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A thermal imaging system capable of micron-level resolution has been developed by a group of researchers at the Center for Photonics Research at Boston University (Boston, MA). The system applies near-field microscopy to thermal imaging by extending near-field techniques to the mid-infrared region. Although neither technology is new, the combination represents a potentially important advance in high-resolution thermography with applications in the semiconductor industry.

Temperature uniformity and cooling efficiency represent significant limitations to modern integrated-circuit design. If a transistor fails because its temperature is too high, the entire system fails. Consequently, current high-speed microprocessors often come equipped with cooling fins and a built-in fan. It is therefore, critical to pinpoint hot spots and image local temperature profiles in such devices. Current thermo graphy systems, however, are limited in determining thermal distribution of individual devices on a semiconductor wafer.

Bennett B. Goldberg and M. Selim Ünlü, professors of engineering and physics at the center, along with graduate students Chenhui Feng and William D. Herzog, described the imaging system at the Lasers and Electro-Optics Society conference (Boston, MA) last November. They are using a simple technique to work in atmosphere at high resolution. The instrument acts both as a mid-infrared optical device and a topographic mapping system.

Optical imaging at resolution greater than the diffraction limit is obtained by scanning a subwavelength aperture in close proximity to the sample surface. Both the aperture size and height above the sample are less than the wavelength of the emitted radiation, so the resolution is given approximately by the aperture diameter and not by the wavelength of light.

Imaging blackbody radiation

Every object at a finite temperature emits light, known as blackbody radiation. The peak wavelength emitted by an object at 50°C is near 10 μm. Using special fibers and long-wavelength detectors, Goldberg and Ünlü image the blackbody radiation to determine local temperature and electric-current distribution in single, high-power bipolar transistors. The near-field microscope is built as an attachment to a conventional probe station (see Fig. 1). Electric current at normal operating levels is applied to the transistor, causing a local temperature increase in the region where current flows.

The apertures for the near-field imaging are created by tapering multimode chalcogenide glass with an absorption of less than 1 dB/m in the 2- to 10-μm wavelength range.1 Thermal radiation is collected in the fiber tip with a 0.5- to 1-μm aperture. The sides of the tip are coated with metals of high reflectivity at the mid-infrared wavelength of interest.

The coating confines the IR radiation to the tip aperture, and the fiber transmits the light to a detector.

A false-color thermal image is produced from scanning the tip across the sample area (see Fig. 2). The submicron aperture allows for approximately five times better resolution than is available with existing systems, although the group is still striving for a more accurate temperature calibration.

For signal detection, either optical chopping or current modulation in the semiconductor device is used. For optical chopping, a piezoelectric bimorph dithers a silica fiber at its resonant frequency in front of the output end of chalcogenide fiber. Calcium fluoride IR lenses couple the light into the detector. Positioning, data acquisition, and image processing are all computer-controlled.

A topographic map is made of the chip or wafer by running the tip of the fiber along its surface. The tip is lightly vibrated, and as it approaches the surface the vibration amplitude diminishes. Goldberg and Ünlü use this shear-force method to control the tip-to-surface distance and thereby generate a three-dimensional plot. A quartz tuning fork from a commercial wristwatch measures the tip vibration amplitude.

With funding from the National Science Foundation, the group hopes to build an IR thermal inspection station and have it in operation by summer. Future work also includes combining a far-field inspection station with near-field imaging. The re searchers also are developing two-color thermography for absolute temperature calibration.

REFERENCE

1. C. Feng, M. S. Ünlü, B. B. Goldberg, and W. D. Herzog, "Thermal Imaging by Infrared Near-field Microscopy," IEEE LEOS Conference (Nov. 1996).

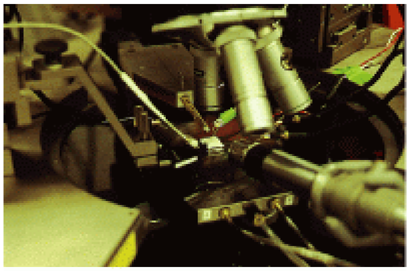

FIGURE 1. Local temperature increase in the region where current flows is monitored by a conventional probe station equipped with a near-field microscope. Light absorbed by the metal-coated probe of the microscope and re radiated into the fiber is currently the largest source of noise in the system.

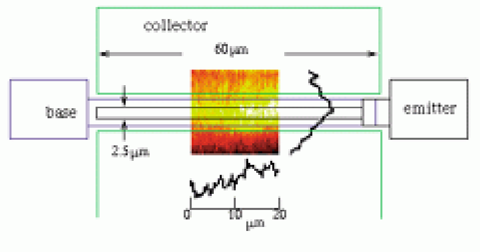

FIGURE 2. Total IR radiation emitted by a sample is a function of sample temperature and the emissivity of the material. This image shows the unequal temperature distribution across the device--yellow represents the hottest portion of the transistor, red the coolest. Note that only one of the collector contacts (top) is externally biased, resulting in asymmetrical current and thus temperature distribution.

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