Characterization of Deep Reactive Ion Etching for Silicon Plasma Singulation

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Abstract:

Bosch deep reactive ion etching (DRIE) was characterized for silicon plasma singulation using SPR 220-4.5 positive photoresist [1]. A 250 cycle study quantified aspect-ratio-dependent etching (ARDE) from 5–100 µm dicing streets, or trenches. Long runs established local 30 µm through-wafer capability and the photoresist limit. Depth decreased from 460.59 µm at 100 µm width to 222.64 µm at 5 µm. A cycle-dependent passivation run showed 0.80–1.00 µm widening, compared with provisional fixed-passivation values of 4–7 µm at matched widths. Optical monitoring identified mask failure but did not qualify a silicon endpoint.

Summary of Research:

1. Campaign from Screening to Final Monitor

Each Bosch cycle [2] used 2.2 s of C4F8-rich polymer passivation, a 2.0 s ion-assisted SF6 trench-bottom clear at 275 W platen bias, a 3.0 s zero-bias high-flow SF6 silicon etch, and a 1.0 s low-flow SF6 transition. Fixed passivation means that the 2.2 s step did not change with cycle number. Reflectometry measured resist loss, and scanning electron microscopy (SEM) measured depth. Aspect ratio was depth divided by nominal width, *D/w*. Normalized depth was *Dw/D*100.

2. Selectivity and Photoresist Survival

A five-run platen-bias/passivation-time screen was completed. Both streaked 225 W conditions were rejected. Accepted conditions spanned 53.45–57.37 nm/cycle and 6.38:1–10.03:1 silicon-depth/resist-loss selectivity. The non-flat 29.27:1 result was rejected for anomalously small resist loss. Clearing trials selected the 275 W/2.2 s fixed-passivation process.

The 350 cycle photoresist-survival run reduced center resist from 3789.592 nm to 542.434 nm, corresponding to 9.278 nm/cycle consumption. Site loss was 2.896–3.247 µm. With nominal 530 µm silicon, the conditional thickness-to-loss ratio was 163:1–183:1. It represents selectivity only where clearing is independently confirmed, not full-wafer mask uniformity. 500 cycle testing cleared 30 µm streets but consumed the photoresist, motivating a more durable oxide or metal hard mask for narrower features [3].

Dense repeated streets with 33.8% open area lost resist, while normally spaced 30 µm die streets with 2.7% open area retained it. This is not a universal density threshold. Silicon depth was not mapped, so accelerated local silicon etching is unproven.

3. Photoresist Loss Decreased with Radius

Matched thin-film reflectometry measurements show radial photoresist consumption. Photoresist-survival sites decreased from 9.23 nm/cycle in the inner radial bin to 8.37 nm/cycle near the edge. The ramped-passivation run decreased from 9.03 nm/cycle to 7.57 nm/cycle. Linear slopes were −0.029 and −0.046 nm/cycle/mm. These are resist-loss, not silicon etch-rate, measurements.

4. ARDE is the Dominant Small-Street Limit

The 250-cycle measurements in Table 1 decrease monotonically with narrower streets. Image scaling was calibrated, but mounting and projection uncertainty were not quantified. The 5 µm trench had a 44.53:1 nominal-width ratio but only 48.3% of the 100 µm-street depth. Through 530 µm silicon would require a geometric ratio near 106:1.

Width (µm)	Depth (µm)	D/w	D_w/D_{100}
5	222.64	44.53	0.483
15	256.04	17.07	0.556
30	306.13	10.20	0.665
50	395.19	7.90	0.858
100	460.59	4.61	1.000

Table 1: SEM-measured depth, nominal-width aspect ratio, and depth normalized to the 100 µm street after 250 fixed-passivation cycles. Each width has one cross-section.

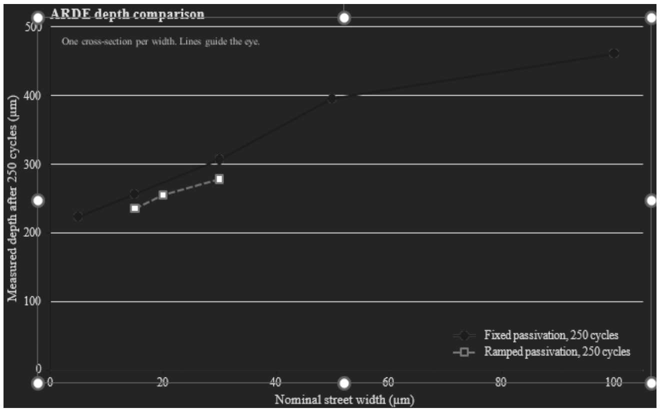

Figure 1: SEM-measured silicon trench depth after 250 Bosch cycles versus nominal opening width. A fixed 2.2 s polymer-passivation step is compared with a linear increase from 2.2–2.5 s. Each point is one cross-section. Lines guide the eye.

5. The Ramped-Passivation Run Showed Less Widening

The ramped-passivation run increased the polymer-deposition step from 2.2 s to 2.5 s over 250 cycles, as a depth-compensation strategy [4], [5]. Confirmed 15, 20, and 30 µm trenches reached 234.95, 254.87, and 277.86 µm, with 0.801, 0.591, and 1.000 µm top-to-bottom widening. Relative to the fixed-passivation depth study's provisional 15 µm and 30 µm widening of 4 and 7 µm, the new values were 80% and 86% smaller. Depth was 8.2% and 9.2% lower at those widths. Nominal-width aspect ratios were 15.66:1, 12.74:1, and 9.26:1. Each profile has one cross-section and no replicate uncertainty.

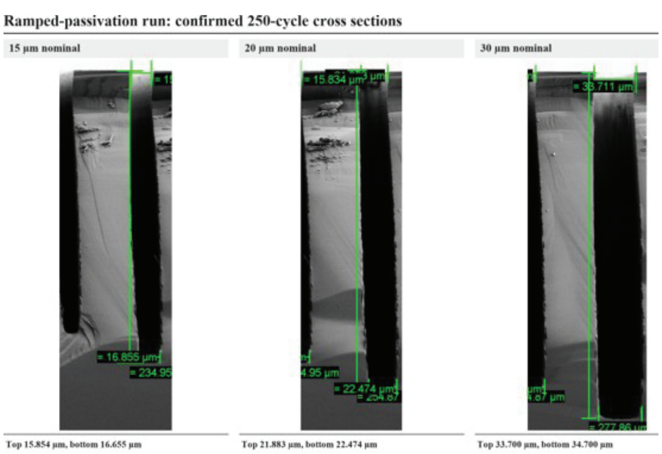

Figure 2: Cross-sectional SEMs after the 250-cycle ramped-passivation process show top width, bottom width, and depth for nominal 15, 20, and 30 µm streets. Green annotations are instrument measurements. No geometric correction was applied.

6. Optical Monitoring Detected Mask Failure, Not Silicon Breakthrough

Optical emission spectroscopy (OES) monitoring was evaluated as a possible method for stopping the etch when silicon streets clear [6], [7]. The trial established a compact data-collection method and identified a late optical transition associated with local photoresist loss. It did not establish a silicon-breakthrough endpoint because the transition was not correlated with physical clearing of 30 µm streets. Automatic termination therefore remains outside the characterized process scope until the optical transition is reproduced and verified against physical breakthrough.

Conclusions and Future Steps:

Fixed passivation enabled normally spaced 30 µm streets with bottom widening. Ramped passivation showed less widening but lower depth. ARDE, pattern density, and mask survival constrain smaller streets. Hard masks are the smaller-street path. Optical termination remains disabled pending repeatable physical clearing.

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