Semiconductor Technology from A to Z

Photolithography

EUV Tool Technology

The Light Source – Laser-Produced Plasma (LPP)

Generating EUV radiation is the technically most demanding part of the entire tool. A droplet generator fires molten tin as droplets roughly 20 µm in diameter into the vacuum chamber at a rate of about 50,000 droplets per second. Each droplet is first hit by a weak pre-pulse from a CO_2 laser, which flattens it into a disc and thereby increases the target area for the following main pulse. Only this main pulse – a high-power CO_2 laser with an average power of roughly 20 kW – heats the tin to several hundred thousand degrees and creates a highly ionized tin plasma that emits at 13.5 nm in the EUV range (see Challenges and Cost).

The conversion efficiency of this process is low: only around 5 % of the laser energy used leaves the source as usable EUV radiation, the rest is released as heat and as energetic ions. A curved collector mirror immediately behind the plasma source focuses the radiation toward the illumination optics – placing it directly in the hottest and dirtiest part of the tool. Tin particles and ions deposit on its surface and would ruin the reflectivity of the multilayer mirror within a short time. To counter this, hydrogen gas is continuously fed into the chamber: it reacts with the deposited tin to form gaseous stannane (SnH_4), which is continuously pumped away, keeping the mirror free of debris.

Projection Optics and Scanner Principle

From the source, the radiation travels through an illumination system of several mirrors to the mask, which homogenizes the beam and shapes it into the desired illumination setting. Because the EUV mask is a mirror, the beam must strike it at an angle so that incoming and reflected light can be separated – a constraint that does not exist for transmissive DUV masks (see reflective masks for EUV exposure). The structured light reflected from the mask then passes through the projection optics: a system of typically six to eight aspheric mirrors that image the pattern onto the wafer at 4× reduction.

Each of these mirrors reflects only around 70 % of the incident radiation; with six mirrors in the beam path, only a few percent of the originally generated power reaches the wafer. The mirrors themselves rank among the most precise optical components ever manufactured – surface errors must stay within a few picometers, since even the smallest deviations distort the image at a wavelength of 13.5 nm. Because this extreme precision can only be maintained over a narrow, arc-shaped field, the entire field is not exposed at once: mask and wafer move synchronously through a narrow exposure slit (step-and-scan) until the whole chip field has been scanned. The High-NA generation pushes this principle further: the anamorphic optics halve the usable field per exposure again, adding further complexity to the scan strategy (see High-NA EUV).

EUV Photoresist Chemistry

Conventional chemically amplified resists (CAR), as used in DUV, run into a fundamental limit with EUV: the RLS trilemma of resolution, line edge roughness, and sensitivity. Because individual EUV photons carry far more energy than DUV photons, the same dose (energy per area) delivers far fewer photons at the wafer – producing a noisier exposure image (see shot noise). Every absorbed photon also triggers a photoelectron and a cascade of secondary electrons that spread several nanometers through the resist before depositing their energy. This electron blur smears out what would otherwise be a sharp exposure edge and becomes the limiting factor at the smallest feature sizes – regardless of how well the optics themselves could still image.

One way around this is metal-oxide resists based on tin- or hafnium-oxide clusters. The heavy metal atoms have a much higher absorption cross-section for EUV radiation than the light carbon compounds of classic CAR resists, so fewer photons are needed for the same exposure effect and the electron blur stays more tightly confined. These resists are increasingly deposited not by spin coating but by a dry, ALD-like vapor-phase process, which avoids defects from uneven wetting and integrates more easily into the tool's vacuum chain. This does not fully solve the underlying problem: as already described in the chapter Next-generation exposure methods, stochastics remains, alongside overlay and cost, one of the central limits of EUV lithography.