Chromium hard mask patterning of sub-20 nm films for single-digit nanofabrication

Daniel Staaks[1,2], Zhaoning Yu[3], Simone Sassolini[1], Scott D. Dhuey[1], Kim Y. Lee[3], Ivo W. Rangelow[2] and Deirdre L. Olynick[1]

[1] *Molecular Foundry, Lawrence Berkeley National Laboratory, Berkeley, 94720, United States*
[2] *Ilmenau Univ. of Technology, Dept. of Micro- and Nanoelectronic Systems, 98684, Germany*
[3]*Seagate Technology LLC, Fremont Research Center, Fremont, CA 94538, United States*
dstaaks@lbl.gov

Chromium has been used for years for optical mask and reticle fabrication due to its optical density and high etch selectivities. It is also an advantage for micro and nanofabrication as highly selective hard mask in ion driven plasma etching and direct patterning for new devices. To etch at the deep nanoscale, dimensions must be controlled to the nanometer [1] This requires a new level of mechanistic understanding especially with shrinking feature sizes towards the single-digit nanometer regime. For example, we use it as a highly selective hard mask when etching SiO_2 to achieve Bit Patterned Media templates towards sub-5 nm features (7TB/in²).

To address the need for anisotropy in nanoscale chromium etching, we here investigate the patterning of chromium thin films in plasma dry etching. By using highly selective hydrogensilsesquioxane (HSQ) resist, features are etched into 20 nm and 10 nm thin chromium films. High density inductively coupled plasma (ICP) at low pressure (5 mTorr) and low power (5 W_{RF}) is used. Chromium is etched in an oxygen and chlorine chemistry to transfer trench sizes from 100 nm down to 15 nm. Feature and trench profiles are evaluated from high resolution cross-sectional SEM images. Oxygen to chlorine gas ratios and substrate temperatures are varied between 1% and 87% and between +20°C and -50°C respectively. We find best anisotropy at -50°C and 50% oxygen concentration in 10 nm ultra thin chromium films. Furthermore, the ternary chromium etch system shows many different and competing etch mechanisms depending on temperature, O_2 concentration and feature size. Etch results suggest that re-deposition of non-volatile intermediate reaction compounds is of main importance for anisotropy at low temperature, whereas re-emission of reactive species dominates high temperature etching.

References

[1] D. Staaks, X. Yang, K. Y. Lee et al., “Low temperature dry etching of chromium towards control at sub-5 nm dimensions,” *Nanotechnology,* vol. 27, no. 41, pp. 1–9, 2016.

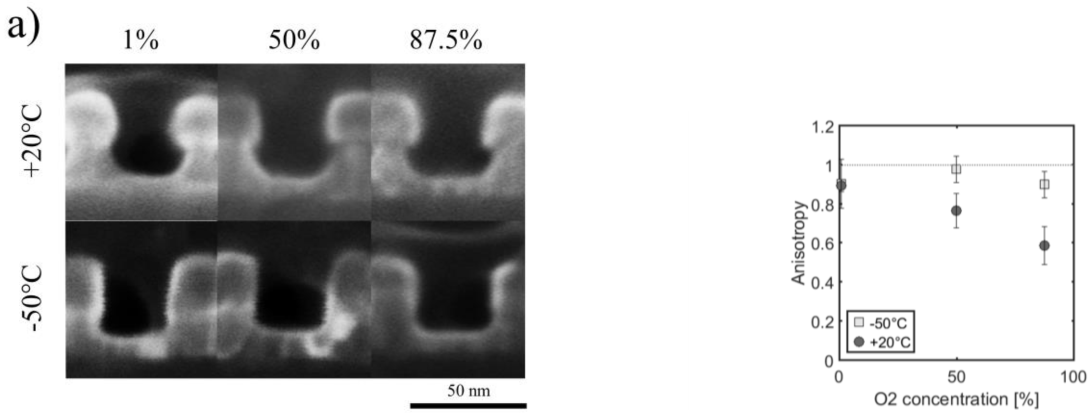

Figure 1: **Left:** cross-sections of HSQ masked, etched chromium with 30 nm trench width for different O_2/Cl_2 concentrations at +20°C and -50°C. **Right:** measured anisotropy as function of O_2 concentration. (b) cross-sections of sample type 2 with 15 nm trench width etched at -50°C at different oxygen concentrations.

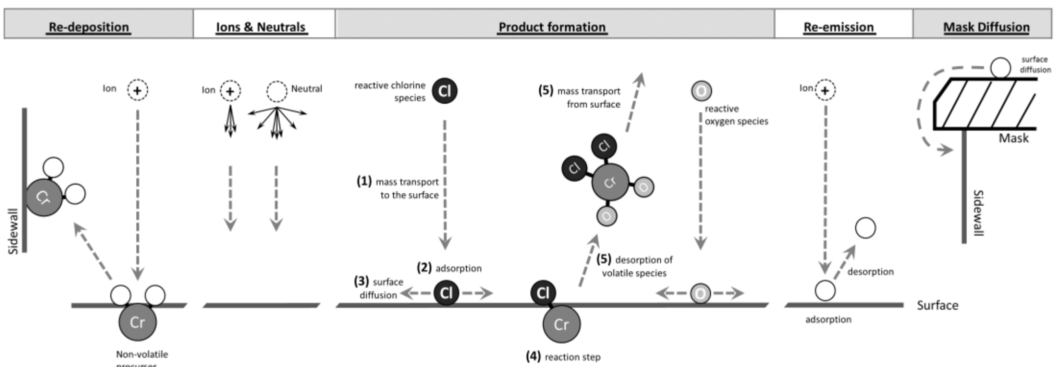

Figure 2: Simplified schematic of surface processes to be considered for chromium etching. The ternary nature of the chromium is mechanistically more complex than in binary systems. The product formation of the volatile CrO_2Cl_2 requires oxygen and chlorine mass and surface transport, reaction and compound formation and desorption. Re-deposition of non-volatile intermediates can occur as well as re-emission form the trench surface. Ion and neutrals from the plasma have to be considered in terms of shadowing and flux.

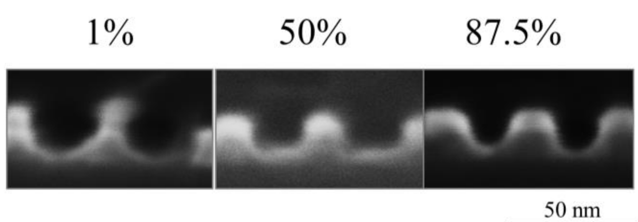

Figure 3: cross-sections of etched chromium with HSQ mask, with 15 nm trench width etched at -50°C at different oxygen concentrations.