Confocal Annular Aperture Microscopy and NAIL Allow High Lateral Resolution in Backside Imaging of Integrated Circuits

Optical methods for detection of defects in silicon integrated circuits (IC) typically rely on light at wavelengths greater than 1 μm, where silicon is relatively transparent, which limits the lateral resolution to ~1 μm. F.H. Koklu, B.B. Goldberg, and M.S. Ünlü from Boston University, and S.B. Ippolito from the IBM Semiconductor Research & Development Center in Hopewell Junction, New York, achieved a better imaging resolution by combining a confocal laser scanning microscope with a silicon numerical aperture increasing lens (NAIL). A silicon NAIL placed on the backside of a silicon substrate effectively transforms it into an integrated solid immersion lens with increased numerical aperture (NA) of a factor of the square of the refractive index to a maximum of 3.5, the refractive index of silicon. Confocal laser scanning microscopes yield a lateral spatial resolution determined by the spot size of the laser beam. By combining the two techniques in conjunction with angular spectrum engineering, the researchers achieved a lateral spatial resolution of 145 nm at λ_0 = 1.3 μm, which represents a resolution of ~$\lambda_0/9$, as they reported in the April 15 issue of *Optics Letters* (DOI: 10.1364/OL.34.001261; p. 1261).

The confocal microscopy setup the researchers developed is a single-path, reflection-mode fiber-optical scanning microscope that uses a single mode fiber-coupled laser diode emitting at 1.3 μm and a 2 × 2 optical coupler. The researchers coupled the light in and out the single mode fiber with a collimating objective with matching NA and illuminated the sample and the NAIL using a second objective with NA = 0.26, the same objective that collected the reflected signal. The NAIL consisted of an undoped silicon hemisphere with radius of 1.61 mm. The images were generated by scanning the sample with the NAIL using a piezo translation stage. The researchers controlled the polarization direction of the incoming light with a half-wave plate located before the imaging objective. They modified the angular spectrum by blocking the center of the optical path in front of the imaging objective in such a way that they formed an annular aperture of variable inner radius. With this setup, they scanned an IC fabricated in a 0.35 μm process with 4 metal layers and 2 polysilicon layers deposited on a silicon substrate. The silicon substrate was thinned to a thickness of 458 μm ± 2 μm in order to optimize the resolution and imaging quality of the combined imaging approach. The structures imaged were passive calibration structures embedded into the first polysilicon layer.

The researchers were able to demonstrate that by tailoring the angular spectrum with an annular aperture while using linearly polarized illumination it was possible to significantly improve the spatial resolution in one direction. The research team achieved a record lateral spatial resolution of 145 nm in the direction perpendicular to the polarization direction of the incoming light for one-photon excitation schemes by engineering the pupil function. The researchers said that together with its contribution to longitudinal localization, angular spectrum tailoring proved to be a powerful and simple technique to improve the optical inspection of ICs.

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