

The Effect of Surface Roughness on the Interfacial Defect Density between High-k and Silicon Channel of GAAFETs

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Selective removal of sacrificial SiGe is a key step in forming suspended Si nanosheet channels in gate-all-around FETs (GAAFETs). As devices scale down, isotropic chemical dry etching (CDE) is increasingly adopted for channel release [5,6], while wet chemistries suffer from stiction and pattern collapse in narrow gaps [6]. The exposed Si becomes the channel and the gate-dielectric interface, so release-induced damage maps directly onto the interfacial defect density (D_{it}) and subthreshold swing. Here we compare dry- and wet-released surfaces and provide a recovery solution based on sacrificial thermal oxidation.

Two candidates can degrade the interface: *atomic-scale roughness* and *residual fluorine*. CDE (a bias-free $CF_4/O_2/N_2$ plasma) attacks the exposed Si once the SiGe is cleared [1,2], whereas wet release (peracetic acid with buffered oxide etchant) proceeds through oxidation of Ge-containing bonds and fluoride-assisted dissolution [3,4]. AFM quantifies the morphological imprint (Fig. 1a): R_q reaches 1.79 nm after 30 s of CDE (16 times the wet value) and keeps increasing during over-etch, whereas wet-released Si stays near 0.1 nm even after 210 s. XPS isolates the chemical imprint (Fig. 1c): only dry-released Si shows an F 1s peak at 686.6 eV (SiO_xF_y), while Ge is below detection and the Si 2p oxide component stays at the native level on all samples.

A single sacrificial cure (5 min dry O_2 oxidation at 800 °C growing 2.5 nm, followed by oxide strip) recovers both axes at once (Fig. 1b,c): R_q of the CDE surface drops by 59% to 0.74 nm, the wet surface stays pristine, and the fluorine disappears below detection on every sample. PEALD SiO_2 cycle splits show identical growth on both surfaces (1.67 Å/cycle), so the electrical comparison probes the interface alone.

Because the cure erases the chemical difference, MOSCAPs (PEALD $SiO_2/HfO_2/TiN$) on four splits (dry/wet release $\times$ with/without cure) isolate the effect of the remaining roughness on D_{it} . For the uncured dry split we anticipate a mid-gap D_{it} on the order of $10^{12} \text{ cm}^{-2}\text{eV}^{-1}$, versus the low- 10^{11} range for the cured and wet-released splits. Measured D_{it} , V_{FB} , and hysteresis will be presented, with correlation to GAAFET devices in fabrication.

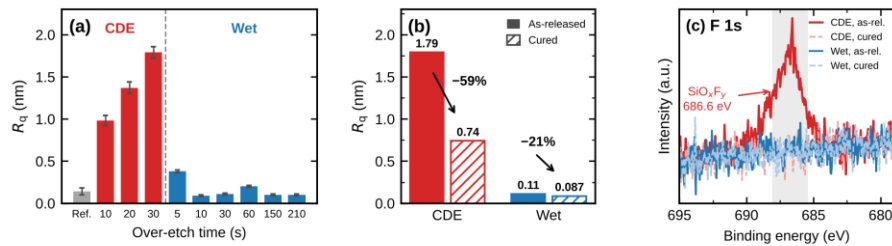


Figure 1. (a) R_q after CDE/wet release; (b) R_q before/after the 800 °C cure; (c) F 1s spectra.

[1] S. Borel et al., Microelectron. Eng. 73-74, 301 (2004). [2] M. Orlowski et al., ECS Trans. 33, 777 (2010). [3] T. K. Carns et al., J. Electrochem. Soc. 142, 1260 (1995). [4] U. Wieser et al., Semicond. Sci. Technol. 15, 862 (2000). [5] N. Loubet et al., Symp. VLSI Technol., T230 (2017). [6] X. Sun et al., Nanomaterials 13, 504 (2023).

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Supplementary Page

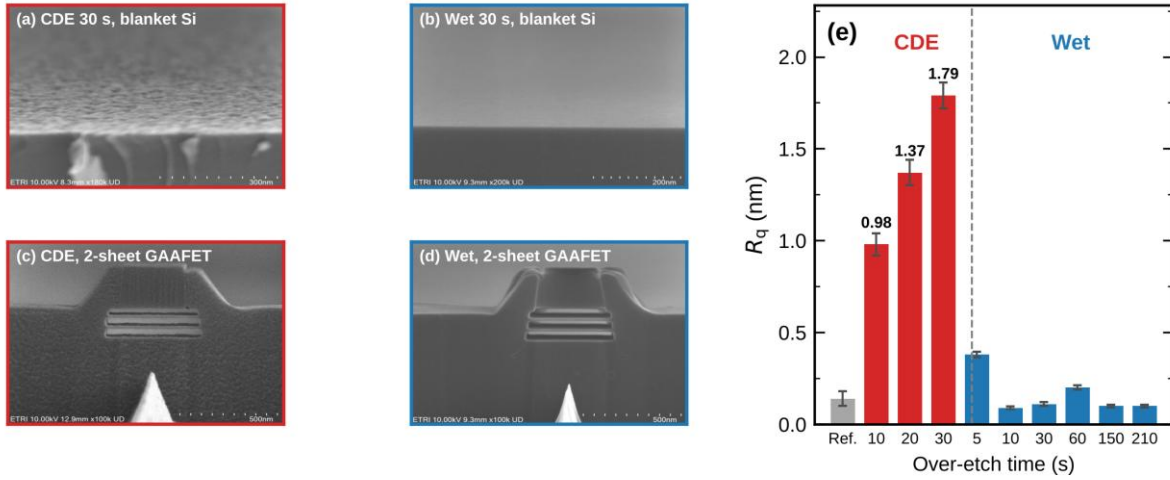


Figure S1. SEM of blanket Si and 2-sheet GAAFET structures after wet and CDE release (a-d), and AFM R_q versus over-etch time (e).

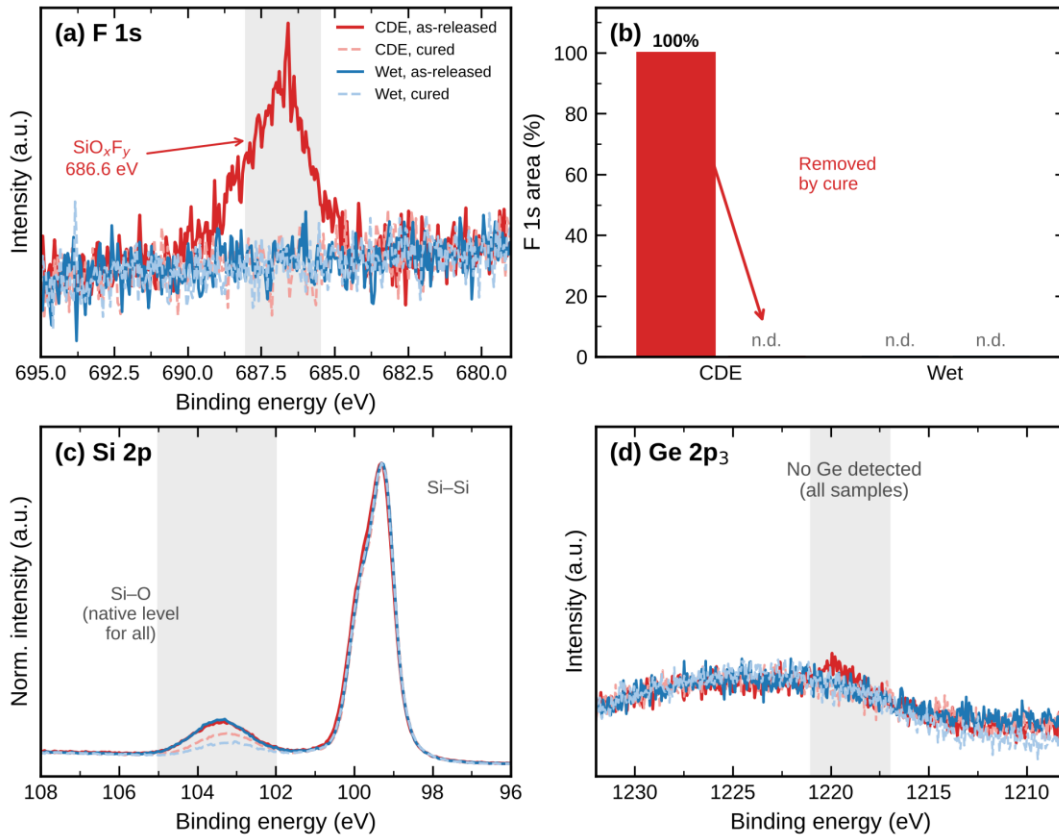


Figure S2. XPS of released Si before/after the cure: (a) F 1s spectra, (b) F 1s peak area, (c) Si 2p, (d) Ge 2p₃. The fluorinated oxide on CDE-released Si is the only chemical difference and is completely removed by the cure; no Ge residue is detected on any sample.

Acknowledgments This research was supported by the National Research Council of Science & Technology (NST) grant by the Korean government (MSIT) (No. GTL24043-000).