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Application Note

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Detecting Hot-Spots and Other Thermal Defects on a Sub-Micron Scale in Electronic and Optoelectronic Devices

The Future of Thermal Imaging is Here!!!

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Introduction

Detecting sub-micron time-dependent thermal defects and identifying those that represent potential device failures is a challenge in analysis for today's complex electronic devices. The scaling of device features results in a significant reduction in time response and an increased sensitivity to transient events. With today's complex devices very small localized temperature 'hot spots' can occur due to an unintended functional anomaly in a circuit with a tight design margin or a timing perturbation resulting from a small change in capacitance or another parameter elsewhere in the circuit. As device features continue to shrink so do the challenges of detecting circuit-induced thermal defects. This has led to the development of statistics-based, large-area sampling methods that can be time-consuming with results that often miss small scale circuit defects.

Thermoreflectance thermal imaging offers a cost-effective approach for detecting and analyzing hot spots on a sub-micron scale and, with the addition of transient analysis capability, offers the potential to identify time-dependent temperature events with nanosecond resolution.

This application note is focused on the ***hot spot detection*** aspect of thermoreflectance thermal analysis. It will provide some insight as to the spatial resolution that is achievable and provide an example to illustrate the thermal imaging results that can be obtained.

Thermoreflectance enables thermal imaging on a sub-micron scale

Thermoreflectance imaging is based on the fact that a material's surface reflectivity is a function of the material's temperature. On a microscopic level, the refractive index is temperature-dependent since the distance between atoms varies with temperature. This results in a small change in the material's reflectivity. To a first orfder, the change in reflectivity can be expressed as:

$$\frac{\Delta R}{R} = \left(\frac{1}{R}\frac{\partial R}{\partial T}\right)\Delta T = \kappa \Delta T$$

Where $\boldsymbol{\kappa}$, is the ***Thermoreflectance Coefficient***

The Thermoreflectance Coefficient is an inherent property of the material being analyzed and is strongly dependent on the wavelength of the illuminating source. Further discussion about the thermoreflectance coefficient and its material dependence can be found in these references. [1, 2]

For ***top-side imaging***, the Microsanj NanoTherm-Series thermal analyzers use illuminating sources in the visible range, with wavelengths from 450 nm (Blue) to 700 nm (Red). This wavelength range encompasses optimal choices for generally encountered materials used in today's optoelectronic and electronic devices. For ***'thru-the-substrate' imaging***, wavelengths in the near-IR range from 750 nm to about 1400 nm are used. Silicon is virtually transparent at a wavelength of 1100 nm.

At low magnification levels, the spatial resolution is essentially given by the camera pixel pitch divided by the overall magnification of the optics. At higher magnifications, the spatial resolution is limited by diffraction and the numerical aperture (NA). The spatial resolution is approximately equal to $\lambda/2$ for NA = 1. Fig. 2 shows the relationship for other NA values.

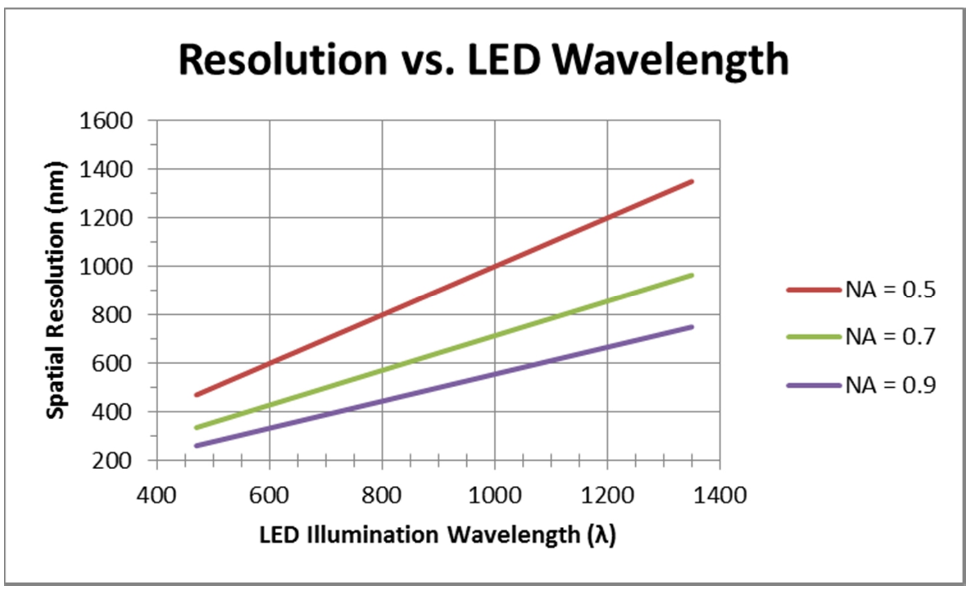

Figure 1: Spatial resolution vs. illumination wavelength and NA

Example: A multi-finger Silicon MOSFET with a gate defect

In this example a gate defect in a silicon multi-finger MOSFET is used to illustrate the spatial resolution of the thermoreflectance technique in the detection of a hot-spot caused by. The LED illumination wavelength for this example is 470 nm. Fig. 1a shows the thermal image of the device overlaid on the 50x optical image. Fig. 1b provides an enlarged view of the region with the defect. Fig 2c shows the temperature scan along the line-scan shown in Fig 1b which passes through the OBSERVED hot-spot. The full-width-at-half-maximum hot-spot size is measured to be approximately 1.4 µm.

The overlay of the 50x optical image and thermal image shows the precise location of the defect on the MOSFET. The averaging time for this image was 3 minutes enabling a temperature resolution of approximately 0.1 °C. The temperature rise at the hot-spot is more than 50 °C. If the absolute temperature is of interest, it can be determined from knowledge of the surface material for the hot-spot location or by knowing the specific thermoreflectance coefficient at the location of interest. With that information, the absolute temperature can be automatically calculated by the embedded SanjVIEW software.

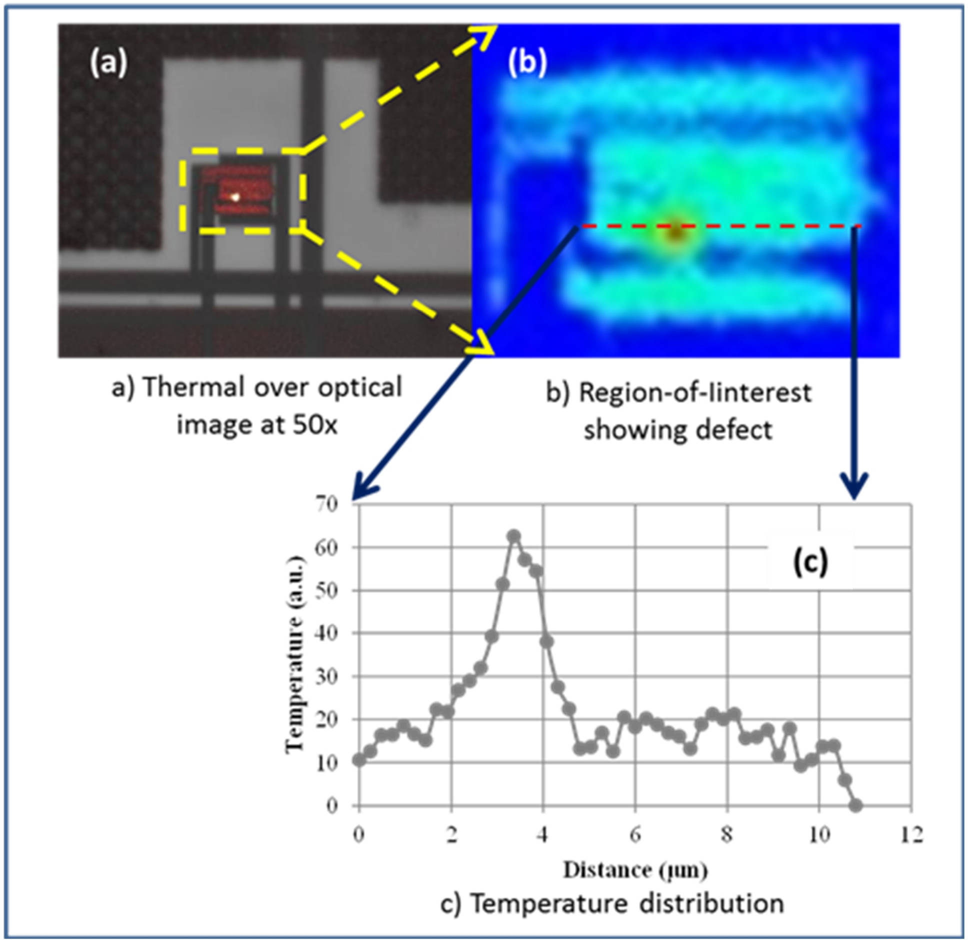

Figure 2: Thermal analysis of MOSFET with gate defect

It is important to mention that thermal measurements as described in this note can be obtained without any special sample preparation as may be required by other thermal imaging techniques. Thermal images can also be obtained at ambient temperature, there is no need to elevate the device or wafer temperature to get high quality images with good spatial resolution.

Conclusion

Many types of defects in microelectronic or optoelectronic devices will cause excessive power dissipation at or near the area of the defect resulting in a thermal hot spot. The resulting hot spots can be detected and analyzed with thermal imaging. Only thermal imaging based on the thermoreflectance technique can detect hot spots on a sub-micron scale, a scale essential to meet the imaging requirements of today's commercially available devices.

References

[1] AN-003: Understanding the Thermoreflectance Coefficient
http://www.microsanj.com/application-notes/understanding-thermoreflectan...

[2] Understanding the Thermoreflectance Coefficient for High Resolution Thermal Imaging of Microelectronic Devices
http://www.electronics-cooling.com/2013/03/understanding-the-thermoreflectance-coefficient-for-high-resolution-thermal-imaging-of-microelectronic-devices/

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