

PROCEEDINGS

In-Situ TEM Study of Dislocation Loop Evolution in Tungsten Under Dual-Beam Irradiation

Pengfei Ma¹, Yan Liu², Liuxuan Cao², Xiurui Li¹, Wenxi Tian¹, Suizheng Qiu¹, Guanghui Su¹, and Yapei Zhang^{1,*}

¹School of Nuclear Science and Technology, Xi'an Jiaotong University, Xi'an, 710049, China

²School of Energy, Xiamen University, Xiamen, 361105, China

*Corresponding Author: Yapei Zhang. Email: zhangyapei@mail.xjtu.edu.cn

ABSTRACT

Fusion reactors are regarded as the ultimate source of energy for addressing future power problems. However, before the construction of fusion power plants, several scientific challenges, including the substantial degradation of plasma-facing materials (PFMs), needed to be overcome. [1,2]. Due to its excellent irradiation resistance at high temperatures, tungsten (W) is considered a promising PFM for fusion reactors. The application of W in fusion reactors faces stringent environmental challenges, primarily due to the substantial thermal loads, neutron flux, and gas atoms such as hydrogen and helium generated during fusion. Numerous studies have employed ion irradiation to simulate the service environment of PFMs and to develop fusion reactor materials with strong irradiation resistance. High-energy ion irradiation induces lattice defects, including interstitial atoms and vacancies, which often aggregate into two-dimensional dislocation loops with Burgers vectors of $1/2\langle 111 \rangle$ or $\langle 100 \rangle$ in body-centered cubic (BCC) materials [3-6]. In the study of dislocation loops, the irradiation damage dose and damage rate significantly influence the formation and evolution of dislocation loops. Gas ion irradiation of tungsten materials exacerbates dislocation loop reactions, with the ratio of $1/2\langle 111 \rangle$ to $\langle 100 \rangle$ dislocation loops varying with the irradiation dose. Current research on the irradiation resistance of tungsten mainly focuses on irradiation temperature, dose, and ion species effects of single ion beam or in-situ sequential beam irradiation, while studies on the synergistic effects by damage dose of simultaneous dual-beam irradiations in tungsten via in-situ TEM remain insufficient. Therefore, the present experiment primarily investigates the effects of varying irradiation damage doses on tungsten under high-temperature conditions (700°C) using dual-beam Kr^+ & He^+ irradiation. In-situ TEM is employed to observe the evolution of $\langle 100 \rangle$ and $1/2\langle 111 \rangle$ dislocations under different irradiation doses, with a quantitative analysis of the dislocation evolution. In the unirradiated tungsten, no pre-existing dislocations were observed. As irradiation progresses, dislocation loops gradually nucleate, forming small-sized dislocation loops. The nucleation process spans the entire dislocation evolution process. As the dislocation loops grow, they interact and merge or absorb some point defects, eventually presenting as dislocation lines. Due to the entanglement of dislocation lines and loops, a dislocation network structure is formed. Increasing the irradiation dose also leads to the growth of $1/2\langle 111 \rangle$ dislocation loops and the annihilation of $\langle 100 \rangle$ dislocation loops. This dislocation evolution mechanism can be attributed to two main factors: the reaction between $1/2\langle 111 \rangle$ dislocation loops forming $\langle 100 \rangle$ dislocations and the reaction at specific locations and temperatures where $\langle 100 \rangle$ dislocations transform into $1/2\langle 111 \rangle$ dislocations [7,8]. The formation and annihilation of $\langle 100 \rangle$ dislocation loops under Kr^+ and He^+ dual ion irradiation is expected to significantly impact the mechanical properties of tungsten. This study deepens the understanding of the microstructural evolution of irradiation-induced defects in tungsten, providing a fundamental basis for the application of tungsten in fusion reactors.

KEYWORDS

Plasma-facing materials; tungsten; dual-ion beam irradiation; in-situ TEM; dislocation loop



Copyright © 2026 The Author(s). Published by Tech Science Press.

This work is licensed under a Creative Commons Attribution 4.0 International License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Acknowledgement: The authors appreciate the financial support from the National Natural Science Foundation of China (No. 12375173).

Funding Statement: The study is supported by the National Natural Science Foundation of China (No. 12375173). Prof. Yapei Zhang received the grant and the URLs is <https://www.nsfc.gov.cn>.

Conflicts of Interest: The authors declare no conflicts of interest to report regarding the present study.

References

1. Bai, R. Y., Wang, K., Bai, Y. K. et al. (2018). Comparison of H and He ion irradiation impact on oxide film of domestic ZIRLO. *Atomic Energy Science and Technology*, 52(11), 2020–2027.
2. Chen, Q., Zhang, K., Liu, R. D. et al. (2020). Irradiation damage in GH3535 alloy under He ion irradiation at high temperature. *Atomic Energy Science and Technology*, 54(4), 688–695.
3. Ei-atwani, O., Cunningham, W. S. Trelewicz, J. R., et al. (2020). Revealing the synergistic effects of sequential and simultaneous dual beam irradiations in tungsten via in-situ TEM. *Journal of Nuclear Materials*, 538, 152150.
4. Peng, Q., Meng, F. J., Yang, Y. Z. et al. (2018). Shockwave generates < 100 > dislocation loops in bcc iron. *Nature Communications*, 9(1), 4880.
5. Li, M. M., Kirk, M. A., Baldo, P. M. et al. (2012). Study of defect evolution by TEM with in situ ion irradiation and coordinated modeling. *Philosophical Magazine*, 92(16), 2048–2078.
6. Luo, F. F., Guo, L. P., Chen, J. H. et al. (2014). Damage behavior in helium-irradiated reduced-activation martensitic steels at elevated temperatures. *Journal of Nuclear Materials*, 455(1), 339–342.
7. Ding, Y. F., Guo, L., Li, Y. P. et al. (2021). In-situ TEM observation and MD simulation of the reaction and transformation of loops in tungsten during H₂⁺ & He⁺ dual-beam irradiation. *Scripta Materialia*, 204, 114154.
8. Li, Y. P., Wang, L., Ran, G. et al. (2021). In-situ TEM investigation of 30 keV He⁺ irradiated tungsten: Effects of temperature, fluence, and sample thickness on dislocation loop evolution. *Acta Materialia*, 206, 116618.