Implications of Wall Recycling and Carbon Source Locations on Core Plasma Fueling and Impurity Content in DIII-D*

EX-D

M. Groth,[1] L.W. Owen,[2] G.D. Porter,[1] N.H. Brooks,[3] M.E. Fenstermacher,[1] W.H. Meyer,[1] T.W. Petrie,[3] D.L. Rudakov,[4] G. Wang,[5] J.G. Watkins,[6] and N.S. Wolf[1]

[1]Lawrence Livermore National Laboratory, Livermore, California 94550-9234, USA
email: groth@fusion.gat.com
[2]Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA
[3]General Atomics, P.O. Box 85608, San Diego, California 92186-5608, USA
[4]University of California, San Diego, California 92093-0417, USA
[5]University of California, Los Angeles, California 90095-1597, USA
[6]Sandia National Laboratories, Albuquerque, New Mexico 87185, USA

The spatial distribution of the neutral deuterium and low-charge-state carbon line intensities was measured in the DIII-D divertor and in the high-field side scrape-off layer (SOL), and the ionization rates and impurity densities were simulated using the UEDGE/DEGAS code package [1,2]. A decrease in the D_α emissivity by three orders of magnitude was observed from the high-field side plasma strike point to the high-field side midplane region. The effect of the location of recycling on core plasma fueling and carbon production and transport into the core was extracted from the simulations. Plasma contact with the main chamber wall, which limits the performance and the operational space of future fusion devices, was found to be small in low density L-mode plasmas. This is consistent with low convective radial transport measured in similar plasma conditions in Alcator C-Mod [3] and DIII-D [4]. Results obtained in ELMy H-mode plasmas for different densities, magnetic configurations, and $\mathbf{E}\times\mathbf{B}$ and $\mathbf{B}\times\nabla B$-induced particle flows also suggesting a dominance of divertor sources are presented.

Impurities sputtered from the main chamber walls have a much higher probability to reach the core plasma and, thus, even a small first-wall impurity source can significantly increase the core impurity content. Particle recycling at the main chamber walls results in higher main chamber neutral pressures, which adversely cools the H-mode pedestal region, and also increases the impurity production at the main chamber wall through enhanced charge exchange sputtering. Larger main chamber neutral pressures reduce the fuel compression in the divertor, therefore lessen the efficiency with which fuel and helium ash can be exhausted in the magnetic divertor. Consequently, restricting plasma-wall interaction to the divertor region is a key issue for optimizing tokamak performance.

The stronger D_α emission from the inner divertor leg [Fig. 1(b)] suggests a much colder inner divertor plasma in which significant recombination is observed, providing an enhanced

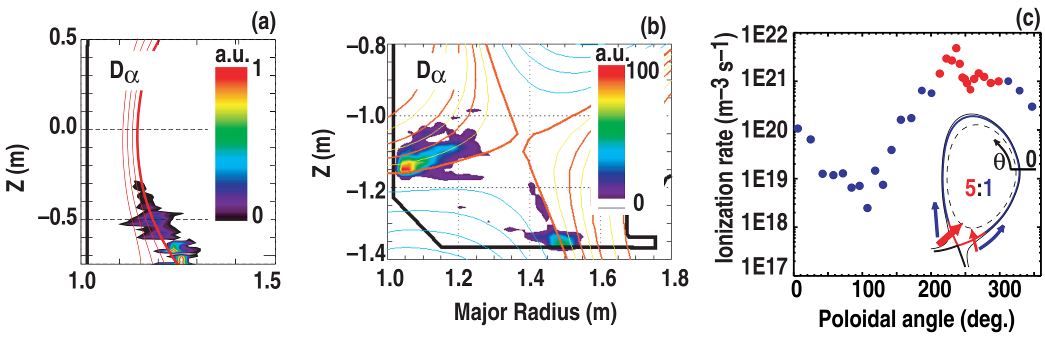

Fig. 1. Tomographic reconstruction of the inner SOL midplane (a) and lower divertor D_α (b) emission profile. The intensities are given in arbitrary units. The D_α emissivity is estimated to decrease by three orders of magnitude from the inner strike zone to the midplane. (c) Poloidal distribution of the ionization source along the separatrix as a function of poloidal angle from DEGAS [2]. The poloidal angle runs counter-clockwise starting at the outer midplane.

*Work supported by U.S. Department of Energy under Contracts W-7405-ENG-48, DE-AC05-00OR22725, DE-FC02-04ER54698, DE-AC04-94AL85000, and Grants DE-FG02-04ER54758 and DE-FG03-01ER54615.

pathway for neutrals to reach the X-point region from the inner target. The data shown in Fig. 1 were taken in low-density ($n/n_{GW} \sim 0.2$) L-mode plasmas in a lower single-null configuration with the **B**×∇B drift into the lower divertor. The 2-D D_α (656 nm) distribution, as well as CII (515 nm), and CIII (465 nm), were measured from a set of tangentially viewing charge-injected device (CID) cameras [5]. The measured D_α emissivity decreases over 3 orders of magnitude from the inner divertor strike point toward the midplane, indicating a strong reduction of the neutral density along the inner wall. This implies that recycling at the inner wall surfaces is significantly lower than at the divertor plates.

The calculated distribution of the ionization source from Monte-Carlo code DEGAS [5] coupled to the edge fluid code UEDGE shows that 80% of all the neutrals penetrating the core are ionized around the divertor X-point [Fig. 1(c)]. Leakage of neutrals out of the divertor constitutes the remaining 20%. Comparison of the measured and simulated divertor and main chamber D_α distribution indicates agreement to within a factor of two.

Analysis of the low-charge-state carbon emission also suggests that carbon largely originates in the divertor. The midplane CII and CIII distribution are vertically extended along the inner main SOL, with their maximum in the vicinity of the lower divertor X-point. UEDGE modeling including the effects of **E**×**B** and **B**×∇B drifts indicates a complex carbon flow pattern: carbon is (physically and chemically) sputtered at the target plates and preferentially transported into the inner divertor leg due to **E**×**B** drift in the private flux region. Chemical sputtering of carbon at the entrance to the inner divertor allows neutral carbon to enter a region where, upon ionization, the frictional drag on the carbon ions toward the target plate is insufficient to overcome the thermal forces driving carbon ions upstream. Hence, carbon leaks out of the inner divertor and into the main SOL, where it diffuses into the core plasma.

Studies in medium-density ($n/n_{GW} \sim 0.4$-0.6) H-mode plasmas with Type-I ELMs showed that the midplane D_α distribution is also dominated by emission occurring from the region closest to the divertor X-point. As shown in Fig. 2(c), in an upper single-null plasma with the **B**×∇B drift into the upper divertor, the maximum emission is observed in the region closest to the upper divertor X-point. In the upper and lower divertor [Fig. 2(a,b)] the emission profile is determined by the direction of the **E**×**B** and **B**×∇B drifts. The strongest D_α emission is observed from the upper, inner plasma strike zone [Fig. 2(a)]. Along the inner wall, the emission is estimated to decrease from the upper, inner strike zone to the tokamak midplane by three orders of magnitude. Since the magnetic geometry of these plasmas was close to forming a secondary X-point in the lower divertor, there is also significant plasma-wall interaction in the lower divertor. In double-null configurations, D_α emission was found to be symmetric between the inner and outer divertor legs. The maximum emission from the divertor in the direction of the **B**×∇B drift is approximately two orders of magnitude higher than in the other divertor. Detailed analysis of the plasmas using the UEDGE/DEGAS code package will be presented.

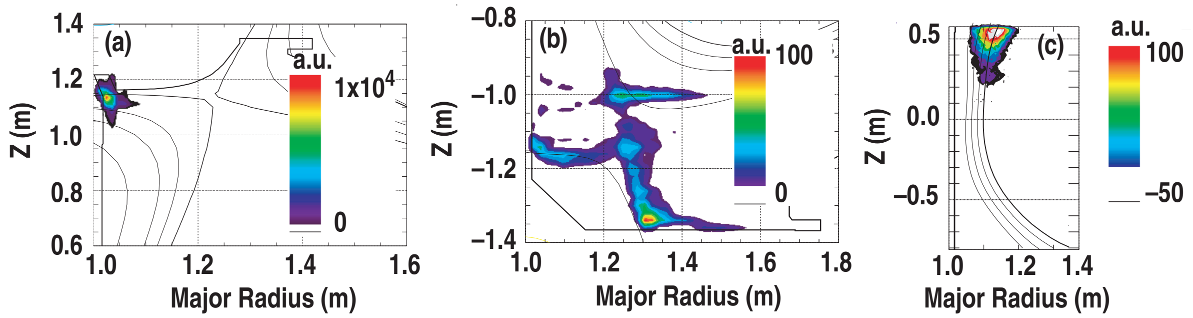

Fig. 2. Reconstruction of the D_α emission profile in the upper (a) and lower (b) divertor and inner main SOL (c) in an upper-single null, medium-density ELMy H-mode plasmas. The intensities are given in arbitrary units; the color bars indicate an estimate for the relative magnitude of the D_α emissivity.

[1] T.D. Rognlien, *et al.*, J. Nucl. Mater. **196-198**. 347 (1992).
[2] D.B. Heifetz, J. Comp. Phys. **46**, 309 (1982).
[3] B. La Bombard, *et al.,* Phys. Plasmas **8**, 2107 (2001).
[4] D.L. Rudakov, *et al.,* Plasma Phys. Control. Fusion **44**, 717 (2002).
[5] M.E. Fenstermacher, *et al.,* Rev. Sci. Instrum. **68**, 974 (1997).