Hot Spots: Methods for Detection and Analysis

Thomas Tarter
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Thermal Design Center

PACKAGE SCIENCE SERVICES LLC

3287 Kifer Road
Santa Clara, CA 95051
+1-800-218-1573 +1-408-969-2388
www.pkgscience.com

Outline

- Hot Spots
- Detection
- Package Defects: Void Formation
- Detection
  - Non-destructive Methods
  - Heating Curve
  - Destructive Methods
- Summary
- Q&A

Hot Spots

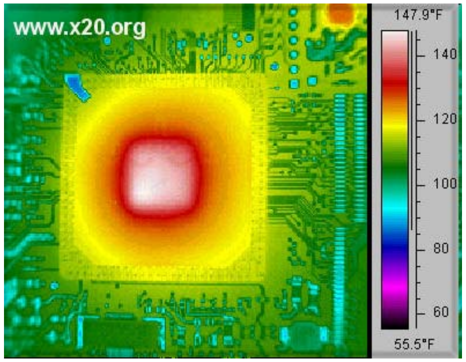
- Localized areas with a higher temperature than the surrounding area
- Can be caused by several phenomena
    - Short or near short circuit
    - On-chip circuitry with concentrated power dissipation
    - Voids in materials that aid in heat transfer away from the power dissipating element
        - Die attach
        - Mold compound
        - TIM 0
        - Underfill

Surface Hot Spot Detection

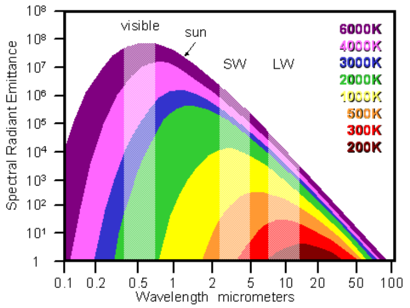
- Hot spots on chip surfaces
  - Temperature and stress gradients
  - Overtemperature condition
  - Material failures
  - Thermal runaway
  - Signal and power integrity problems
- Detection methods
  - Infrared
  - Thermoreflectance
  - Emission microscopy
  - Liquid crystal

Infrared Thermography

- IR cameras used for thermography
  - Typically fall in the long-wave IR category
    - ~10um wavelength
  - Use a micro-bolometer focal plane array to gather information on the radiosity of an object
  - This information is in turn ‘colored’ to produce temperature information
- All objects emit radiation as a function of temperature
  - Emissivity
    - Reflection and transmission



Infrared Thermography



- Measurement of radiosity
  - Infrared radiation emitted by a body
  - Emitted, reflected and transmitted infrared energy
  - Conservation of energy

$$\varepsilon + \rho + \tau = 1$$

    - ε = emissivity, ρ = reflectivity, τ = transmissivity
  - For opaque targets, $\tau = 0$

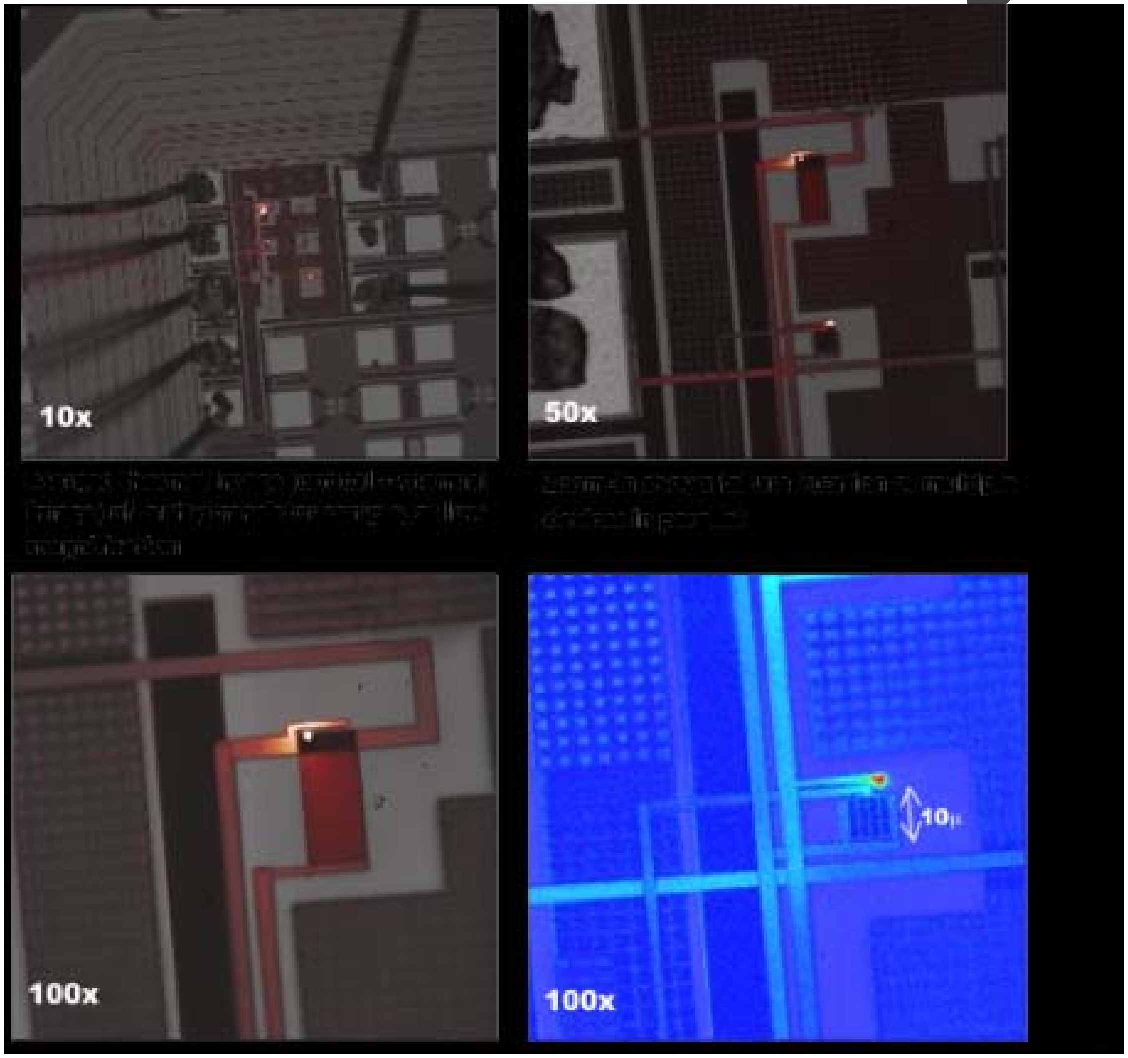
$$\varepsilon + \rho = 1$$

    - Emissivity is inversely proportional to reflectivity
  - Sample is prepared to have as high emissivity as possible
    - Flat black paint, talc, etc. used to lower surface reflectivity

Thermoreflectance

- Thermoreflectance depends on the fact that the optical reflectance of most materials depends slightly on temperature
- Test materials or devices are illuminated by an external light source, and the reflected light is imaged onto a camera
- The resulting reflectivity map is used to extract a spatially resolved image of the thermal distribution
- Requires lock-in software to extract accurate data
- Resolution of 250nm
- Temperature resolution of 10mK

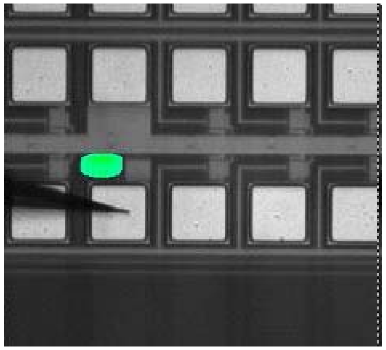
Thermoreflectance Images



Courtesy Microsanj, Inc.

Emission Microscopy

- Although this method does not report a temperature, it can be used to find hot spots
- Works by counting electrons emitted
- Must be performed in a dark environment
- Sensitive to shorts, high current areas, ESD damage, leakage current and other defects
- Slow and cumbersome, typically used for defect location on integrated circuit wafers



Courtesy Quantum Focus Instruments, Inc.

Void Formation in Materials

- Die attach
  - Thin bond lines are more problematic
  - Causes
    - Flatness, cleanliness, chip backside metallization, impurities
- Overmold
  - Voids within material or at material to chip interface
  - Causes
    - Contamination, cleanliness, moisture, process conditions

Void Formation in Materials

- Thermal Interface Materials
  - Liquid or paste formulations
  - Causes
    - Pump-out
      - Voids can propagate due to CTE of dissimilar materials
    - Contamination, dry out, flatness, shock or vibration
- Underfill
  - Less of an effect on thermal due to typically low thermal conductivity compared to bumps
  - Causes
    - Contamination, material properties, application process

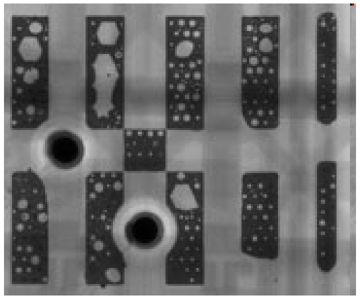
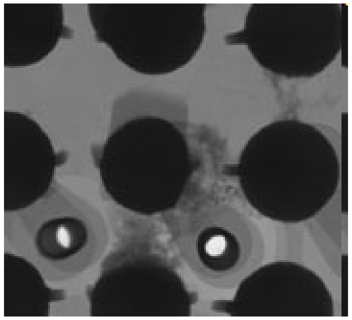
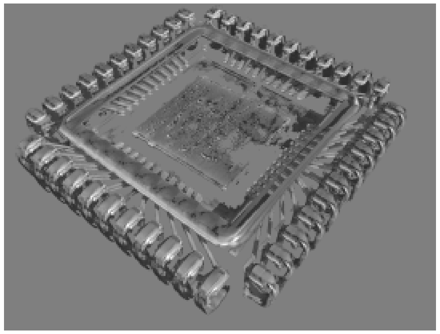
Effect on Thermal Performance

- Materials in contact with chip
  - Provide a better path for heat transfer than air
    - Voids in materials at the chip surface
      - High heat flux / temperature gradients local to void
    - Voids within material
      - Decrease effective thermal conductivity
- Increase thermal resistance and maximum temperature of the device
- High stress/strain
  - Nucleation site for water, contaminants, delamination, crack formation

Detection Methods

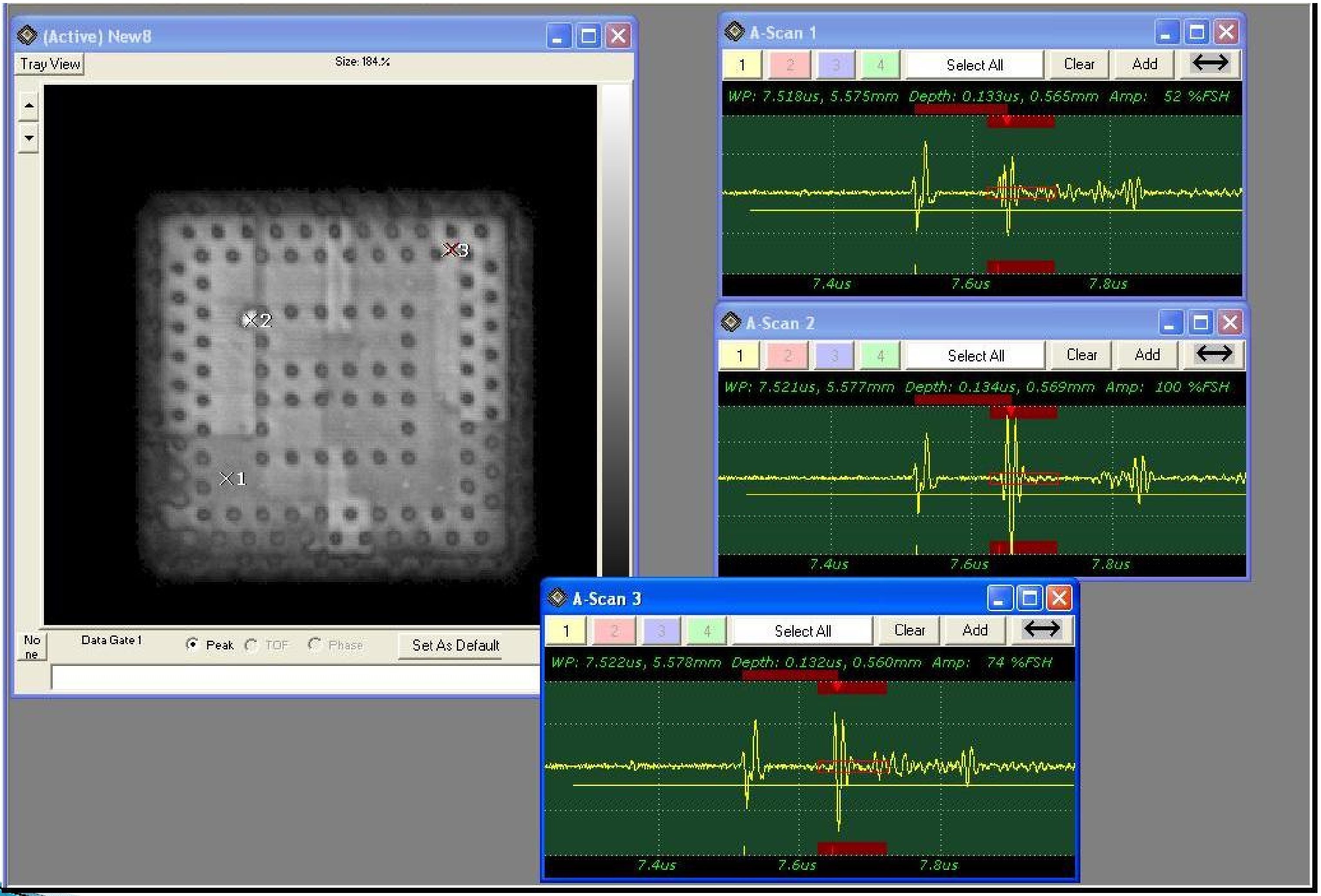
- Detection methods for internal package problems include non-destructive and destructive processes
- Voids are typically very small and must use some form of magnification to detect
- Two primary non-destructive methods
  - X-ray
  - Scanning Acoustic Microscopy
  - Heating curve analysis
  - Laser Flash

Non-Destructive Detection

- X-ray
  - High magnification x-ray units can be used to detect and analyze voids
    - Voids may be detected visually
    - Multi-axis sample fixtures aid in inspection
- Acoustic Microscopy
  - C-SAM and other names
  - Acoustic wave impinged on sample
    - Typically immersed in water
    - Reflection and transmission properties measured
    - Uses time-of-flight to calculate density changes in materials or composites

C-SAM Image and Response



A-Scan 1: WP: 7.518us, 5.575mm Depth: 0.133us, 0.565mm Amp: 52 %FSH

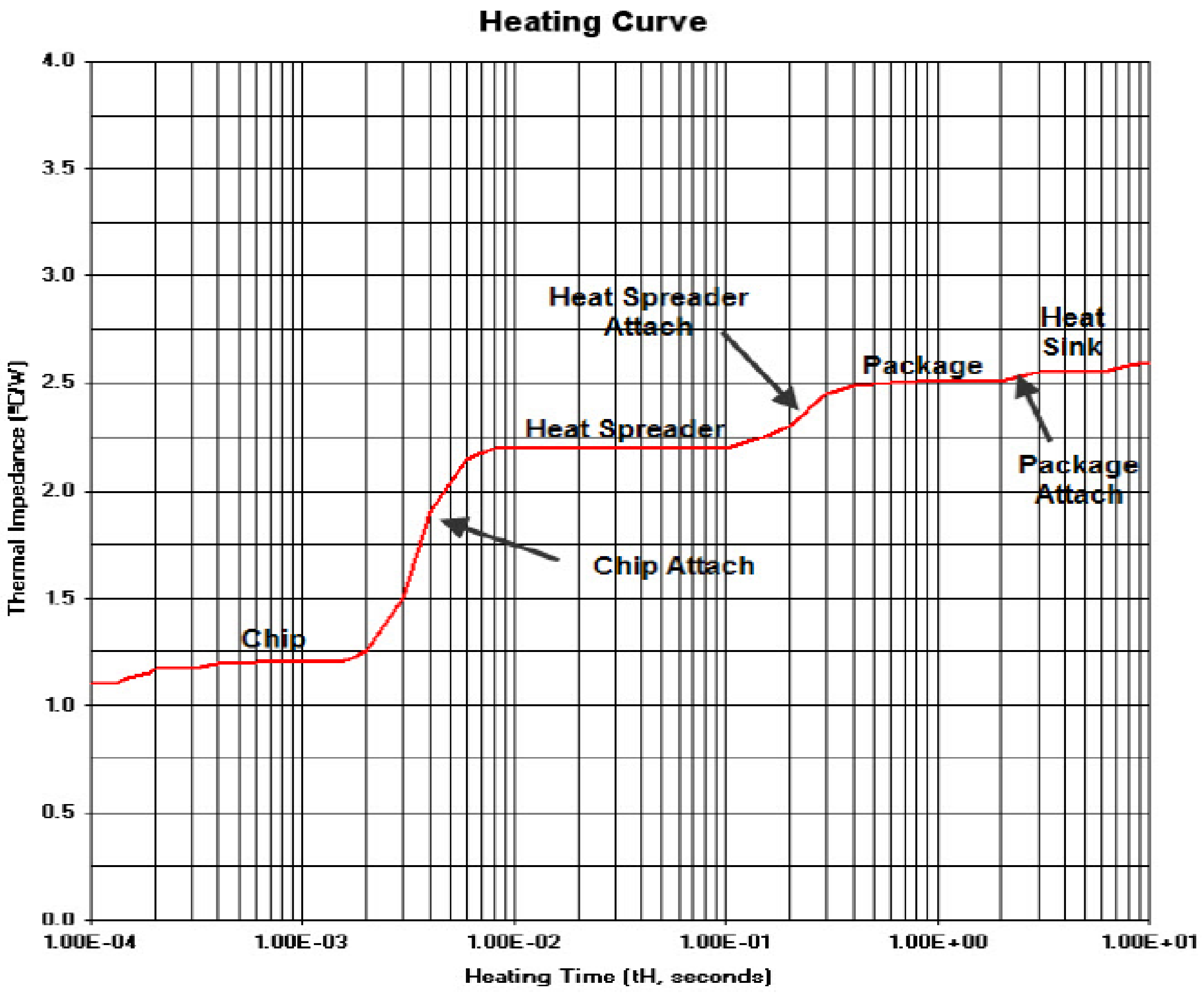
A-Scan 2: WP: 7.521us, 5.577mm Depth: 0.134us, 0.569mm Amp: 100 %FSH

A-Scan 3: WP: 7.522us, 5.578mm Depth: 0.132us, 0.560mm Amp: 74 %FSH

Non-Destructive Detection

- Heating Curve
  - Change in temperature as a function of time
  - Time delay for materials in the heat path depends on:
    - Material properties
    - Volume
    - Contact resistance
  - Compare results to find defects
  - Applicable for production line use

Heating Curve



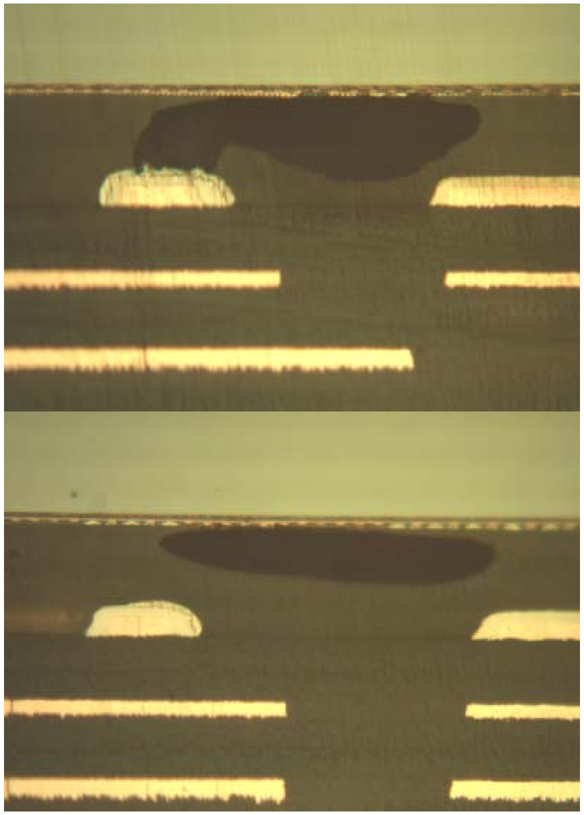
Courtesy Thermal Engineering Associates, Inc.

Non-Destructive Detection

- Laser Flash
  - Laser or xenon lamp flash on surface
  - IR measurements on the opposite side of the sample
  - Provides thermal properties
    - Thermal impedance
    - Thermal conductivity
  - May detect voiding or other defects by comparing to known good sample

Destructive Detection

- Cross-section
  - Used when a suspect is located to further investigate the defect
  - X-ray or C-SAM location
  - Cut and fine polished to defect location
- Material separation
  - Large voids can be detected using mechanical test
    - Instron™ or other equipment can be used to test bond strength
    - Inspect failed interfaces for void formation



Summary

- Hot spots can be caused by
  - Circuit defects
  - Crowded chip design
  - Voids or delamination in materials contacting the chip
- Can be detected by various means
  - Measurement on chip surface
  - Void detection, destructive, non-destructive
- Methods can help to find and analyze hot spots

Questions?

THANK YOU