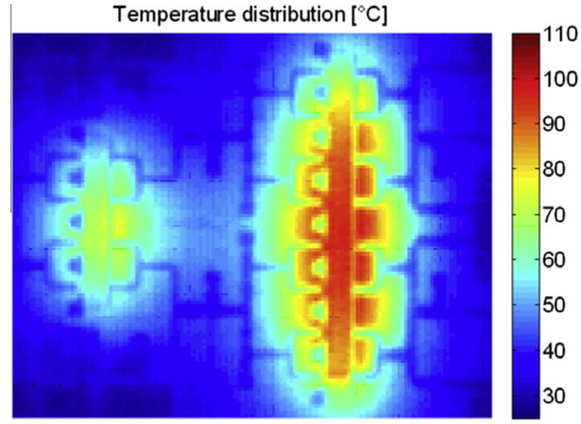

Fig. 3. Temperature map on a GaN HPA subject to steady state biasing.

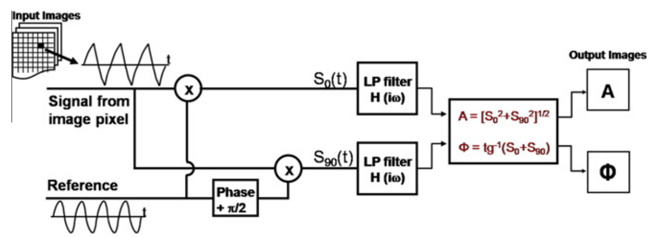

Fig. 4. Block diagram of a lock-in detection approach.

the device under test, can be retrieved from steady-state measurements, as the dissipated power is known from the electrical bias point and the temperature increase can be directly evaluated from the thermograms.

If the temperature variation, or in other terms, the current flow is not high enough to be detected, the lock-in approach can be used [1]. We recall that this very accurate technique consist in the synchronous detection of the device heating using an heterodyne demodulation scheme as reported in Fig. 4.

The minimum temperature detectable with a lock-in scheme, for a full-frame sampling frequency of 50 Hz common to most of IR cameras, falls quickly toward the 100uK range in minutes as it is represented Fig. 5.

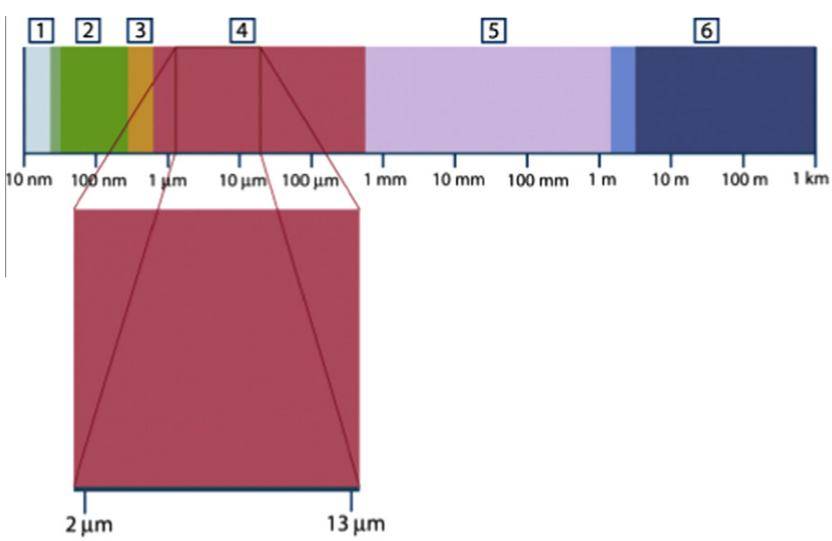

Fig. 2. The electromagnetic spectrum. (1): X-ray; (2): UV; (3): visible light; (4): IR; (5): microwave; (6): radio waves.