Laser Scanning Confocal Thermo-reflectance Microscope for Sub-surface Thermal Imaging of Semiconductor Devices

Dong Uk Kim, Chan Bae Jeong, Jung Dea Kim and Ki Soo Chang

Division of Scientific Instrumentation, Korea Basic Science Institute, Daejeon, Kore

More powerful and faster semiconductor devices mean hotter devices, which can lead to a decrease in performance and lifetime of devices. Thus, thermal characterization of devices, such as surface temperature profile measurements and localized heat generation detection under their operating conditions, have become an important factor in the development of devices. Several thermal imaging and analysis techniques, such as scanning thermal microscopy [1], micro-Raman thermography [2], and infrared micro-thermography [3], have been developed to investigate thermal properties in micro- and nano-scale devices. In particular, thermo-reflectance microscopy (TRM) is an optical imaging technique that provides a two-dimensional thermal image of sample with high spatial and thermal resolution [4-6].

Thermo-reflectance microscopy is based on measurement of the relative change in the reflectivity of a sample (device) surface as a function of change in temperature. As the temperature of the sample changes, the refractive index, and therefore the reflectivity, varies. In this presentation, we report on a confocal thermo-reflectance microscope system that can provide sub-surface thermal image of semiconductor devices through the substrate. Figure 1 (a) shows a schematic of the laser scanning confocal thermo-reflectance microscope. The system is based on a laser scanning confocal microscope, which is combined with a CCD-based wide-field microscope, and provides a direct way to compare the performance of thermo-reflectance measurements obtained using the two different methods (wide-field TRM vs. laser scanning confocal TRM). The laser scanning confocal TRM primarily consists of a scan head, two relay lenses (a scan lens and a tube lens), and an objective lens. The wide-field TRM consists of an NIR broadband light source (MHAB-100W-IR, MORITEX), a sliding beam splitter pair, a 10-nm bandpass filter with a center wavelength of 1150 nm (2-1155, Optometrics Corporation), and an InGaAs CCD camera (12-bit, NIR-300FCL, ALLIED Vision Technologies). Figure 1 (b) represents the design of a micro-heater that was used as the test device, and also shows the illumination directions for the topside and backside measurements.

Figure 2 shows the backside reflection and thermo-reflectance images obtained by the wide-field and confocal TRM systems using a 100× objective lens (NA 0.5). As the incident angle of the objective lens increased, the reflection from the front of the substrate, which is a source of background noise, became stronger. Then, the image contrast in the wide-field backside image shown in Figure 7(a) was additionally decreased by ~35 % from that of the backside measurement using the 50× objective lens. However, the confocal backside imaging with an optimized pinhole (50 μm diameter), i.e., the optical sectioning capability, was much more robust in the presence of strong reflections, as shown in Figures 7(b) and 7(d). As a result, the confocal backside thermo-reflectance measurement was found to exhibit a ~23 times improvement in the thermal sensitivity over that of the wide-field systems, from the ratio between the variations $\Delta R/R$ shown in Figures 7(c) and 7(d). Therefore, we believe that the developed confocal TRM system is particularly valuable for investigating the thermal characteristics of micro-electronic devices.

References:
[1] I. Jo et al., Nano Lett. 11, (2011), p.85.
[2] D. Chae et al., Nano Lett. 10, (2009), p.466.
[3] K. S. Chang et al., Sensors 12, (2012), p.4648.
[4] M. Farzaneh et al., J. Phys. D: Appl. Phys. 42, (2009), p.143001
[5] D. U. Kim et al., Opt. Express, 24, (2016), p.13906.
[6] D. U. Kim et al., Sensors, 17, (2017), p.2774.

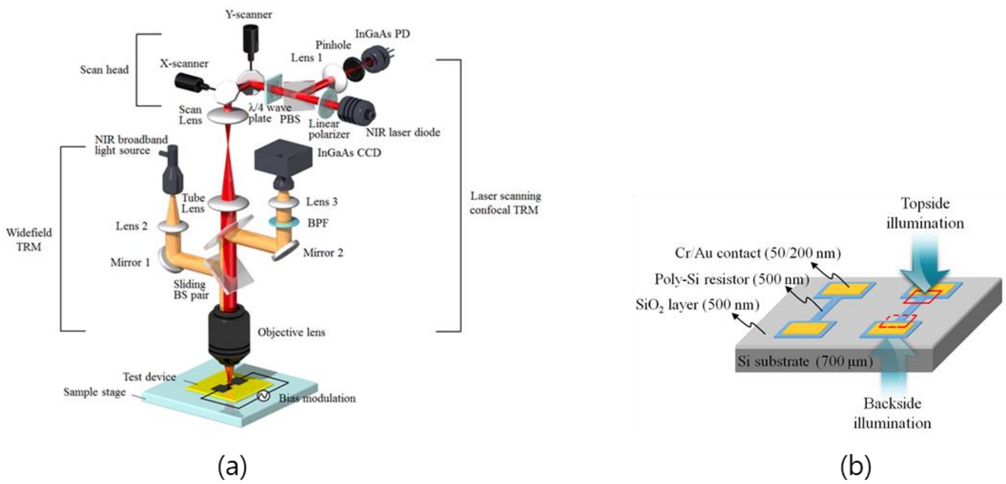

Figure 1. (a) Schematic diagram of the NIR laser scanning confocal thermo-reflectance microscope (TRM) combined with wide-field TRM. (b) Polycrystalline silicon micro-resistor on a SiO2 layer/silicon substrate and the illumination direction for topside and backside measurements.

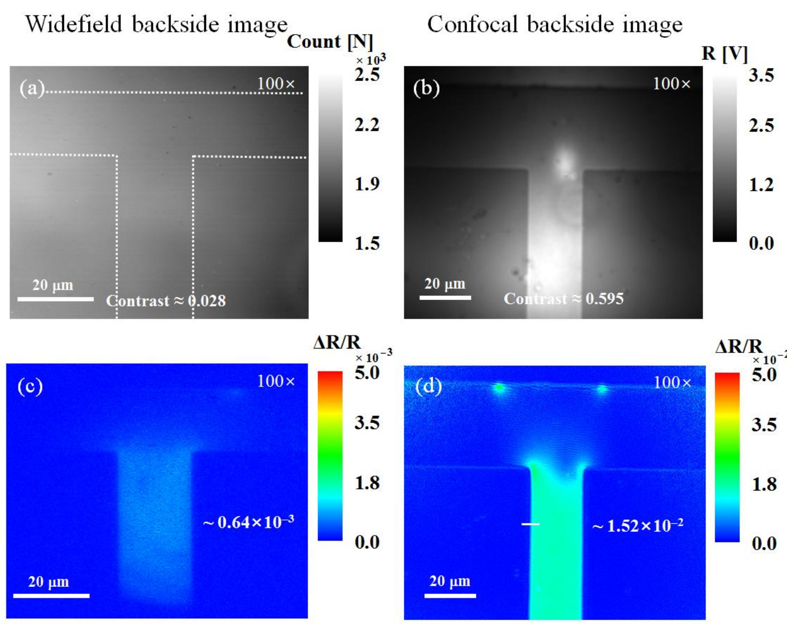

Figure 2. Backside reflection (top) and backside thermo-reflectance (bottom) images of the poly-Si micro-resistor obtained by (a, c) wide-field and (b, d) confocal TRM systems with a 100× objective lens (NA 0.5), respectively. The dotted line inside (a) represents the approximate region of the poly-Si resistor. The numbers inside (c, d) indicate the ΔR/R value of the micro-resistor.