I-15

Femtosecond laser-induced ablation – quadrupole mass spectroscopy for depth- and lateral profiling of helium and hydrogen-isotopes in fusion materials

Steffen Mittelmann, Benedikt Buchner, Udo von Toussaint, Matej Mayer, Andreas Theodorou, Thomas Dürbeck, Wolfgang Jacob, Thomas Schwarz-Selinger

Max Planck Institute for Plasma Physics, Germany

We present our new instrumentation LAMA (Laser Ablation Mass Analysis) using femtosecond pulsed Laser Induced Ablation (fs-LIA) in combination with a Quadrupole Mass Spectrometer (QMS) for the simultaneous detection of helium (He) and hydrogen (H) isotopes in relevant materials used in fusion devices. Our study highlights the importance of using sub-picosecond laser pulses for an accurate depth-resolved detection of gaseous species trapped in metallic substrates. Notably, our experiment is the first to demonstrate the feasibility of fs-LIA-QMS, as previous pioneer experiments have only used picosecond and nanosecond laser pulses [1, 2, 3]. These pulse durations are not sufficient to achieve the required depth resolution due to heat affected diffusion and desorption of the gaseous species.

Our fs-LIA-QMS experiment detected deuterium (D) and He in tungsten (W) and EUROFER steel samples with depth resolution better than 20 nm or high lateral resolution better than 20 µm. In order to achieve this, we developed a deconvolution algorithm that takes into account the crater shape and the ablation rate, allowing us to gain more reliable depth-resolved information. Depending on the configuration and possible size of ablation area, a detection limit of less than 0.02 at.?oncentration per ablated layer is achieved with the presented device. This is tested using displacement-damaged W samples decorated with D and He-implanted W and EUROFER samples.

The fs-LIA-QMS technique offers the potential for high depth and lateral resolution, making it an attractive tool for the investigation of plasma-facing components in future fusion devices. This can in many cases enable the detailed characterization of the distribution of impurities in these materials, which is crucial for the development of next-generation fusion reactors.

We compare our fs-LIA-QMS results quantitatively with Nuclear Reaction Analysis (NRA) and Thermal Desorption Spectroscopy (TDS) data, demonstrating the accuracy and reliability of the fs-LIA-QMS technique. Furthermore, we discuss future applications and necessary developments to make the fs-LIA-QMS technique a reliable depth and laterally resolved method.

[1] O.S. Medvedev, et al., Nuclear Materials and Energy, 41, 101829 (2024)
[2] G. Shaw, et al., Phys. Scr., 2020, 014029 (2020)
[3] J. Oelmann, et al., Spectrochimica Acta Part B: Atomic Spectroscopy, 2018, 144 (2018)