In Situ Observation of Dislocation Loop Behavior During Annealing by WB-STEM in Neutron-Irradiated Reactor Pressure Vessel Steel

The dynamic behavior of loops and interactions between loops as well as loops and dislocations play key roles in microstructure variation, which is strongly connected to radiation-induced embrittlement in reactor pressure vessel (RPV) steels. The dedicated weak-beam scanning transmission electron microscope at the Oarai center was employed to observe and analyze the coalescence of loops and the interactions between loops and dislocations during annealing in neutron-irradiated RPV steel.

Neutron-irradiation-induced defects, especially dislocation loops, significantly contribute to embrittlement in reactor pressure vessel (RPV) steels during the long-term operation of nuclear power plants [1]. Therefore, understanding the thermal stability of defects is crucial.

The Burgers vector of dislocation loops is an important factor in microstructural evolution. In iron-based ferritic steels, the formation of <100> loops becomes more dominant than the formation of ½ <111> loops with the increase in irradiation temperature. However, the mechanism behind the transformation of ½ <111> loops to <100> loops remains unclear.

In the Oarai center, weak-beam scanning transmission electron microscopy (WB-STEM) was developed to achieve a more accurate quantification of irradiation-induced defects [2]. In situ WB-STEM observation was performed during annealing for a surveillance test specimen of RPV steel, which was neutron-irradiated to a fluence of 8.2 × 10^{23} neutrons·m^{-2}.

As shown in Fig. 1(a) and (b), this is the first time to directly observe that two ½ <111> dislocation loops collided with each other and coalesced to form a <100> dislocation loop. Small ½ <111> dislocation loops could be absorbed by large <100> dislocation loops, whereas the Burgers vector of the <100> loops remained unchanged, as illustrated in Fig. 1(c) and (d). Dislocation decoration by loops occurred during annealing because of the interaction between the dislocations and loops. The dislocations decorated by loops forming helical configurations were fairly stable during the continuous annealing process [3].

This study provides direct experimental evidence for the formation mechanism of <100> dislocation loops and provides a better understanding of the temperature-dependence of dislocation loop evolution.

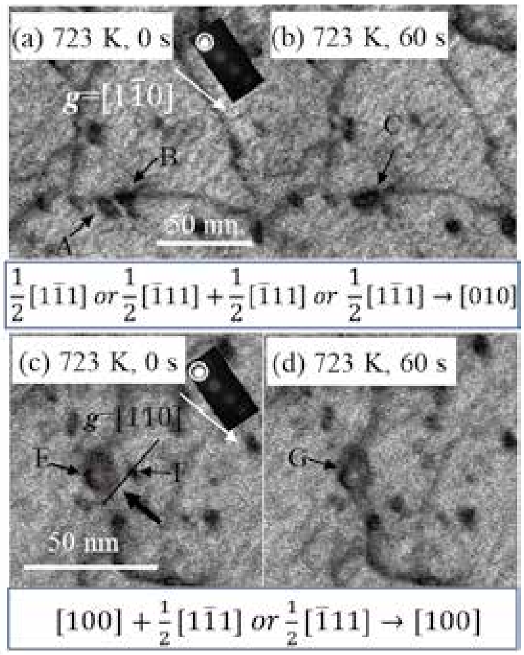

Fig. 1 In situ observation of dislocation loop evolution in neutron-irradiated RPV steel during annealing at 723 K with diffraction vector g = [1$\bar{1}$0] near [001] zone axis in STEM mode: (a) (b) loop coalescence; (c) (d) loop absorption.

The interaction between loops and dislocations suggests a new mechanism of loop-impeding dislocation motion.

References

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Yasuyoshi Nagai (Irradiation Effects in Nuclear and Their Related Materials Research Laboratory)
E-mail: nagai@imr.tohoku.ac.jp
URL: http://www.imr.tohoku.ac.jp/en/about/divisions-and-centers/research-division/11.html