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Boundary faceting in Goss orientated nickel with a nanolaminated structure

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ABSTRACT

Nanolaminated structure was fabricated in pure nickel with Goss orientation via dynamic plastic deformation and subsequent cold rolling, and the structural coarsening during post annealing was investigated. Local faceting of lamellar boundaries that are typical high angle boundaries with misorientation angle larger than 15° is observed during annealing. The facets are roughly parallel to the traces of {111} planes and more readily occur for boundaries misoriented from 15 to 40°. The local faceting of lamellar boundaries leads to structural coarsening and polygonization of lamellar structure.

Considerable research attentions have been paid to grain boundary energy and mobility, mainly focused on boundary misorientation angle or axis [1,2]. Recently, experiments and computational simulations demonstrate that the grain boundary energy and mobility are also dependent upon boundary plane orientation, exhibiting boundary anisotropy [3–5]. As a result, boundary faceting in restricted inclination angles that correspond to low-energy configurations influences the grain growth behaviors during annealing [6,7]. Boundary faceting is frequently observed in the recrystallized polycrystalline materials with grain size of micrometer order [8,9]. Our recent study shows that the structural coarsening of nanolaminated structure with low angle boundaries ($\theta < 15°$) in a Brass-oriented pure Ni single crystal is also initiated by local faceting [10]. These flat facets are inclined each other by ~70° and aligned with one of the {111} planes. In contrast, thermally induced structural coarsening of lamellar structures containing high angle boundaries, mostly misoriented from 40° to 60°, is triggered by locally pulling the lamellar boundaries toward the interconnecting boundaries [11] or by the motion of triple junctions composed of high angle boundaries [12], namely, free from boundary faceting. Therefore, it is keen to examine the role of faceting played in the structural coarsening for nanolaminated structure with high angle boundaries misoriented from 15° to 40°.

Nanolaminated structure can be successfully fabricated by plane strain compression with high strain rate, during which the boundary types can be manipulated through selecting specific crystallographic orientations. Previous investigation has demonstrated that Brass-oriented single crystal subjected to plane strain compression undergoes less lattice reorientation, forming nanolaminated structure composed of mainly low angle boundaries [10]. Compared with Brass orientation, Goss orientation is also stable against lattice rotation but show moderate lattice spread [13], making it appropriate to fabricate nanolaminated structure with medium misorientation angle.

A single crystal Ni (99.945 wt%, chemical compositions see in [10]) was made into rectangular shape of $10 \times 8 \times 6.8$ mm^3 (ND × RD × TD) and subjected to channel die dynamic plastic deformation (DPD) and cold rolling at room temperature. Following our previous investigation [10], the compression direction during DPD is coincident to the normal direction (ND) and parallel with [110], while the rolling direction (RD) and transition direction (TD) are parallel with [001] and $[1\bar{1}0]$, respectively, as shown in Fig. 1a, namely, Goss orientation (110)[001]. The crystallographic orientation was determined by electron backscatter diffraction (EBSD), being deviated from the ideal Goss orientation within 3°. The sample was subjected to DPD at a strain rate of 10^2–10^3 s^{-1} to a von Mises effective strain (ε_{vM}) of 3.0, supplemented with cold rolling with an extra effective strain of ~1.0. The deformed sample was then annealed in vacuum at 375 °C for 15 min and 1 h, respectively, followed by cooling into water.

The microstructures of the deformed and the annealed samples were characterized by EBSD equipped on scanning electron microscope

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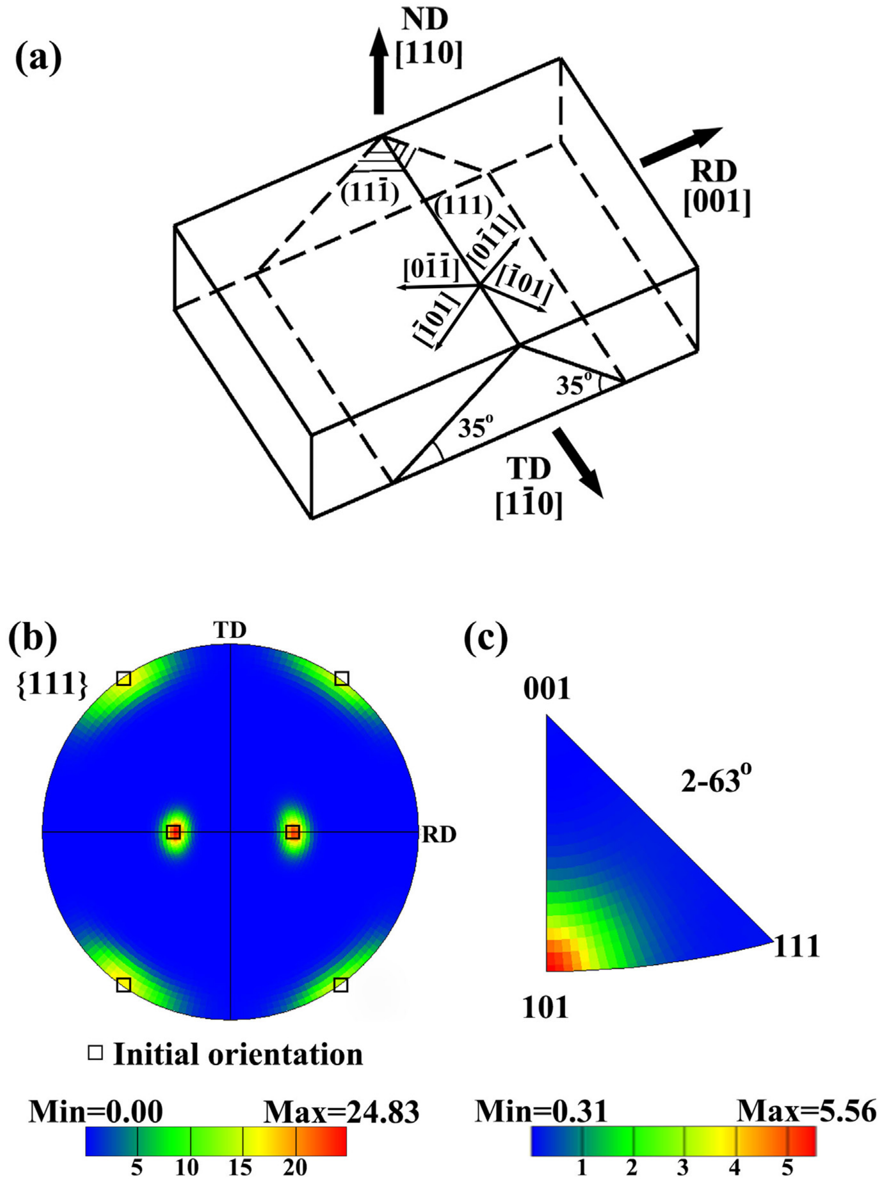

Fig. 1. (a) Schematic presentation of orientations and the primary slip {111} planes with respect to the sample coordination. The {111} pole figure (b) and misorientation axis distribution (c) obtained from EBSD data of the deformed single crystal Ni.

(SEM), and by convergent beam electron diffraction (CBED), precession-assisted crystal orientation mapping technique (PACOM) on a FEI F20 transmission electron microscope (TEM). The textural information was obtained from a big area of 0.5 mm^2 with a step size of 0.5 μm by EBSD, while the boundary parameters were determined by EBSD from an area of 400 μm^2 with a step size of 20 nm and by PACOM with a step size of 7 nm. CBED allows the boundary misorientation as small as 0.1° being measured, while the angular resolution for PACOM can be as high as 0.6° [14].

Experimental results show that an accumulative strain of 4.0 induces a slight crystal split in the Goss-oriented Ni sample. This is evidenced by the {111} pole figure (Fig. 1b), where ideal Goss orientation (marked by empty rectangle) gives highest intensity of 24.83 MUD and orientation spread up to 10° from the ideal one show low intensity around 10 MUD. Such orientation spread can be viewed as a rotation around ND, agreeing with the observation in Goss-oriented Al alloy subjected to large plastic deformation, where the Goss orientation was rotated into two complementary components of {110}⟨112⟩ around ND [15]. The misorientation axes are close to ⟨110⟩ with a density of 5.56 MUD (Fig. 1c).

TEM observation confirms that typical laminated structure was fabricated, as indicated in Fig. 2a. It is in contrast with equiaxed microstructures in Al single crystals deformed by channel die compression [15,16], due to a larger strain with higher strain rate in this study. The microstructure resembles that developed in polycrystalline pure Ni subjected to DPD [17] and surface mechanical grinding treatment [18,19], characterized by long and sharp lamellae containing interconnecting dislocation boundaries and loose dislocations. The lamellar boundaries are straight and roughly perpendicular to the ND, whereas wavy boundaries originated from the presence of localized shear are also found. Compared with the lamellar structure induced in pure metals during large strain deformation with low strain rate, say high pressure torsion (HPT) [20] or cold rolling (CR) [21–23], the present laminated structure differs in several aspects. First of all, the lamellar boundary spacings spanned from 10 to 300 nm with an average of 77 nm (Fig. 2b) that is 50 nm smaller than the saturate spacing in HPT Ni (130 nm). Secondly,