Characterizing erosion and re-deposition properties of silicon carbide for use as a plasma-facing material in PISCES and DIII-D[1]

G. Sinclair[a], T. Abrams[b], S. Bringuier[b], D.L. Rudakov[c], J.H. Yu[c], D.M. Thomas[b], C.J. Lasnier[d], R.S. Wilcox[e], L. Holland[b], R.P. Doerner[c], S. Gonderman[b]

[a] *Oak Ridge Associated Universities, Oak Ridge, TN 37830, USA*
[b] *General Atomics, San Diego, CA 92121, USA*
[c] *University of California, San Diego, La Jolla, CA 92093, USA*
[d] *Lawrence Livermore National Laboratory, Livermore, CA 94550, USA*
[e] *Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA*

sinclairg@fusion.gat.com

Deuterium plasma exposures in the PISCES linear device [1] and the DIII-D tokamak measured a 66-80% reduction in the carbon source from silicon carbide (SiC) than from graphite at detached divertor conditions. Uncertainties regarding the viability of metallic plasma-facing components (PFCs) in next-step devices warrant consideration and qualification of alternative materials. SiC may be a viable PFC candidate material due to very low levels of hydrogen diffusivity, low radiative losses, high temperature strength, mechanical resilience to neutron damage, and recent advances in manufacturing high-strength SiC fiber composites. Exposures across a range of deuterium ion impact energies (E_i), sample temperatures (T_s), and ion fluences all resulted in silicon (Si) surface enrichment <15% by atomic basis. Measurements of preferential C erosion were consistent with recent molecular dynamics modeling [2]. Observation of the CD molecular emission band (430 nm) revealed the presence of C chemical erosion, and emission increased between E_i of 20 eV and 100 eV. Overall CD emission was 3-5× lower from SiC than from graphite. Si chemical erosion from SiC was not detected via the SiD molecular emission band (410-425 nm). Elevated levels of Si II emission at low impact energies near and below the physical sputtering threshold may, however, be indirect evidence of silane production. Additional experiments conducted with L-mode, attached plasma conditions in the DIII-D divertor measured a sputtering yield of ~0.017 Si/D and a redeposition fraction of 30% from an amorphous, 80 nm thick SiC coating [3].

Characterization of the gross and net erosion properties of SiC are needed to determine the compatibility of these PFCs with a high-performance plasma core. Crystalline samples with a coating thickness of 100-200 μm were fabricated via chemical vapor deposition on graphite substrates. Samples were exposed to D plasmas in PISCES-E at a flux (ϕ) ~ 5×10^{20} m^{-2} s^{-1}, electron temperature (T_e) ~ 3 eV, electron density (n_e) ~ 3.5×10^{16} m^{-3}, E_i ~ 20-90 eV, and T_s ~ 500-900 K. Additional samples were exposed in the DIII-D divertor via DiMES, a removable materials exposure probe, at a ϕ ~ 10^{22} m^{-2} s^{-1}, T_e ~ 2-20 eV, n_e ~ 10^{19}-10^{20} m^{-3}, and $T_{s,base}$ ~ 300-500 K. Material erosion was measured using three different techniques: mass loss, optical emission spectroscopy, and Rutherford backscattering spectrometry.

[1] G. Tynan *et al.*, J. Vac. Sci. Tech. A 15 (1997) 2885-2892.
[2] S. Bringuier *et al.*, Nucl. Mat. Energy 19 (2019) 1-6.
[3] D.L. Rudakov et al., Phys. Scr. *in review* (2019)

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