Dependences of the divertor and midplane heat flux widths in NSTX

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Divertor heat flux plays a crucial role in the lifetime of plasma facing components (PFCs) but it is also correlated to heat transport through the scrape-off layer (SOL) and cross-field transport in the edge plasma. Spherical tokamaks in particular have high heat fluxes due to their compact geometry. Divertor performance and lifetime ultimately impact the overall performance of all fusion reactors. Here we report the dependencies of National Spherical Torus Experiment (NSTX) lower divertor heat flux profiles, measured using ELM-averaged infrared thermography, on a wide range of discharge and plasma shapes. Of special interest is how the heat flux and its associated figures of merit scale as plasma current and beam power are increased. For example, the proposed upgrade to NSTX is predicted to have equal or greater divertor heat flux than in ITER. These measurements therefore provide an unique opportunity to study PFC behavior under intense heat fluxes as well as methods of mitigating the heat flux through magnetic flux expansion, massive gas injection and evaporative coatings on the PFC surface all of which impact divertor performance. The experimental details will be presented as well as the impact on the performance of future spherical tokamaks.

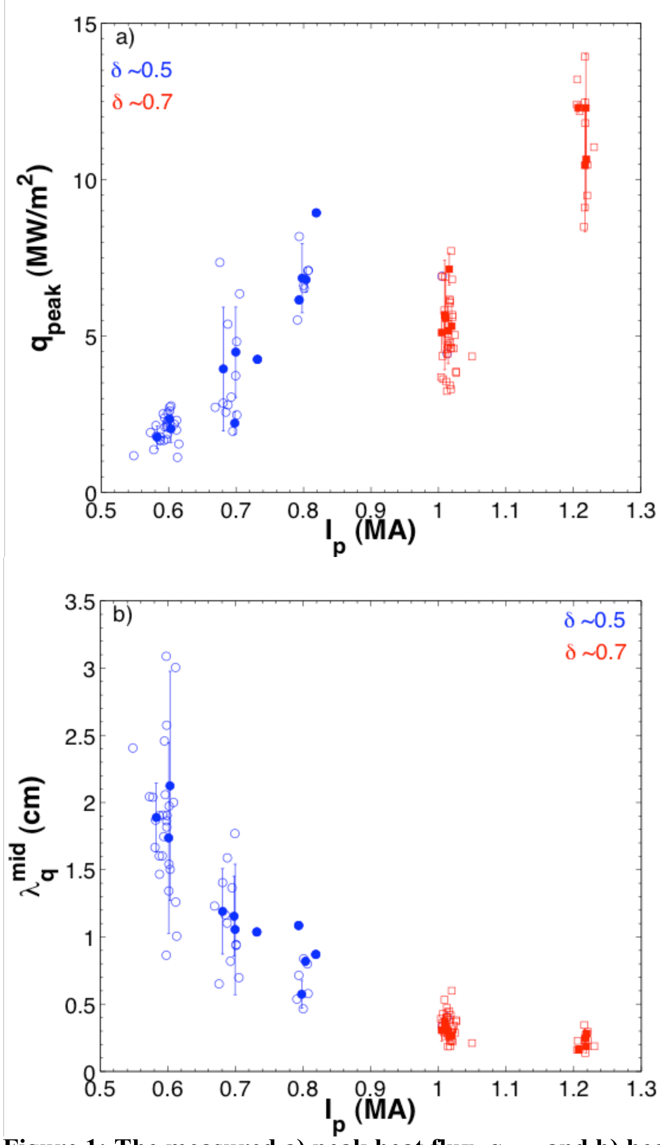

Figure 1: The measured a) peak heat flux, q_{peak} and b) heat flux width mapped to the midplane, λ_q^{mid} as a function on increasing plasma current for low (blue) and high (red) triangularity discharges.

Previously it was found[1] that the SOL heat flux widths (λ_q^{mid}, magnetically mapped from the divertor profiles obtained from thermography) decreased with increasing I_p, and was relatively independent of P_{NBI} at high P_{NBI}. However, all of the previous results were limited to lower divertor triangularity δ ~ 0.5. Here we have extended the studies to higher triangularity of δ ~ 0.7, extending and confirming the previous trends up to 1.2 MA. Moreover a new more detailed scan of $2 \leq P_{NBI} \leq 6$ MW demonstrated that the λ_q^{mid} contracts with increasing plasma current in low triangularity discharges from 2 to 1 cm as shown in Figure 1b. At higher triangularity, as shown in Figureb, the same relative trend is observed with a 50% contraction in λ_q^{mid} when the plasma current is increased from 1 to 1.2 MA.

For low triangularity discharges, λ_q^{mid} is observed to be relatively constant at ~ 10 mm over a wide range of δ_r^{sep}. However, for high triangularity discharges, a trend of increasing heat flux profile is shown for δ_r^{sep} decreasing from -5 to -15 mm. This results in increased heat flux as δ_r^{sep} increases at high triangularity. λ_q^{div} shows as strong increase as the magnetic flux expansion, f_M in creased over a range of f_M = 10-40. This leads to a strong reduction of the peak heat flux as shown in Figure 2, where the peak heat flux is reduced from 8 to 2 MW/m^2 as the magnetic flux is expanded from $10 \leq f_M \leq 40$.

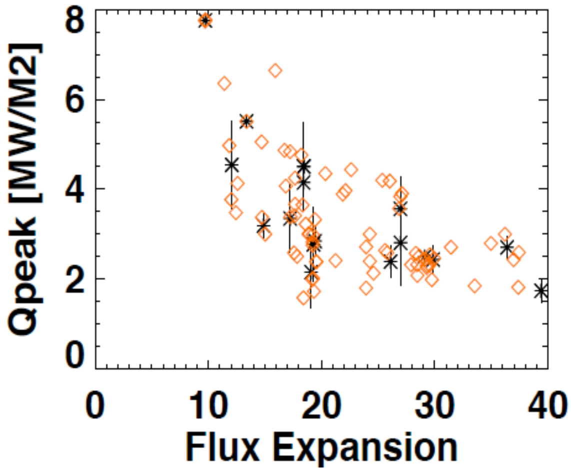

Figure 2: Peak heat flux decreases as flux expansion increases. Orange diamonds denote individual data points, while * denotes ensemble averages during a discharge.

Finally, NSTX utilizes unique lithium conditioning to condition its graphite PFCs[2]. This results in ELM-free discharges[3], which as shown in Figure 3, leads to a further contraction of the heat flux profile. While uncertainty in the emissivity for lithium coated graphite plasma facing surfaces limits a direct comparison of the magnitude of the heat flux profile, the relative change in radial profile shape from pure graphite to a lithium coated surface is still applicable. This assumes that the emissivity of the lithium coated graphite surface is spatially and temporally uniform, with in reason, during the discharge. Future work will involve implementing a two-color IR thermography system to reduce the dependence in the surface emissivity. The reduced edge collisionality due to the lithium coating appears to lead to an increase in transport of thermal energy onto the divertor.

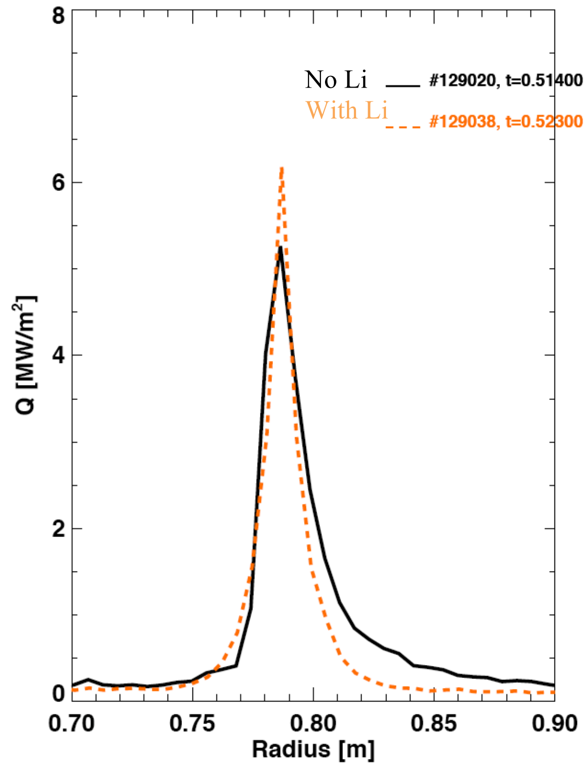

Figure 3: Measured heat flux profiles for bare graphite (black) plasma facing components and lithium coated graphite (orange) showing a reduction in the width of the profile with the addition of lithium.

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References

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