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Evaluating laser ultrasound for the in-situ inspection of plasma-facing components.

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In order to operate for long pulses, magnetic confinement fusion (MCF) devices are typically equipped with actively-cooled plasma-facing components (PFCs). These have been installed in several existing long-pulse MCF machines, but are expected to be more widely used in the next generation of high-powered, long-pulse devices (e.g. ITER, DEMO & commercial power plants). The circulation of fluid coolant inside PFCs introduces the risk of *in-vacuum vessel loss of coolant accidents* (in-VV LOCAs) should the PFCs suffer excessive in-service damage. Such accidents could have serious consequences for nuclear safety and machine availability (particularly for future MCF devices handling larger quantities of radioactive material than present or past machines), and as such every effort should be taken to prevent them. Theoretical models of PFC ageing and extrapolations from representative experiments may enable predictions of PFC service lifespan, but these will carry significant uncertainty in the case of first-of-a-kind machines operating in unexplored regimes. In the face of this uncertainty, methods to directly inspect PFCs for damage in-situ during their service lifespan could help to prevent dangerous failure accidents through the early detection and characterisation of defects. Additionally, the data gathered from regular in-situ inspections could improve scientific understanding of PFC ageing mechanisms and feed back into improved PFC designs. A suitable non-destructive inspection technology for this purpose must possess certain critical capabilities. Not only must the technique be capable of detecting and characterising the relevant types of PFC defect (e.g. cracks, thickness changes due to erosion & interfacial delaminations), but it must be remotely deployable in the extreme environment of an aged MCF vacuum vessel (i.e. compatible with ultra-high vacuum, radiation, magnetic fields etc.). Laser-based ultrasonic inspection has the potential to meet these requirements. By both generating and detecting ultrasound pulses in a target using laser beams, the advantages of ultrasound for through-thickness inspection can be leveraged without the need to make physical contact with the component or apply ultrasonic coupling fluid. In this work, the authors report on laboratory-scale experiments to assess the suitability of laser ultrasound for the in-situ inspection of PFCs. A twin-laser scanning system has been used to demonstrate non-contact ultrasonic imaging of artificial defects in a tungsten sample. Furthermore, a novel method for component thickness measurement using thermoelastic laser ultrasound excitation has been developed, and demonstrated on tungsten tiles with thicknesses of 2-10mm simulating various levels of erosion. The effect of surface finish on laser ultrasound signal quality has also been explored for tungsten tiles with treated surfaces. Finally, the authors demonstrate automated deployment of the laser ultrasound scanning system on a robotic arm, simulating practical in-situ deployment. The results of these experiments are discussed, to assess the level of capability that has been demonstrated and identify priorities for development toward the use of laser ultrasonic inspection inside future MCF devices.

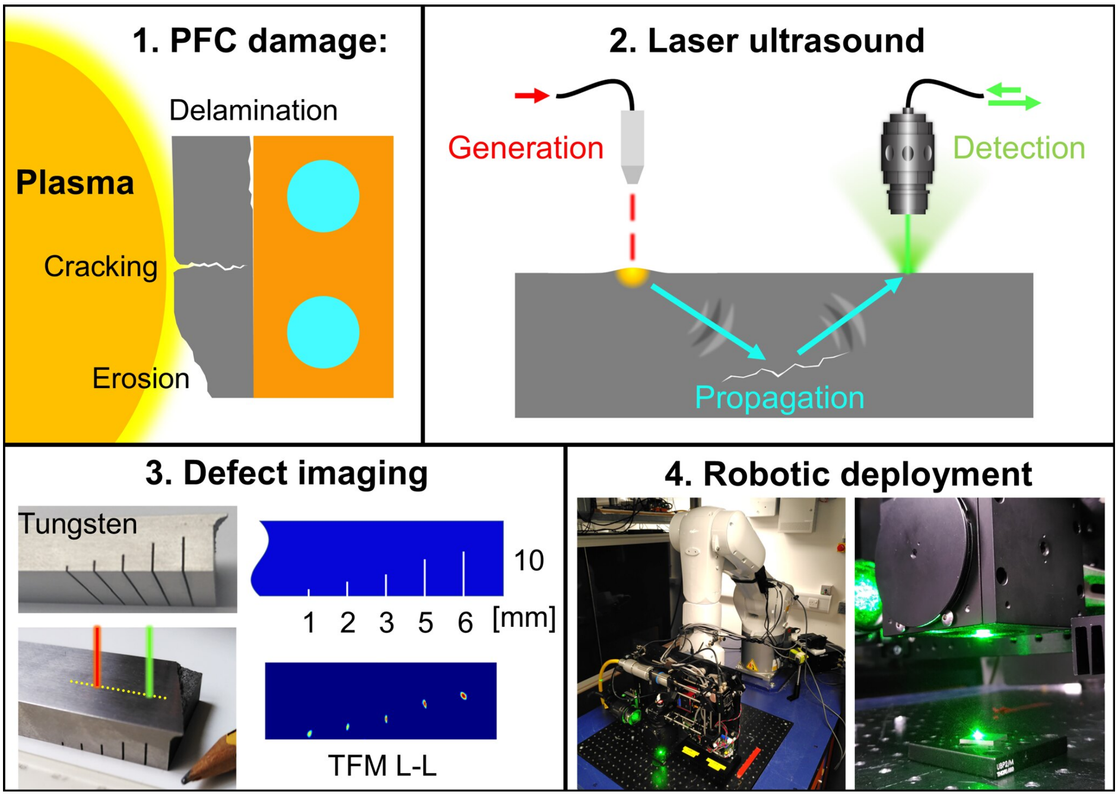

Figure 1: Figure

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