Creep fracture of submicrometer-sized single crystal Al

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Introduction. Submicrometer-sized single-crystal metals demonstrate different mechanical properties from those of bulk counterparts; e.g., yield and flow stresses increase with decreasing specimen size at the micro- and submicrometer scales. For the long time use of submicrometer-sized metals, understanding of creep deformation and fracture as well as plastic properties is essential. Our previous creep experiments revealed that creep rate for single-crystal metals such as gold and aluminum (Al) decreased with decreasing specimen size at the micro- and submicrometer scales⁽¹⁾. The submicrometer-sized metals showed creep properties which were different from those of bulk materials; i.e., the creep curve exhibited intermittent strain bursts, and the arrested region where the strain hardly increased appeared in the submicron metals. However, detailed mechanisms and mechanics dominating the creep fracture remain unclear. The purpose of the study is to clarify the microscopic mechanisms and mechanics of creep fracture of submicrometer-sized single-crystal Al. Particular interest is on the role of stress concentration on the creep fracture. We conducted *in situ* TEM creep experiments at room temperature for tensile specimens with and without a notch.

Materials and methods. An Al single crystal of purity 99.999% was used as a sample. The sample was annealed at 873 K for 72,000 s in vacuum. Fig. 1 shows the dimensions of a specimen. Specimens were fabricated by focused ion beam. In order to discuss the mechanics of creep fracture at stress concentrated site, we made the specimen with a notch. The stress concentration factor α was ~ 9 which was estimated by FEM. The specimen had a single slip system and the primary slip system is indicated by the Thompson tetrahedron in Fig.1. A nanomechanical loading system (Hysitron, Inc. PI-95 TEM Picoindenter) was used for creep experiments, and a tensile force was applied to the upper section of the specimen by a gripper. The creep experiment was conducted at room temperature under *in situ* TEM observation. The applied force was controlled by a closed-loop control where the nominal net stress σ_{net} increased to a target value in 5 s and then maintained constant until the specimen fractured. We measured the specimen elongation δ from *in situ* TEM images and the nominal strain ε was defined as $\varepsilon = \delta/L$ (L : the initial specimen length).

Results and discussions. Fig.2 shows the relationship between the nominal strain ε and time t in a creep experiment and the corresponding *in situ* TEM images. In this experiment, σ_{net} was maintained constant at ~ 180 MPa during the experiment. In the early stage, the strain gradually increased with small strain bursts. The strain

became almost constant at ~ 500 s, and thereafter, a large strain burst occurred in the period 740-800 s. The strain increased again accompanied with small strain bursts, and finally the specimen fractured at the stress concentrated region. In all stages, the deformation was localized around the notch root. The fracture life of the specimen was 1027 s, which was smaller than that of smooth specimen, indicating the creep fracture was enhanced by the stress concentration. The presence of the arrested region was similar to the smooth specimen. The mechanics governing the creep fracture will be addressed by conducting experiments with different stress concentration conditions α and σ_{net} .

Fig. 1 Specimen configuration and slip system.

Fig. 2 Creep curve and *in situ* TEM images.

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References.

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