The Effect of Annealing Atmosphere on the Evolution Behavior of Inhibitors in Thin-Gauge Grain-Oriented Silicon Steel

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In this paper, 0.18 mm thin-gauge S-type steels with MnS and N-type steels with AlN as main inhibitors, respectively, were fabricated using three different final annealing systems. Moreover, the evolution behavior of the MnS and AlN [(Al, Si)N] particles and grain orientation were investigated. Number density and mean diameter of second-phase particles were statistically determined by field-emission scanning electron microscopy. Results indicated that evolution of MnS and AlN would be suppressed with increased N₂ content during annealing. The onset ripening temperature of MnS was lower than that of AlN particle, which caused secondary recrystallization in the S-type samples at lower temperature compared with that of the N-type samples. Moreover, for the N-type steel fabricated by nitriding method, the effective inhibitor was (Al, Si)N formed by the decomposition of (Al, Mn, Si)N. The decomposition of (Al, Mn, Si)N particles and coarsening of (Al, Si)N inhibitors were strongly inhibited and delayed with increased N₂ content in annealing atmosphere. In conclusion, N₂/H₂ ratio of annealing atmosphere could be an effective control parameter to enhance the inhibition ability and delay secondary recrystallization onset in forming sharp Goss texture. [doi:10.2320/matertrans.M2017114]

(Received April 28, 2017; Accepted August 28, 2017; Published September 29, 2017)

Keywords: thin-gauge cold-rolled grain-oriented silicon steel, annealing atmosphere, inhibitor, MnS, AlN

1. Introduction

Cold-rolled grain-oriented silicon steel widely used in electric and electronic industry is the core material that affects the energy consumption of a transformer. Decreasing the thickness of the steel can significantly reduce eddy current loss and promote the energy saving of transformers. Thus, this process has become a main trend in the development of advance technology on steel fabrication. However, compared with thick-gauge silicon steel, production of thin products requires heavy cold-rolling deformation which will lead to significant reduction in proportion of Goss texture component¹⁾. Moreover, this process might increase the sensitivity of grain growth due to the change in atmosphere during final annealing. Simultaneously, the ripening rate of inhibitors in thin-gauge silicon steel is also hastened such that the pinning effect of particles in the surface layer of matrix will be easily invalidated, hampering the formation of sharp Goss texture²⁾. Therefore, controlling the ripening rate of inhibitors in thin-gauge grain-oriented silicon steel during preparation is the key to obtain sharp Goss texture.

The inhibitors of grain-oriented silicon steel mainly include MnS, AlN, and Cu₂S. Numerous studies on 0.23–0.30-mm thick grain-oriented silicon steels^{3–9)} have focused on the solution, precipitation, and coarsening of MnS and AlN particles. MnS particles are likely to precipitate during hot rolling^{5,10)} and tend to nucleate and precipitate at the dislocation when the deforming temperature is low, but precipitate at grain boundaries¹¹⁾. After partial dissolution in the matrix during cold-rolling deformation^{12–15)}, MnS particles will precipitate completely by decarburizing annealing at 850°C^{11,15)} and start to coarsen at 875°C during final anneal-

ing¹⁶⁾. The pinning force of MnS is weaker and tends to disappear earlier than that of AlN^{17,18)}, hindering the abnormal growth of Goss grains to have enough time to inoculate to obtain a sharp Goss texture. Therefore, a single inhibitor by MnS is usually used to prepare common grain-oriented silicon steel. AlN particle is usually used to produce high-magnetic induction oriented silicon steel using inherent or acquired inhibitor method^{19,20)} as its strong inhibition^{21,22)}. In the inherent inhibitor method, the AlN particle is mainly derived from the precipitation in the normalized stage⁷⁾. Meanwhile, under the 25%H₂+75%N₂(volume fraction, vol%) annealing atmospheric condition in the final annealing process, AlN particles start to ripen at 900°C and lose inhibition ability below 980°C²³⁾. For the acquired inhibitor method, due to the initial alloy composition, the formation of large amount of AlN particles mainly depends on the decomposition and transformation of Si₃N₄ formed by nitriding treatment as temperature reaches more than 700°C in the final annealing process^{24,25)}. In addition, the ripening temperature of AlN particles is higher than that of the inherent inhibitor method and causes the temperature of secondary recrystallization to be higher than 1000°C²⁶⁾.

The annealing atmosphere, annealing temperature, and inhibitor type are the key factors in the inhibitor ripening behavior and in the characteristics of annealing microstructure and texture. In particular, the ratio of N₂ and H₂ in the annealing atmosphere is the main parameter that influences the precipitation and coarsening behavior of inhibitors. The evolution behavior of MnS under different annealing atmospheres during the final annealing process is rarely reported. For AlN inhibitors, AlN precipitation is inhibited in 0.23- and 0.30-mm thick oriented silicon steels, and secondary recrystallization temperature increases at high N₂ partial pressure¹⁹⁾. By contrast, the secondary recrystallization tempera-

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ture would be lower and AlN is more likely to decompose at a lower temperature as the N_2 partial pressure becomes lower²³). A study on the evolution behavior of AlN particles under different atmosphere conditions showed that more N atoms will be lost from the matrix, and AlN particles are more likely to coarsen at 920°C with prolonged treatment at lower N_2 partial pressure²⁷). These studies on atmospheric factors are based on 0.23–0.30-mm thick oriented silicon steel. Thickness reduction will make the steel more sensitive to atmospheric changes during final annealing, and the inhibitors are more likely to ripen. Consequently, the evolution behavior of inhibitors in thin-gauge grain-oriented silicon steel in the final annealing will differ from that of the thick-gauge grain-oriented silicon steel. Accordingly, the evolution behavior of MnS and AlN inhibitors in 0.18-mm or thinner grain-oriented silicon steel under different atmospheres cannot be determined based on existing studies. Moreover, the ripening of two kinds of particles under different annealing atmospheres and its effect on annealing microstructure and texture remain unclear.

In our previous work, the effects of nitrogen content in the annealing atmosphere on the behavior of inhibitors of grain-oriented silicon steel with different thickness (0.23 and 0.18 mm) was investigated²⁸). In this paper, the evolution behavior of MnS and AlN particles in 0.18 mm specimens under different annealing atmospheres and soaking times was systematically analyzed. In addition, the effect of evolution behavior of particles on the formation of Goss texture was evaluated. This study can provide a theoretical basis to improve the control of the final annealing atmosphere for preparing thin-gauge silicon steel with different inhibitors.

2. Experimental Procedure

Two components of normalized plates with 2.20 mm thickness were used as raw materials. The plate with MnS as the main inhibitor was labeled as S-type, and the plate with AlN as the main inhibitor was labeled as N-Type. The two kinds of plates were cold-rolled to 0.18 mm and then treated by decarburizing annealing at 850°C. N-type samples after decarburizing annealing underwent nitriding treatment at 750°C. Then, the samples were heat-treated at 850°C for 2 h to ensure the complete decomposition of Si_3N_4 which was formed in the surface layer after nitriding^{24,25}) and to diffuse the N atoms from the surface to the central layer to dissolve into the matrix or react with Al to form nitrides^{29,30}). The compositions of the treated N-type samples and annealed S-Type samples are shown in Table 1. Then, the effect of atmospheric nitrogen was studied by annealing the samples under 10% H_2 +90% N_2 , 50% H_2 +50% N_2 , and 90% H_2 +10% N_2 atmosphere. The S-type samples were annealed at 950°C, while the N-type samples were annealed at 950°C (labeled as N-type₁) and 1000°C (labeled as N-type₂). The heating

rate was 8°C/s. Both S-type and N-type samples were taken after certain periods (1, 3, and 5 h) by interrupting the evolution of precipitate with water quenching. The specific process is shown in Fig. 1. The surfaces of the interrupted samples were ground in a rolling plane and a cross-sectional plane, followed by polishing and erosion treatment. Then, the microstructure was observed by BX51m Olympus metal-lurgical microscope, and orientation was analyzed by Oxford HKL Channel5 electron backscatter diffraction in the cross section. In addition, the particles were observed by scanning electron microscopy (SEM) (ZEISS-ULTRA55) and transmission electron microscopy (TEM) (G2 F30 Tecnai) with energy-dispersive spectroscopy (EDS) in the rolling surface.

3. Results and Discussions

3.1 Microstructure and grain orientation characteristics

The S-type samples completely underwent secondary recrystallization under 90% H_2 +10% N_2 atmosphere at 950°C for 1 h, and the {200} pole figures show that deviated Goss orientation was the main texture component, as shown in Fig. 2. The samples under 10% H_2 +90% N_2 atmosphere completely underwent secondary recrystallization after 3 h of soaking time, and the deviation angle from Goss orientation was smaller than that under 90% H_2 +10% N_2 . The samples annealed under 50% H_2 +50% N_2 atmosphere had the longest secondary recrystallization time. These samples started to undergo secondary recrystallization after 3 h of soaking time and completely formed sharp Goss texture at 5 h.

No significant change in the grain size was found in N-type specimens soaked at 950°C or 1000°C for 5 h, and these samples did not undergo secondary recrystallization under any annealing atmosphere, as shown in Fig. 3.

3.2 Observation of second-phase particles

Data were collected from 100 micrographs in the precipitation region to enhance the accuracy of the statistical data. Figures 4 and 5 show the average diameter and number density of particles of S-type and N-type₂ samples at different annealing atmospheres and times. The number density and average diameter of particles changed obviously with increase in soaking time, and the variation trends of the parti-

Table 1 Nominal composition of samples (mass%).

	C	Si	Mn	S	Al	N
S-Type	<0.003	3.0	0.12	0.018	0.016	0.006
N-Type	<0.003	3.0	0.05	0.005	0.03	0.033

Fig. 1 Annealing process associated with Atmosphere-Temperature-Time.

Fig. 2 Microstructure and {200} pole figures of S-Type samples under different soaking time and annealing atmosphere at 950°C (a) 10% N₂+90% H₂-1 h, (b) 90% N₂+10% H₂-1 h, (c) 90% N₂+10% H₂-3 h, (d) 50% N₂+50% H₂-3 h, (e) 50% N₂+50% H₂-3 h, (f) 50% N₂+50% H₂-5 h.

Fig. 3 Microstructure of N-Type samples under different annealing conditions (a) 950°C-10% N₂+90% H₂-5 h, (b) 1000°C-10% N₂+90% H₂-5 h, (c) 1000°C-90% N₂+10% H₂-5 h.

cle states of the two types of samples differed under distinct atmosphere conditions. In this experiment, MnS precipitated almost completely in the early stages. Thus, MnS particles mainly coarsen when soaked at 950°C, and the coarsening rate will be affected by changing the annealing atmosphere. Referring to Fig. 4, prolonged soaking time for the S-type samples resulted in the downward trend for the number density of particles, which varied in the range of 1–8/μm², but increasing trend for the particle size, which changed from 30 nm to 100 nm. The maximum number density of particles and minimum average diameter were observed under

Fig. 4 Number density and mean diameter of the particles of the S-Type samples at different atmospheres and time at 950°C.

Fig. 5 Number density and mean diameter of the particles of the N-Type₂ samples at different atmospheres and time at 1000°C.

50% H₂+50% N₂ atmosphere, compared with those under the other two atmospheric conditions. For N-type₂ samples, the number density of particles varied in the range of 1–9/μm², and particle size changed from 30 nm to 120 nm. Moreover,

the variation trend of these samples significantly differed from that of the S-type samples, as shown in Fig. 5.

No obvious changes in the microstructure and inhibitor state were observed for N-type₁ samples soaked at 950°C. The average particle size (115 nm) and number density of particles ($1.2/\mu\text{m}^2$) were almost unchanged under different conditions, indicating the very slow ripening rate of AlN inhibitors in 0.18 mm specimens. Compared with reported results²⁷⁾, increasing the thickness of the oriented silicon steel may result in higher ripening temperature of AlN.

3.3 Comparative analysis of particle evolution behavior

Figure 6 shows the morphologies and chemical compositions of particles in S-type samples under different atmospheric conditions and soaked at 950°C for 3 h. Under

10%N₂+90%H₂ atmosphere, the particles were circular and elliptical, and these particles mainly consisted of MnS with size of approximately 100–500 nm with reference to Figs. 6(a) and (b). Under 50%N₂+50%H₂ atmosphere, the particles not only included circular composite particles formed with (Al, Si)N and MnS, but also a certain number of rectangular (Al, Si) N particles with reference to Figs. 6(c) and (d). The chemical compositions of composite particles are corresponding to the large plot and the chemical compositions of fine (Al, Si) N particles are corresponding to the small plot in Fig. 6(d). Under 90%N₂+10%H₂ atmosphere, the particles were mainly MnS of small size, only a few big-sized MnS was found with reference to Figs. 6(e) and (f). Nitride particles were not observed under 10%N₂+90%H₂ or 90%N₂+10%H₂ atmosphere, whereas a

Fig. 6 Morphologies and chemical compositions of particles in S-Type samples soaking at 950°C for 3 h (a) 10% N₂+90% H₂, (b) EDS profile for MnS particle in Fig. (a), (c) 50%N₂+50% H₂, (d) EDS profiles for composite particle in Fig. (c), (e) 90%N₂+10% H₂, (f) EDS profile for MnS in Fig. (e).

large number of nitride particles were observed under 50%N₂+50%H₂ atmosphere. These results indicate that nitrides can be formed by nitriding under 50%N₂+50%H₂ atmosphere. The samples were heated very fast, and they reached 950°C in a very short period of time. The state of the particles did not change during the heating process. Figures 2–4 show that the particle coarsening rate was fastest under 10%N₂+90%H₂ atmosphere because of the high H₂ content, and the density was lower and particle size was bigger than those under the other two atmospheres. Moreover, the S atoms in the silicon steels can be easily lost, decreasing the secondary recrystallization temperature and time³¹). Thus, the samples underwent secondary recrystallization first and formed deviated Goss texture at 1 h under 10%N₂+90%H₂ atmosphere. Increasing soaking time led to the gradual coarsening of the particles such that the number density of particles continued decreased, and particle size gradually increased. The coarsening of MnS particles was strongly inhibited under 90%N₂+10%H₂ atmosphere. During the early soaking stage, the average number density of particles was higher than that under 10%N₂+90%H₂ atmosphere with reference to Fig. 4. This characteristic will also lead to a slowdown in the failure of the pinning force, delaying the occurrence of secondary recrystallization. Coarsening of the MnS particles resulted in the complete secondary recrystallization of the samples within 3 h of soaking time. By contrast, higher density and finer particle size were observed in the initial soaking stage under 50%N₂+50%H₂ atmosphere because of the formation of fine

nitride particles. This phenomenon might cause a stronger pinning force and prolonged time for secondary recrystallization than that under 90%N₂+10%H₂ atmosphere. With prolonged soaking time, the coarsening of particles was dominant, and the pinning force was weakened. This process resulted in the secondary recrystallization at 3 h, which was completed at 5 h, and a sharp Goss texture was formed.

Figure 7 shows the morphology and chemical composition of the N-Type₁ and N-Type₂ samples after soaking at 950°C for 5 h and 1000°C for 1 h, respectively, under 10%N₂+90%H₂ atmosphere.

No obvious changes were found in the number density and size of particles in N-type₁ samples soaked at 950°C. Thus, the state of the particles in N-Type₁ samples at 950°C during insulation stage did not change significantly under this atmospheric condition and may not change in all atmospheres. Moreover, the particles were mainly coarse (Al, Mn, Si)N with reference to Figs. 7(a) and (b). By contrast, soaking at 1000°C for 1 h, (Al, Mn, Si)N in N-type₂ specimens under 10%N₂+90%H₂ atmosphere were not observed but square (Al, Si)N was found. Meanwhile, according to the change in the number density in Fig. 5, the coarse (Al, Mn, Si) N gradually transformed into (Al, Si)N particles with reference to Figs. 7(c) and (d). Compared with the change in the number density and particle size in Fig. 5 under 10%N₂+90%H₂ atmosphere with low nitrogen, the decomposition and transformation could not be suppressed, and a large number of fine (Al, Si) N nitrides could be formed by the decomposition of (Al, Mn, Si)N in 1 h. These

Fig. 7 Morphologies and EDS profiles of particles in N-Type samples (a) N-Type₁ sample: 10% N₂+90% H₂-950°C soaking for 5 h, (b) EDS profile for (Al, Si, Mn)N particle in Fig. (a), (c) N-Type₂ sample: 10% N₂+90% H₂-1000°C soaking for 1 h, (d) EDS profile for (Al, Si)N particle in Fig. (c).

processes led to higher number density and smaller particle size compared with those under the two other atmospheres. Prolonged holding time resulted in the rapid coarsening of particles similar to the particles in the S-type samples. Under 50%N₂+50%H₂ and 90%N₂+10%H₂ atmosphere, the decomposition of (Al, Mn, Si)N in the matrix was inhibited in the early soaking stage. Prolonged soaking time resulted in the formation of a large number of fine (Al, Si)N nitrides in the later period of heat preservation. This phenomenon led to increased overall number density and gradually decreased average size of particles. Although the particle state changed obviously after soaking at 1000°C, secondary recrystallization did not occur at this temperature within 5 h.

Comparison of the S-type and N-type samples showed that the atmosphere significantly affected the particle coarsening behavior. For S-type samples, high N₂ ratio of atmosphere can play a role in increasing the inhibitors, enhancing the ability of particle inhibition, and suppressing the coarsening of MnS that delayed the secondary recrystallization time. By contrast, for N-Type samples, the final annealing atmosphere can control the particle evolution behavior by influencing the coarsening of the nitride particles.

3.4 Comparative analysis of particle Zener-pinning

The pinning ability of inhibitors, which is usually used to determine the extent of particle ripening, plays a decisive role in the occurrence of secondary recrystallization. This ability determines the time and temperature of secondary recrystallization. Hence, pinning ability is an important parameter to measure the effect of inhibitors. In this paper, annealing time was processed as variable to analyze the relationship between pinning factor and secondary recrystallization. N-type samples did not undergo secondary recrystallization in this study. Thus, discussing the pinning ability of nitrides is not necessary. Only the pinning ability of MnS in S-type samples was analyzed in this paper. According to the theory of Zener relation^{32,33}, the particle pinning ability at different atmospheres and time can be estimated by a Zener factor Z , which can be simplified as follows:

$$Z = \frac{3}{2} f_v / d \quad (1)$$

where f_v is the volume fraction of precipitates, and d is the mean diameter of precipitates. The calculated results of S-type specimens are shown in Fig. 8.

According to eq (1), Z is directly proportional to f_v but inversely proportional to d . Hence, higher number and finer particles will result in stronger pinning force. Theoretically, with prolonged soaking time, the gradual coarsening of particle will become dominant, the number of particles will decrease, and the average size will increase. These phenomena will lead to decreased particle Zener-pinning, which is consistent with the calculation results, as shown in Fig. 8. Thus, Fig. 2 and the above analysis shows that the sample processed under 50% N₂+50% H₂ atmosphere started to undergo secondary recrystallization when the holding time was approximately 3 h. Moreover, 221 may be the critical value of the Zener factor, below which the particles cannot effectively pin the grain boundaries, and secondary recrystallization will occur. During the whole heating preservation, the

Fig. 8 Zener factor of precipitates of the S-Type samples in different atmospheres and at different soaking time.

value of Zener factor in the different atmospheres followed the rule $Z_{50\%N_2} > Z_{90\%N_2} > Z_{10\%N_2}$. Secondary recrystallization occurred first because of the minimal Zener factor of 10% N₂+90% H₂ atmosphere. By contrast, under 50% N₂+50% H₂ atmosphere, increased nitride particles finally resulted in secondary recrystallization.

The final secondary recrystallization grains of S-type samples formed after annealing were mainly Goss or deviated Goss with reference to Fig. 2. Comparison and analysis of the pole figures of samples annealed under the three atmospheres showed that the deviated angle from the exact Goss orientation was minimal under the 50%N₂+50%H₂ atmosphere. Accordingly, an appropriate annealing atmosphere for N₂/H₂ ratios may exist, and some nitrogen can be infiltrated into S-type samples and promote the formation of nitride particles. This characteristic will enhance the inhibition ability, delay the onset time for secondary recrystallization, and form sharp Goss texture. The deviated Goss grains tended to grow abnormally when the N₂ ratio in annealing atmosphere was too high or too low. For the 0.18-mm thick S-type samples fabricated in this paper, the relationship between final annealing atmosphere, holding time, and secondary recrystallization are expressed in Fig. 9. Nevertheless, annealing atmosphere of 50%N₂+50%H₂ is not necessarily the optimum atmosphere for the preparation of 0.18-mm thick S-type specimens in this paper. Higher optimal annealing atmosphere ratio that makes sharper Goss texture may exist. Moreover, for 0.18-mm thin-gauge plates of different compositions, the ideal secondary recrystallization with Goss texture may be obtained by optimizing the final annealing atmosphere.

Studies^{34–36} have shown that when the secondary recrystallization occur near 1050°C, a special orientation relationship between the Goss grains and the surrounding grains exists, which is high-angle grain boundaries. Moreover, Goss grains are less affected by particle pinning and tend to grow abnormally at low temperature prior to the deviated Goss grains¹¹. The difference in the orientation between Goss and deviated Goss texture is very small, and the threshold for suppressing abnormal Goss and deviated Goss grain growth and temperature range of rapid migration of grain boundaries might be very close. A study showed that the Σ9 grain boundaries favorable to the abnormal growth of Goss grains had high mobility at approximately 975°C³⁷. Therefore, in

Fig. 9 The relationship between final annealing atmosphere, holding time and secondary recrystallization.

the temperature range close to 975°C, the deviated Goss grains may also have high mobility and form a competitive relationship with abnormal growth of Goss grains. In this study, Fig. 8 shows the difference in the pinning capacities of inhibitors with extended soaking time at 950°C under different atmospheres. This phenomenon led to variations in the onset time between abnormal Goss and deviated Goss grain growth. According to Figs. 2 and 8, faster reduction in the pinning force to below the critical value will tend to the abnormal growth of more deviated Goss grains prior to Goss grains. This result is consistent with the simulation results of Fortunati and Abbruzzese³⁸). By contrast, slow reduction in the pinning force results in longer inoculation time of Goss grains, leading to gradual increase in Goss grains and inhibiting the abnormal growth of deviated Goss grains. These conditions are conducive to improve the sharpness of Goss texture. Accordingly, the abnormal growth of Goss grains and deviated Goss grains may be greatly affected by annealing atmosphere. Thus, the grains have priority to grow abnormally depending on the specific annealing conditions.

The nitride inhibitors can be added by nitriding the thin-gauge oriented silicon steel with MnS as the main inhibitor and improve the formation environment of Goss texture.

4. Conclusion

In this study, final annealing experiments of two kinds of 0.18 mm thin-gauge cold-rolled grain-oriented silicon steel with MnS and AlN [mainly(Al, Si)N] as primary inhibitors were performed. The ripening rate and state parameters of the two types of inhibitors under different annealing atmospheres were investigated. The following conclusions were drawn:

(1) The ripening temperature of MnS was lower than that of AlN particle. The particle gradually coarsened, and the number density of particles decreased with increased holding time under different atmospheric conditions. Higher proportion of N₂ in the annealing atmosphere resulted in the more gradual ripening of the particle. Under 50%N₂+50%H₂ atmosphere, nitrogen could be infiltrated into the samples and form nitride inhibitors. This phenomenon enhanced the inhibition ability, which was stronger than those under the

two other atmospheric conditions.

(2) For the 0.18 mm MnS-typed samples, faster decreasing rate of pinning force led to the increasing tendency of abnormal growth of deviated Goss grains prior to Goss grains. By contrast, longer inoculation time for Goss grains resulted in increased grain size for the Goss grains and inhibited abnormal growth of deviated Goss grains.

(3) For the 0.18 mm samples fabricated by the acquired inhibitor method, the coarse (Al, Mn, Si)N particles were the main products during the early stage, and the ripening rate under the different atmospheres was very slow when soaked at 950°C. At 1000°C, low proportion of N₂ in the annealing atmosphere led to the rapid decomposition of (Al, Mn, Si) N particles, forming (Al, Si) N inhibitors. By contrast, the decomposition of (Al, Mn, Si) N particles and the coarsening of (Al, Si) N inhibitors were strongly inhibited and delayed with increased N₂ content in the annealing atmosphere. Soaking at 950°C and 1000°C for 5 h showed no secondary recrystallization for the N-type samples.

So far, numerous studies have been conducted on the thermodynamics and dynamics of MnS and AlN as inhibitors in silicon steel. These studies can be used as the basis to meet the needs of this paper. In this study, the coarsening behavior of MnS particles in plates fabricated by high-temperature hot-rolling method and the transformation of nitrides in plates fabricated by nitriding method are more complex because of the change in atmospheric factor. Therefore, in this paper, we mainly analyzed and discussed the annealing atmosphere and its effect on the evolution behavior of particles. The recrystallization behavior in thin-gauge plate was also investigated, and the annealing atmosphere suitable for preparing 0.18 mm MnS-typed sheets in three kinds of atmosphere was determined. Further calculations and discussions about the kinetics and thermodynamics will be performed in subsequent work.

Acknowledgments

This work is supported by National Key R&D Program of China (Grant No. 2017YFB0903901, 2017YFB0903900) and China's State Grid Corporation of Science and Technology Projects(Grant No. SGRI-WD-71-13-002).

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