Nanoscale dynamics in ultrafast relaxation from radiation damage in SiO_2

B. Dromey[1*], M. Coughlan[1], H. Donnelly[1], C. Arthur[1], M. Afshari[1], N. Breslin[1], B. Villagomez[1,2], F. Currell[2], C. L. S. Lewis[1], D. Riley[1], M. Zepf[3], M. Yeung[1]
*E-mail: b.dromey@qub.ac.uk

[1]*Centre for Plasma Physics, School of Mathematics and Physics, Queen's University Belfast, BT7 1NN*
[2]*University Manchester, Dalton Cumbrian Facility, Westlakes Science & Technology Park*
[3]*University Jena, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Helmholtz Institut Jena, Fröbelstieg 3, 07743 Jena*

Abstract

Ionisation dynamics on the nanoscale seed the processes that govern relaxation to macroscopic equilibrium in irradiated matter. Therefore, understanding the conditions that underpin this transition is critical in a wide range of applications from healthcare to radiation science. Recently we have demonstrated that laser driven ion accelerators can provide an ultrafast tool for studying this inherently multiscale regime with temporal resolution < 0.5 ps [1,2]. Here we demonstrate that it is possible to interrogate these ultrafast processes in real-time by contrasting how recovery scales with interaction dimensionality for different ionising species. We employ single-shot optical streaking to track the decay time constant, τ_c, of free carriers in SiO_2 due to picosecond-scale (ps, 10^{-12} s) pulses of X-rays and protons from a single laser-driven accelerator. Exploiting the nanoscopically heterogeneous density of SiO_2 aerogels, our results reveal a strong scaling of τ_c with average density (ρ_{av}) for proton interactions. Conversely, τ_c is observed to be nearly independent of ρ_{av} for X-ray interactions. Cross referencing these observations with novel numerical simulations exposes the delicate interplay between the nanoscale conditions and emergent mechanisms, namely electron-phonon interaction, that drive ultrafast recovery in irradiated bulk SiO_2.

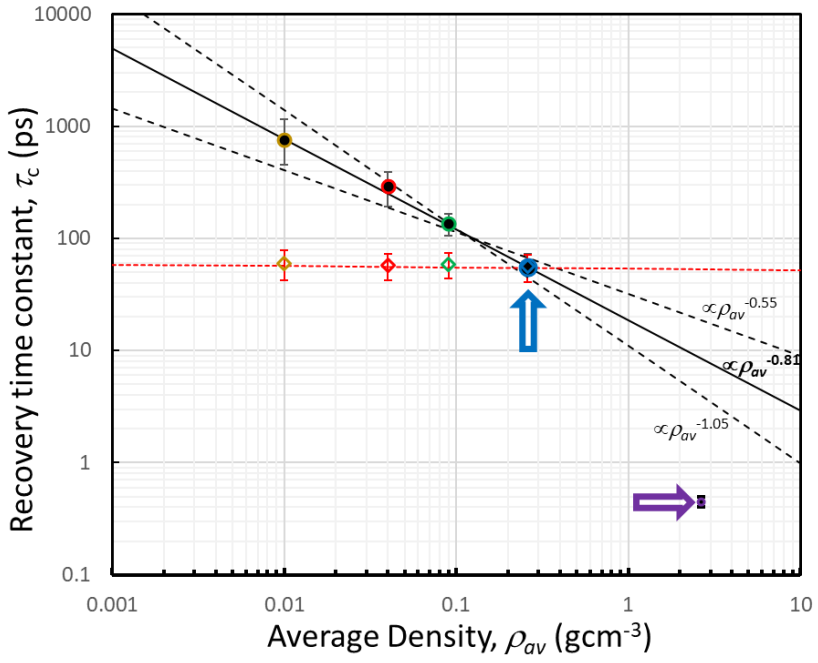

Figure 1. The scaling of the recovery time constant for ps scale pulses of X-rays (red dotted line) and protons (black solid line) interacting in SiO_2 (ρ_{av} = 2.66 gcm^{-3}) and silica aerogels (ρ_{av} = 0.01 – 0.26 gcm^{-3})

References

[1] Dromey, B., et al., *Nat.Comms.*, **2016**, 7, 10642
[2] Senje, L., et al., *App. Phys. Letts.*, **2017**, 110, 104102