

# Appendix — Thermoreflectance Technical Reference

# Appendix — Thermoreflectance Technical Reference

*(Source Appendix A/B — retained here as background reference material.)*

## Thermoreflectance Imaging Fundamentals

Thermoreflectance imaging is based on a linear change in a material's reflection coefficient with temperature (Equation 1 in the source:  $\Delta R(x,y,\lambda)/R(x,y,\lambda) = C_{th}(x,y,\lambda) \cdot \Delta T$ , where  $C_{th}$  — the thermoreflectance calibration coefficient, typically  $10^{-3}$  to  $10^{-5}$  per  $^{\circ}\text{K}$  — depends on sample material, illumination wavelength, angle of incidence/surface roughness, and sample composition). This is a highly sensitive lock-in technique measuring per-pixel changes in reflected light, sensitive to shifts/thermal expansion at length scales of 580 nm at 20x magnification. Proper experimental setup and surface condition are important for measurement quality. First noted in the 1960s.

Reference publications cited in the source:

- J. Christofferson, K. Maize, Y. Ezzahri, J. Shabani, X. Wang, A. Shakouri, "Microscale and Nanoscale Thermal Characterization Techniques," J. Electronic Packaging, Dec 2008, Vol.

130, Issue 4, 041101.

- Y. Ezzahri, J. Christofferson, G. Zeng, A. Shakouri, "Short time transient thermal behavior of solid-state microrefrigerators," J. Appl. Phys, 106, 114503 (2009).
- B. Vermeersch, J. Christofferson, K. Maize, A. Shakouri, G. De Mey, "Time and Frequency Domain CCD-Based Thermoreflectance Techniques for High-Resolution Transient Thermal Imaging," Proc. IEEE 26th SEMI-THERM, Feb 23–25, Santa Clara CA, pp. 228–234, 2010.
- Mihai G. Burzo, Pavel L. Komarov, Peter E. Raad, "Non-Contact Transient Temperature Mapping Of Active Electronic Devices Using The Thermoreflectance Method," IEEE Trans. Components and Packaging Technologies, Vol. 28(4), pp. 637–643, 2005.
- Pavel L. Komarov, Peter E. Raad, "Performance Analysis of the Transient Thermoreflectance Method for Thermal Conductivity of Single Layer Materials," Int. J. Heat and Mass Transfer, Vol. 47, pp. 3233–3244, 2004.
- M. Farzaneh, K. Maize, D. Luers, J.A. Summers, P.M. Mayer, P.E. Raad, K.P. Pipe, A. Shakouri, R.J. Ram, Janice A. Hudgings, "CCD-based thermoreflectance microscopy: principles and applications," J. Physics D: Applied Physics, vol. 42, p.143001, 2009.
- M. Farzaneh, Joe Summers, R.J. Ram, J.A. Hudgings, "Thermal and optical characterization of photonic integrated circuits by thermoreflectance microscopy," J. Quantum Electronics, vol. 46(1), p.3-10, 2010.

Because reflection changes are imperceptible to the human eye, the system relies on high-resolution, low-noise equipment and sophisticated averaging. The NT220 provides two averaging modes:

- **Low Frequency Imaging:** Uses frequency-domain filtering to resolve minute reflection changes. Can be done without pulsed illumination; enables lower-frequency thermal imaging (down to 0.48 Hz) in "Transient" mode. It's possible to obtain low-frequency thermal images without the BNC 6040/202H LED pulse generator, provided illumination is CW (non-pulsed) — this allows illumination wavelengths beyond the provided pulsed LEDs (e.g., white light plus a bandpass filter for a specific wavelength). Disable the pulse generator (uncheck "use BNC 6040/202H" in Project Manager) when using CW illumination to avoid unnecessary wear on the BNC and pulsed LED.
- **Transient Thermoreflectance Imaging:** Captures thermal image "snapshots" at precise points in the heating/cooling cycle via precise timing of illumination flash vs. device excitation. Has a slightly lower noise floor (0.2°C vs. 0.5°C) than low-frequency imaging and is preferred when possible. A transient image series visualizes the device's change across the active heating cycle; the analyzer can display temperature at a given point across different times.

# Thermoreflectance Material Coefficient

The thermoreflectance coefficient is a material property that depends on temperature and illumination wavelength. Unlike IR emissivity, it is not strongly dependent on surface preparation or deposition method, so per-device calibration is generally not necessary (e.g., Microsanj has found consistent thermoreflectance coefficients for gold across various thermal/E-beam evaporation techniques). If the material's visual color changes significantly due to major microstructure/porosity changes, the coefficient may be modified significantly. Microsanj provides thermoreflectance coefficients for basic IC materials at the system's included LED colors. For new material systems: the coefficient can be extracted directly if there's an embedded on-chip temperature sensor near the ROI; otherwise, a small chip sample (1x1 mm<sup>2</sup> up to 1x1 cm<sup>2</sup>) can be sent to Microsanj for in-house characterization.

For a region of interest covered in Aluminum, use the provided 780 nm LED — the coefficient is too small at 530 nm (green) or 470 nm (blue) for usable thermal images.

Additional reference materials cited:

- G. Tessier et al., "Thermoreflectance temperature imaging of integrated circuits: calibration technique and quantitative comparison with integrated sensors and simulations," 2006 J. Phys. D: Appl. Phys. 39, 4159.
- Burzo, M.G., Komarov, P.L., Raad, P.E., "Pixel-by-pixel calibration of a CCD camera based thermoreflectance thermography system with nanometer resolution," Thermal Investigations of ICs and Systems, THERMINIC 2009.

**Dielectric coatings:** Coatings change the reflectance coefficient and therefore the thermoreflectance coefficient. Where uncoated regions exist on the sample, use temperature continuity on the surface to calibrate the image; otherwise, Microsanj can determine the coefficient for a coated sample if a small piece is provided. Thin-film interference can cause oscillations in the reflected data on samples with non-uniform film thickness (an inherent optical property) — averaging measurements across different color LEDs can help detect and remove this oscillation envelope/optical artifact.

**Microscope objective numerical aperture:** The thermoreflectance coefficient can depend on objective NA due to the light component polarized perpendicular to the surface (non-negligible above NA ~0.5). Microsanj-provided coefficients specify the objective and illumination LED used. For precise temperature-distribution measurements with high-NA lenses, it's suggested to first measure with a low-NA lens over a larger area, then switch lenses (without altering the device) and scale the temperature data accordingly. Standard objectives are optimized for the visible (VIS) band but can be used beyond that range with reduced sensitivity; Microsanj offers objectives optimized for NUV or NIR performance.

- **12.2.2.1 Optional Objectives for TR Mode** (NA, FOV, Working Distance, resolution): [diagram/image in source — not reproduced here, table not extracted]
- **12.2.2.2 Optional Objectives for IR Mode** (FOV, Working Distance, resolution, for the NTIR220): [diagram/image in source — not reproduced here, table not extracted]. With the 1x or 2x optional IR lens, spatial resolution improves with an offset in Field of View (FOV).

**Measurements at different ambient temperatures:** Thermoreflectance can operate over a wide temperature range down to cryogenic temperatures — Microsanj has imaged gold contact layers in small devices with sub-micron spatial resolution from 10 K to 800 K. For measurements below 5–10°C, use a cryostat with an optical window to avoid water condensation on the sample.

# CCD Camera / 4D Nano Align Temperature Controller Reference

*(Source Sections 13.1–13.2 — content in the source consists entirely of figures/tables with no extractable body text.)*

[diagram/image in source — not reproduced here: Section 13.1 CCD Camera reference; Section 13.2 4D Nano Align Temperature Controller Reference]

---

Revision #1

Created 2026-08-26 18:17:02 UTC by Accounts

Updated 2026-08-26 18:17:02 UTC by Accounts