Widefield Subsurface Microscopy of Integrated Circuits

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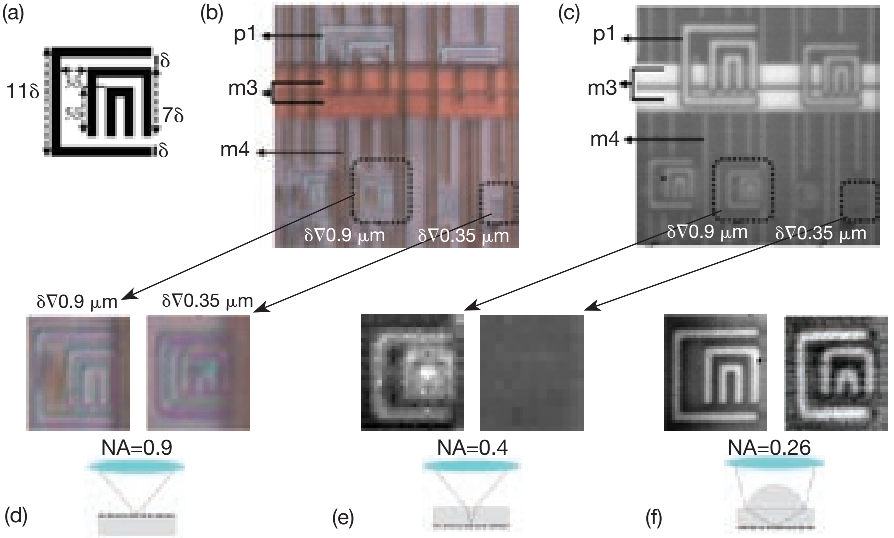
Optical methods for defect detection and imaging of silicon integrated circuits (ICs) are crucial for microelectronics. Circuit analysis relies on either the monitoring of electrical signal variation under optical excitation or the imaging of photoemission and scattering from the microelectronic structures. A correlated reflection image is necessary for registering the analytical information to the circuit layout. Current IC technology includes a multitude of opaque metal layers, thus hindering frontside optical imaging of buried device layers.

Therefore, nearly all optical analysis and inspection techniques require backside imaging through the silicon substrate. In backside imaging, optical absorption in the substrate restricts the optical spectrum to energies below the silicon bandgap, thus limiting the lateral resolution in backside microscopy to about 1 μm in conventional systems. Utilization of solid immersion imaging by the introduction of numerical aperture increasing lens (NAIL) revolutionized the way that IC inspection is conducted, allowing high-resolution backside imaging of silicon ICs.[1] A silicon NAIL placed on the backside of the substrate increases the numerical aperture (NA) by a factor of the square of the refractive index, to a maximum of 3.5 in silicon. An immediate impact of this technique has been observed in high-resolution metrology and failure analysis in the semiconductor industry.

Recently, we demonstrated high-resolution widefield subsurface microcopy of ICs by exploiting the intense focusing ability of the NAIL technique. In contrast to scanning techniques such as confocal microscopy or optical-beam-induced current imaging, our approach can provide instantaneous image acquisition over relatively large areas, since the image is acquired with a conventional camera. The extremely high NA realized by NAIL microscopy ensures very high resolution, even in a simple widefield microscope. We have demonstrated a lateral spatial resolution of 260 nm while imaging ICs from the backside.[2]



(a) The test structure. The sample has 6 test structures scaled with δ = 0.35, 0.6, 0.9, 1.2, 1.5 and 2 μm. (b) Front side image of the sample with a commercial visible wavelength optical microscope. (c) Backside image of the sample with the NIR (λ = 1.2 μm) widefield microscope without a NAIL. (d) The magnified frontside images of the test structures with δ = 0.9 mm (upper) and δ = 0.35 μm (lower) taken with the visible microscope. (e) The magnified backside images with δ = 0.9 and 0.35 μm taken with the NIR microscope without a NAIL. (f) Backside images with δ = 0.9 and 0.35 μm, respectively, using the NIR widefield microscope and a NAIL with an optimum substrate thickness of 458 μm. Notice the upper layers in (b) and (c).

In conventional widefield microscopy, there is no out-of-focus light rejection, and thus no ability to image separate layers. NAIL microscopy can overcome this, since it provides a more pronounced improvement in longitudinal resolution due to the square dependence of the confocal depth on NA. NAIL microscopy allows for very tight focusing; thus, light emanating from other layers results in a nearly uniform background. By subtracting this background, we achieve distinguishable images of features in individual layers with relatively high contrast. Stacked polysilicon and metal layers can be imaged individually down to a longitudinal separation of 1.2 μm.[2]

The fast and easy image acquisition capability of widefield microscopy combined with high-resolution NAIL microscopy offers a unique prospect for assisting failure analysis of ICs. Our experimental demonstration of record lateral and longitudinal resolution in widefield microscopy suggests that this imaging modality will have an impact on the analysis of modern ICs, allowing nanoscale imaging. ◭

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References

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