GRAIN MISORIENTATIONS IN THEORIES OF ABNORMAL GRAIN GROWTH IN SILICON STEEL

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Introduction

Understanding of the texture selection mechanism in the abnormal grain growth in grain oriented silicon steel is crucial for the improvement of the production process and the quality of the product. Unfortunately, details of the phenomenon are not clear. There are two similar but competing views frequently repeated in the literature of the subject. The first one originates in the suggestion that the coincidence lattice (CSL) misorientation relationships are a factor in the secondary recrystallization in silicon steel [1,2]. Recently, an extended version of the "CSL model" of abnormal grain growth is advanced [3–11]. Briefly, according to the model, the boundaries of Goss oriented grains are more frequently of the CSL–type than boundaries of other grains. Moreover, in the presence of precipitates, the CSL boundaries are assumed to be more mobile than general boundaries. Thus, the Goss grains have the opportunity to grow. The second view is based on the assumption that the high mobility is a feature of the so called "high energy" (HE) boundaries defined there as boundaries between grains misoriented by the angle of 20 to 45° [12–19]. Again, the advantage of the Goss grains would come from the fact that they are bounded by the HE boundaries more frequently than other grains. The objective of this note is to discuss some aspects of those hypotheses, with special attention to the early stage of the secondary recrystallization. Our main concerns and some comments on grain misorientations in explanations of the abnormal grain growth phenomenon are listed in the next section.

Queries and comments

Let us begin with recalling the classification of the abnormal grain growth theories into 'oriented growth theories' and 'oriented–nucleation growth–selectivity theories'. Numerous authors favor the latter approach; e.g., [20,21]. The two models described in the introduction advocate the oriented growth.

1. It is worth to repeat the argument against oriented growth theories made in [22]. It follows from experimental observations that better oriented early secondaries are of the same size as those with larger deviations from Goss. This means that the "orientation selection sets in at a very early stage". Oriented growth would start with a broad spectrum of orientations, which would be narrowed by a selection assumed to occur during the secondary recrystallization.

2. The considered models do not explain the sharpness of the final texture. Average deviations from the Goss orientation $\{110\} < 001 >$ are within 7° for conventional steels and $3 - 4°$ in superoriented steels [23]. If only grain misorientations are involved in the selection process, orientations of secondaries are controlled by orientations of their neighbors, i.e., the grains of the primary recrystallized matrix. However, the crystallographic texture of the matrix has a considerable spread. A contradiction appears because the precision of, say 4°, in orientation with respect to the external coordinate system cannot be provided by the primaries with texture components spread many times more than 4° [24]. The frequency of occurrence of the special misorientations may reach maximum at the Goss orientation in accord with the models, but it is not much smaller for other orientations (say, 10° from Goss) due to the weakness of the primary texture.

3. Simple symmetry considerations are against the CSL model. Take the $\Sigma 9$ misorientation relationship, which is considered to be crucial for the growth. A near–Goss orientation is one of 7 non–equivalent orientations with that relationship to the main component of the primary texture ($\{111\} < 112 >$). Assuming that the high mobility of $\Sigma 9$ boundaries is the cause of the abnormal growth of Goss grains, and taking into account that the primary orientation distribution has a non–zero random component, why crystallites with the other orientations do not grow abnormally?

4. The doubts concerning the CSL–based hypothesis are amplified by the fact that the CSL model of grain boundaries for metallic systems does not have any substantial experimental support; see e.g., [25]. (Frequently, outstanding properties of coherent twin boundaries are gratuitously ascribed to high–Σ CSL boundaries with arbitrary inclinations.)

5. The grain misorientation is *not* a sole determinant of boundary properties. If there is an explanation of the abnormal grain growth phenomenon based on properties of grain boundaries, it is unlikely that such a crude characterization of the boundaries will be sufficient.

6. The HE boundaries model uses the misorientation *angle* as the only factor determining high mobility. In the random case, the misorientations with 20 to 45° misorientation angle constitute 54.43% of all misorientations. A close number would be obtained for the primary matrix. That is in clear contradiction with the

reality of the early stage of secondary recrystallization, when only a small fraction of boundaries is involved in the abnormal growth.

7. Both of the considered models are supported by arguments of statistical character; it is argued that, *on average*, Goss grains are more frequently surrounded by special boundaries than other grains. However, there is a problem with equal treatment of all Goss nuclei if only some of them are viable. It is known that one large abnormally grown secondary grain covers a region occupied by about one million grains of the primary recrystallized matrix. Now, one can ask about the number of Goss oriented primary grains in that region. Of course, the answer depends on the allowed deviation from the precise $\{110\} < 001 >$ orientation. Assuming that the Goss grains have the same size distribution as other primary grains, the Goss nuclei with the accuracy of 4° constitute the fraction of $4.3 \times 10^{-4} \times f_{Goss}$ of all grains, where f_{Goss} is the value of the normalized orientation distribution function at the Goss orientation; f_{Goss} is of the order of 0.1 or 1. (For 7° accuracy that fraction is $2.3 \times 10^{-3} \times f_{Goss}$.) Thus, it seems that there are many more primary Goss grains than one per million. If that is true, the analysis of the neighborhood of equally treated Goss nuclei in the primary recrystallized matrix can be unproductive because most of these grains will not grow abnormally.[1]

There are also consequences for experimental results concerning the Goss oriented primary grains. Their usefulness is limited if the number of involved grains is not large enough. For example, in EBSD based orientation mappings, where the number of grains covered in one run is usually a few hundred [27], the probability of encountering a primary grain which will eventually grow abnormally is very low (approximately 10^{-3} per run).

8. The high mobility of boundaries between specially misoriented grains acts in two directions; without the size advantage, a Goss grain has the same probability of consuming a neighboring grain, as of being consumed. Taking into account the relatively small number of Goss oriented grains in the primary recrystallized matrix, they could easily loose the contest. Even simple 2D computer simulations (e.g., [28]) show that high mobility alone is not sufficient for providing grains of a dominant size.

9. In relation to the above issue, we would also like to comment on using the boundary mobility as an underlying element of the abnormal growth theories. As was noticed by Hutchinson and Homma [29], the grain size of the neighbors of secondary grains is equal to the grain size of the matrix, which means that the migration of boundaries of secondary grains is not uniform. It was also directly observed using X-ray topography that the motion is "neither stationary nor uniform" [30]. This suggests that the growth is not a smooth evolution but a jerky process and the boundary mobility (defined as the coefficient relating the driving force to the boundary velocity) is of secondary significance for the issue. The primary factor is the ability of the boundary to overcome the pinning by second–phase particles [21, 22]. Both considered models recognize the importance of the particles; the selective

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[1] Because our discussion above is kept in the spirit of the considered models, also in our arguments all Goss grains are equally treated. Moreover, we must admit that this author has also performed a problematic statistical analysis of a similar type [26].

pinning is employed in the CSL model, and the preferential particle coarsening is used in the HE boundaries model. However, they utilize those arguments only to justify the high mobility of the distinguished boundaries, and concentrate on the preferential mobility as the ultimate reason of the abnormal grain growth.

10. Finally, a credible theory of the abnormal grain growth phenomenon is expected to clarify the issue of the driving force for the growth. The driving force coming from the minimization of the free energy accumulated in boundaries is usually admitted. However, with no experimental support for the size advantage at the early stage of secondary recrystallization, some authors suggested the existence of the volume driving force [31, 32] or other mechanisms (e.g., [33]). The models we consider here are not clear in the respect of the driving force for the growth in its early stage, before the size advantage sets in.

Conclusion

The considered hypotheses are promoted as correct and complete theories explaining the process of secondary recrystallization in silicon steel. In our opinion, the question whether the CSL or HE boundaries mechanisms function as additional filters for the selection of the Goss texture component in the growth of secondaries is still open but none of the models is acceptable as a full explanation of the phenomenon. Both of them are merely scientific speculations and, as such, should be treated with skepticism.

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