

Preparation methods and research progress of $\text{Sm}_2\text{Fe}_{17}\text{N}_x$

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Abstract

$\text{Sm}_2\text{Fe}_{17}\text{N}_x$ rare earth permanent magnet materials have attracted extensive attention because of their good magnetic properties, excellent corrosion resistance and oxidation resistance. The $\text{Sm}_2\text{Fe}_{17}\text{N}_x$ compound is usually prepared through the precursor material $\text{Sm}_2\text{Fe}_{17}$ and subsequent nitriding treatment. At present, there are various preparation techniques of $\text{Sm}_2\text{Fe}_{17}$. The purpose of this paper is to summarize the differences of different preparation methods, as well as their problems, and the magnetic properties.

Keywords

$\text{Sm}_2\text{Fe}_{17}$ alloy; preparation technology; nitriding treatment; $\text{Sm}_2\text{Fe}_{17}\text{N}_x$ compound.

1. Introduction

Thousands of years ago, human beings began to recognize and use magnetic force. The core of Sinan used in China during the Warring States period was a magnet. With the development of science and technology, people's cognition and application range of electromagnetic theory became broader. Generally, permanent magnet materials are divided into four categories: cast permanent magnet materials, ferrite permanent magnet materials, rare earth permanent magnet materials and other permanent magnet materials. There were new permanent magnet materials emerging every ten years, and the development process is shown in Figure 1.

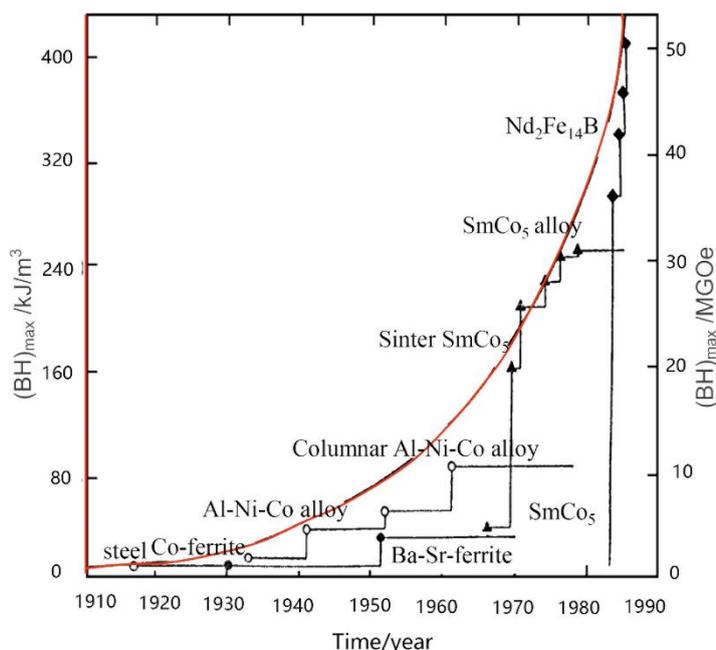


Fig. 1 Development history of modern permanent magnet materials

In the early 20th century, quenched martensitic steel was first used because of its magnetic properties, and then chromium steel and tungsten steel were developed to improve the magnetic properties and application value. In the 1920s, Japanese researchers developed cobalt steel with WCrC, which greatly improved the coercivity H_C of permanent magnet materials and

accelerated the utilization and development of permanent magnet materials. In the 1950s, Philips of the Netherlands manufactured the leading barium ferrite permanent magnet materials, which were widely used because of their low cost, strong coercivity, and easiness to manufacture. Later, in the 1960s, permanent magnet materials with a magnetic energy product of 144 kJ/m^3 were successfully developed, becoming the first generation of rare earth permanent magnet materials [1-2].

In the 1970s, Japan developed the second generation of rare earth permanent magnet raw materials, namely, Sm-Co alloy, and the magnetic energy product of the materials was greatly improved [3]. In the 1980s, the third generation of rare earth permanent magnet material NdFeB was developed. The performance of this material far exceeded that of the previous two generations and was known as the "magneto king". However, after years of research, the performance of NdFeB showed limitations. The short plate which cannot maintain the original state characteristics at high temperature cannot be effectively improved. In the 1990s, Coey et al. Prepared $\text{Sm}_2\text{Fe}_{17}\text{N}_x$ rare earth permanent magnet material through "gas-solid" reaction method, and attracted extensive attention of researchers because of its strong uniaxial anisotropy, excellent magnetic energy product and high Curie temperature [4]. Figure 2 shows the performance comparisons of the two magnetic materials.

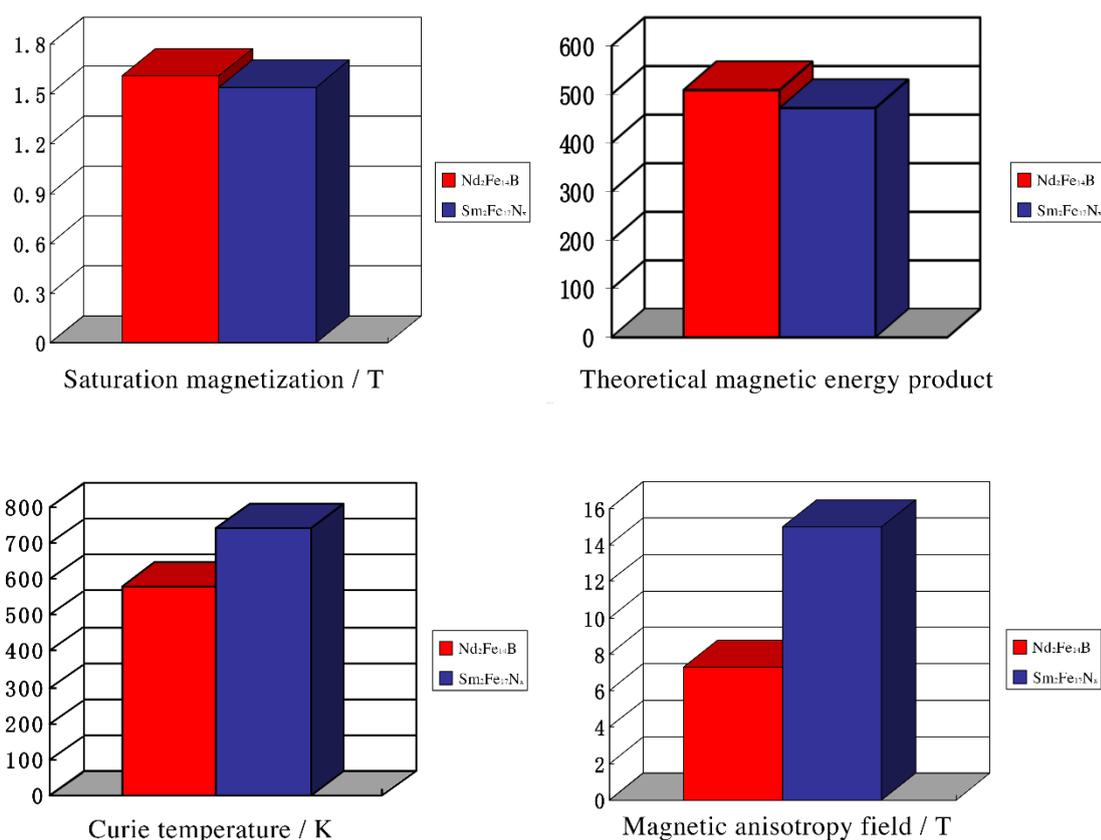


Fig. 2 Comparison of properties of two rare earth permanent magnet materials

Since then, the research of $\text{Sm}_2\text{Fe}_{17}\text{N}_x$ and its precursor material $\text{Sm}_2\text{Fe}_{17}$ has become one of the hotspots in the field of magnetic materials. In recent 20 years, people have carried out a lot of theoretical and practical researches on Sm-Fe based compounds, but Sm-Fe based compounds are easy to volatilize and oxidize in the melting process, which makes many preparation methods difficult to be applied to industrial practice, and there are still some problems to be solved.

2. Preparation method of Sm₂Fe₁₇ alloy

The preparation of samarium iron nitrogen usually includes two steps: the first step is to prepare the precursor material Sm₂Fe₁₇, and the second step is to nitride the Sm₂Fe₁₇ alloy powder to obtain Sm₂Fe₁₇N_x. At present, there are many methods to prepare Sm₂Fe₁₇, including reduction diffusion method, powder metallurgy method, hydrogenation disproportionation method, and rapid quenching method. Sm₂Fe₁₇ material has been widely studied because of its great impact on the properties of the finally prepared Sm₂Fe₁₇N_x.

2.1. Reduction diffusion method (RD)

The method of preparing Sm₂Fe₁₇ alloy powder by reduction diffusion method is to control the temperature in the temperature range of 1173 ~ 1473K, reduce the rare earth oxide Sm₂O₃ to metal Sm by reducing agent metal Ca, and then conduct interdiffusion reaction with transition metal Fe to prepare Sm₂Fe₁₇ alloy.

The preparation of alloy powder by this method can be traced back to Cech et al. [5] in 1974. Rare earth elements were obtained by reducing rare earth oxides with calcium and then conducting diffusion reaction with cobalt to prepare rare earth cobalt magnetic materials. Sumitomo Metal Mining Co. Ltd of Japan prepared Sm₂Fe₁₇ by reduction diffusion method. The main reaction formula is: $\text{Sm}_2\text{O}_3 + 3\text{Ca} + 17\text{Fe} = \text{Sm}_2\text{Fe}_{17} + 3\text{CaO}$. After that, this method developed rapidly in Japan and had been successfully industrialized. In the research and application in China, Guo Guangsi et al., prepared Sm₂Fe₁₇ magnetic powder by reduction diffusion method, and studied the effects of reaction temperature, constant temperature time and nitrogen pressure on nitridation. It was found that Sm₂Fe₁₇N₂ with high nitrogen content can be obtained at 873 K under 200 kPa nitrogen pressure for 5 hours 874K magnetic particle [6]. Deng Gengfeng et al., also prepared the magnetic properties of Sm₂Fe₁₇N_x magnetic powder by reduction diffusion method, with maximum magnetic energy product (BH)_{max} = 39.7 kJ/m³, remanence Br = 0.84 T, and coercivity HC = 0.24 MA/m.

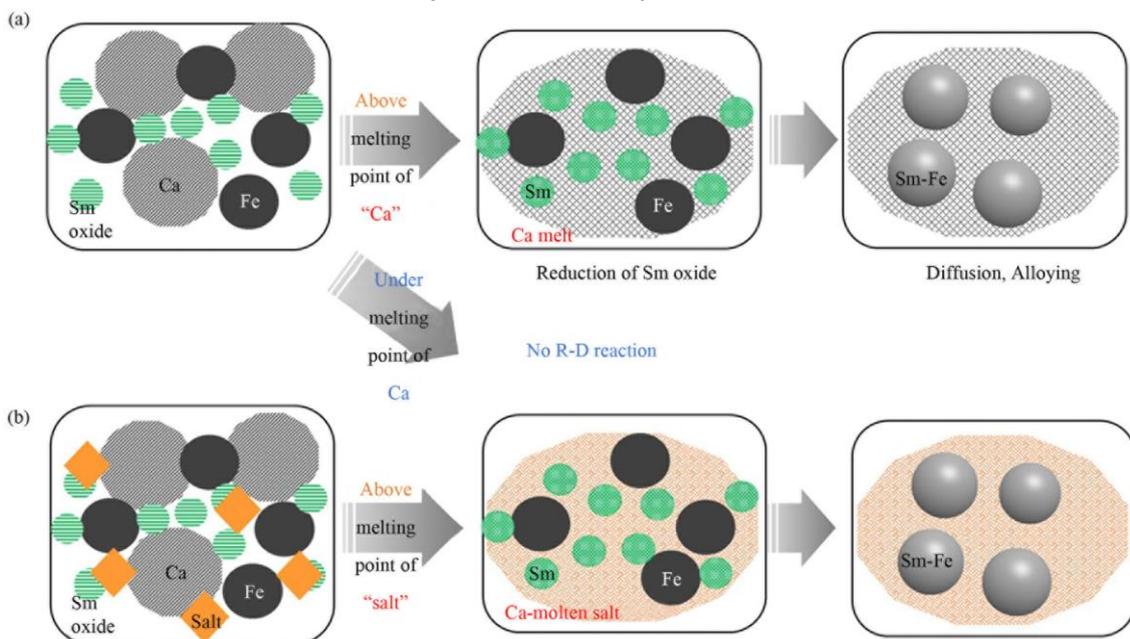


Fig. 3 Schematic images of conventional R-D process (a) and new R-D process (b) using molten salt as a solvent for calcium[47]

According to these results, two characteristics of reduction diffusion method can be summarized: 1) taking rare earth oxide as raw material, 2) being effective in reducing the cost and facilitate storage. The raw materials are mostly powder, so the treatment is relatively simple [25]. Using this method, the reduction of rare earth oxides and the diffusion reaction

between elements can be synthesized together to directly form alloys. The equipment for this method is simple and the operation is convenient. The material composition obtained in this way depends on the matching of raw materials, ambient temperature and time regulation. However, for the alloy materials prepared by reduction diffusion method, Cao or CaCl_2 should be removed by water washing, which easily leads to the oxidation or corrosion of the prepared alloy products. Otherwise, Cao impurities that have not been removed would affect the purity of samarium iron, thus affecting the performance of subsequent preparation of samarium iron nitrogen magnetic materials. Although in the latest research, the preparation process has been optimized (as shown in Figure 3), and the molten salt system has been selected to reduce the preparation temperature, the impurities contained are difficult to be completely removed [47].

2.2. Mechanical alloying (MA)

Mechanical alloying (MA), or high energy milling, is a new technique for preparing alloy powder developed by Benjamin of Inco in 1970. This technique is to mix the element powders to be alloyed in the high-energy ball mill. After the impact of the metal ball for a long time, the rotary mechanical energy is transmitted to the metal powder, which is compounded by the plastic deformation of the powder in the process of ball milling, resulting in diffusion and solid-state reaction, so as to form the alloy powder.

MA technique is widely used to synthesize a series of equilibrium and nonequilibrium alloy phases, including supersaturated solid solution, metastable crystal, amorphous phase, nanostructured phase and quasicrystal, and is also used in the current aerospace field. Schultz of German Siemens first prepared NdFeB permanent magnet by the MA method, and then prepared SmCo_5 , $\text{Sm}_2\text{Co}_{17}$, and other rare earth permanent magnet alloys with metal as raw materials. The rare earth permanent magnet materials SmCo_5 , $\text{Sm}_2\text{Fe}_{17}$ and other alloys were prepared from rare earth oxides and chlorides. This research began in 1988 in China and made good progress [7]. When this method is applied to $\text{Sm}_2\text{Fe}_{17}$ alloy, two-step heat treatment process is generally added to make the microcrystalline permanent magnet powder more efficient. The main operation process is to ball mill the pure metal Sm and Fe to form nano alloy material, and crystallize the alloy into $\text{Sm}_2\text{Fe}_{17}$ phase after vacuum annealing.

The process conditions of mechanical alloying method are relatively simple, the product composition is continuously adjustable, and a variety of rare earth permanent magnet materials have been successfully synthesized. However, the crystallization of alloyed powder needs to be carried out at high temperature, which is easy to cause the oxidation of Sm, and precipitation α -Fe has a negative effect on the magnetic properties of the product. At present, the most advanced German Siemens company is used in MA method. Rare earth oxides, transition metals and calcium oxide are often mixed together to manufacture rare earth permanent magnets, which speeds up the reaction speed, but also causes the problem that the finished products are not easy to purify.

2.3. Rapidly quenched (RQ)

The melt rapid quenching method usually uses high-temperature melting to select a specific proportion of pure metal iron and samarium to melt them into Sm-Fe melt, and uses high pressure to spray the melt through the small hole at the bottom of the reactor to the outer edge of the high-speed rotating water-cooled copper roll for rapid cooling to obtain $\text{Sm}_2\text{Fe}_{17}$ alloy [8,9] in amorphous or microcrystalline thin strip. The process is relatively simple.

At present, the application of this method in NdFeB has been very mature, and the commercialization process has been carried out, while the application of samarium iron permanent magnet material is still in the process of development. The preparation of Sm-Fe-N by this method was first reported by Katter. TbCu_7 type structural samples and $\text{Th}_2\text{Zn}_{17}$ type structural samples can be prepared by changing the linear speed of copper roller. The magnetic

properties of nitrided magnetic particles are TbCu₇ type: maximum magnetic energy product (BH)_{max}= 69.6 kJ/m³, remanence Br= 0.86 T, coercivity HC= 0.49MA/m; Th₂Zn₁₇ type: maximum magnetic energy product (BH)_{max}= 65.6 kJ/m³, remanence Br= 0.73 T, coercivity HC= 1.67 MA/m. The grain size of Sm-Fe-N magnetic powder prepared by He, and others by rapid quenching method is close to that of single domain, and its magnetic properties are: maximum magnetic energy product (BH)_{max}= 45.6 kJ/m³, remanence Br=0.7T, coercivity HC=0.76 MA/m. Saito et al. Studied the magnetic properties of Sm-Fe rapid quenching belt in 2009 and found that Sm_{22.5}Fe_{77.5} was annealed at 973 K to form Sm₂Fe₁₇ phase, and the coercivity exceeded 3.18MA/m [10,11].

However, this method is difficult to produce Sm₂Fe₁₇ with high purity. It is necessary to strictly control the ingredients, rapid quenching speed and crystallization temperature. Moreover, the boiling point of Sm is low. Within the temperature range of alloy vacuum melting, it will cause a large amount of volatilization of Sm and pollute the environment. And volatilization is also difficult to maintain the original ratio, which affects the purity of the product. In short, there are still a series of problems to be solved in the preparation of Sm₂Fe₁₇ by rapid quenching method.

2.4. Hydrogenation disproportionation (HDDR)

The hydrogen disproportionation method uses hydrogen atoms to break the alloy to achieve grain refinement, including four stages: hydrogenation, disproportionation, dehydrogenation and recombination. In the hydrogenation stage, hydrogen enters the crack pores of the alloy to form a brittle hydrogenation alloy. In the disproportionation stage, nanocrystalline hydrogenation phase and metal phase are generated. The dehydrogenation and recombination stages are carried out almost simultaneously. After dehydrogenation of the hydrogenated phase, a highly active metal phase is formed, which diffuses in a short range with another metal phase before, and a phase transition occurs to form a nanocrystalline parent phase [12,13].

This method was first applied to the preparation of Sm₂Fe₁₇N_x magnetic powder by Zhou Shouzeng and his colleagues. After that, a lot of researches have been carried out. For the hydrogenation disproportionation method, the Sm-Fe master alloy is obtained by arc melting or induction melting. The Sm block and Fe block are melted by arc or induction heating, and then cooled to room temperature. Zhao Xinguo and others prepared Sm-Fe-N magnetic powder by HD and HDDR plus nitriding process respectively. The magnetic properties of anisotropic magnetic powder obtained by HD method are: maximum magnetic energy product (BH)_{max}=199 kJ/m³, and the magnetic properties of isotropic magnetic powder obtained by HDDR method are: maximum magnetic energy product (BH)_{max}= 103.5 kJ/m³. Ye and others have done a lot of detailed work on the structural evolution and nitriding process in the process of preparing Sm-Fe-N by HDDR method, The magnetic properties of the prepared bonded magnet are: maximum magnetic energy product (BH)_{max}= 73.7 kJ/m³ [14].

The preparation of Sm₂Fe₁₇ nano alloy fine powder by hydrogenation disproportionation method is roughly divided into four steps: first, from Sm₂Fe₁₇ alloy coarse powder (about 50μm) Sm₂Fe₁₇H_y (Y ≈ 0.1) is obtained by hydrogenation and crushing at about 250 °C for 2~14h; Then, Sm₂Fe₁₇H_y is further absorbed hydrogen at 600 °C, and Sm₂H_z (z > 2) is generated by disproportionation reaction; The third step is to desorb Sm₂H_z at 750 °C for 2h to obtain Sm; The fourth step is to combine Sm and Fe to form nano-sized Sm₂Fe₁₇.

This method involves many reactions, and the process and mechanism are also complex, which has not been studied clearly. At present, the theory of HDDR method is not mature enough to be applied to industrial production.

2.5. Powder metallurgy (PM)

Powder metallurgy is often used to manufacture adhesive magnets. The main process of powder metallurgy method is: the initial raw materials are made into powder by ball milling,

air mill and other methods, and then the evenly mixed powder is pressed into shape, and then sintered at high temperature. During the sintering process, the powder particles form an alloy with uniform composition through a series of physical and chemical processes such as diffusion, recrystallization, fusion welding, combination and annealing. The annealing time range is relatively large, which can be as short as a few hours and as long as a few weeks. Mechanical grinding is usually selected for grinding, and manual grinding in some laboratories will also be applied. This method has been widely used in the manufacture of raw materials. Nitriding is usually carried out by using pure ammonia or nitrogen or ammonia added with hydrogen. Generally, the temperature needs to be maintained at 350 ~ 500 °C, and the time spent is 3h to 30h [15-17].

Powder metallurgy has the advantages of low oxygen content, narrow powder distribution, small particle size, good square demagnetization curve, and high production efficiency. However, this method requires high principle, high cost, long production cycle and high energy consumption.

2.6. Molten salt electrolysis (MSE)

Molten salt electrolysis is a traditional method to produce rare earth and its alloys. Molten salt electrolysis is widely used in large-scale industrial production of rare earth metals and alloys, such as lanthanum, praseodymium, neodymium, neodymium iron alloys. The commonly used molten salt systems for the preparation of rare earth alloys by molten salt electrolysis include chloride system, fluorinated object system, etc. [18-21]. At present, there are three main methods for preparing rare earth and rare earth alloys by molten salt electrolysis:

- (1) Liquid cathode electrolysis generally uses low melting point alloy as the electrode. The deposition potential of rare earth moves forward, precipitates directly on the liquid electrode and forms an alloy with rare earth;
- (2) Solid cathode electrolysis, also known as consumable cathode method, deposits rare earth on the surface of the electrode and forms liquid or solid intermetallic compounds;
- (3) Codeposition electrolysis, also known as eutectoid method, alloy elements and rare earth metals form alloys and precipitate together.

Molten salt electrolysis is easier to produce single-phase metals or intermetallic compounds. Researchers began research as early as the 1970s. Japanese researchers dissolved Sm₂O₃ in a fluorinated body system containing Sm and used Fe as the cathode to obtain samarium rich amorphous Sm-Fe alloy with iron content of 12% to 20%. In the 1980s, Du Senlin studied the characteristics of Sm³⁺ difficult to deposit on inert Mo cathode through KCl-NaCl₂-CeCl₃ molten salt system. Tong Yexiang et al. Found the deposition peak of Sm-Fe alloy by linear sweep voltammetry at 750 °C. After that, the cathodic electrochemical behavior of iron ions and samarium ions in urea NaBr was studied, and Sm-Fe was successfully prepared by induced Co deposition [22]. Zhou Lin et al. Successfully prepared SmFe₂ alloy in LiF-CaF₂ molten salt at 900 °C [23]. Yan Qicao et al. Prepared Sm₂Fe₁₇ by using CaCl₂-CaF₂-SmCl₃ and LiF-CaF₂-SmF₃ system at about 1100 °C [24].

At present, the most widely used method is the solid cathode method, which is mostly used to prepare the intermediate materials of rare earth permanent magnet materials. For example, the raw materials for producing Sm-Fe-N magnetic materials can be Sm metal or Sm-Fe alloy. The main production method of Sm-Fe alloy is to use Fe as consumable cathode and prepare Sm-Fe alloy by molten salt electrolysis in chloride or fluorinated object system. In the electrolysis process, we will find that the rare earth element Sm is a variable valence element in the chlorinated object system, so the self-disproportionation reaction may occur during electrolysis in the chlorinated object system:



In the process of electrolysis, Sm (II) may be re oxidized to Sm (III):



Therefore, the concentration of SmCl_3 in chloride molten salt system determines the solubility of metal Sm in electrolyte. If the selected concentration of SmCl_3 is too low, other metal salts will be discharged in the process of electrolysis, which will affect the current efficiency. The selection of pure fluorinated object system can improve the current efficiency and increase the product output, but the electrolysis temperature is required to be too high, the corrosion resistance of the equipment is also required to be high, the cost is high, and will pollute the environment. Therefore, it is necessary to find a more suitable molten salt system to prepare samarium ferroalloy.

This method uses the preparation of rare earth alloy magnetic materials, which can well reduce the impurity content, improve the purity of the product, and use cheap oxides, chlorides or fluorides to reduce the cost. However, the electrochemical behavior of this method at high temperature is relatively complex, and there is a problem of cyclic transformation of rare earth elements with different valence states, which makes the current efficiency of production have great room for improvement. At present, it can only be completed in the laboratory.

2.7. High temperature diffusion method

High temperature diffusion method puts solid or liquid-solid substances together. Because atoms and molecules move continuously after thermal activation, they are prepared by diffusion and mutual immersion for a long time. The preparation of Sm-Fe binary alloy by this method needs to obtain large activation energy, so that Sm and Fe atoms diffuse each other to form solid solution. In order to speed up the diffusion rate, increasing the diffusion temperature to increase the diffusion coefficient, melting Sm, promoting flow and increasing vapor pressure are beneficial methods.

Because the diffusion method only needs to form solid-solid diffusion couple or solid-liquid diffusion couple at high temperature, the required materials are simple, the experimental device is simple and easy to operate; It does not involve redox reaction, and the theoretical reaction is simple, which is convenient to improve production efficiency; In the experiment, the diffusion coefficient can be calculated, and the product can be obtained quantitatively, which is easy to control. At present, few researchers use this method to prepare $\text{Sm}_2\text{Fe}_{17}$ alloy, and its formation mechanism is shown in Figure 4. Because the law of diffusion speed control will slow down the diffusion speed with time, it is difficult to mass produce the alloy layer [26-29]. At present, it can only be tried in the laboratory.

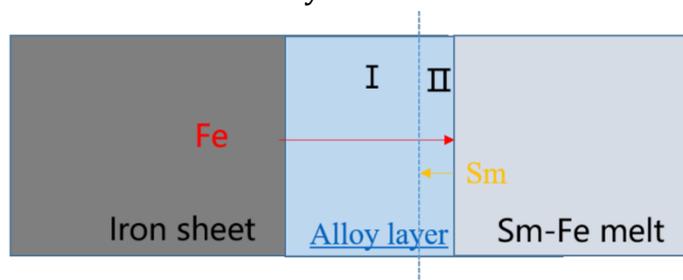


Fig. 4 Diffusion diagram of the Fe and Sm atoms

3. Research status of nitriding treatment

At present, the preparation methods of $\text{Sm}_2\text{Fe}_{17}$ alloy, whether industrial selection or laboratory application, have their own advantages and unsolved problems. However, the preparation of Sm-Fe-N magnetic materials also requires nitriding of $\text{Sm}_2\text{Fe}_{17}$ alloy and the detection of properties after nitriding.

3.1. Nitrogen nitriding

The nitriding process of Sm-Fe-N is usually realized by heating the binary alloy $\text{Sm}_2\text{Fe}_{17}$ magnetic powder to 773K constant temperature in high-purity nitrogen under standard atmospheric pressure for a period of time. X in the prepared $\text{Sm}_2\text{Fe}_{17}\text{N}_x$ is usually 2.3 ~ 2.7. The adsorption of nitrogen source gas molecules on the surface of $\text{Sm}_2\text{Fe}_{17}$ compound particles during nitriding; Nitrogen molecules decompose into nitrogen atoms, and then diffuse into the binary alloy to expand the lattice to complete nitridation.

For the nitriding process, generally only when the size of crystal particles and single domain particles are similar can the coercivity be guaranteed to be high, and the appropriate particle size has a great impact on the nitriding effect. Increasing the temperature can accelerate the diffusion of N atoms and improve the nitriding effect. However, since $\text{Sm}_2\text{Fe}_{17}\text{N}_x$ is easy to decompose when it is higher than 873K, the nitriding temperature generally does not exceed 823K. Increasing the pressure of nitrogen can promote the decomposition and diffusion of nitrogen atoms and improve the efficiency of nitriding. However, without the current research, nitrogen nitriding is difficult to adequately nitride $\text{Sm}_2\text{Fe}_{17}$ magnetic particle particles, the nitrogen content is not easy to control, and the value of X is lower than the theoretical value of optimal magnetic properties 3. In addition, during the nitriding process, when there is partial oxidation on the surface of $\text{Sm}_2\text{Fe}_{17}$ magnetic powder, the decomposition process slows down, and there will be an incubation period in the early stage of nitriding, reducing the production efficiency [30-31].

3.2. Ammonia nitriding

Another nitrogen source in the nitriding process often selects NH_3 . The bond energy of N-H bond in NH_3 is less than that of $\text{N}\equiv\text{N}$ bond in N_2 gas, which is easier to disconnect than $\text{N}\equiv\text{N}$, which is more conducive to nitriding. The research results show that adding H_2 and H atoms to the nitrogen source gas can improve the diffusion rate of N atoms in $\text{Sm}_2\text{Fe}_{17}\text{N}_x$ compounds. In the 1990s, Iriyama, Kobayashi et al., tried to use the mixed gas of NH_3 and H_2 as nitrogen source to improve the nitriding efficiency, and controllably prepared $\text{Sm}_2\text{Fe}_{17}\text{N}_x$ magnetic powder with continuously adjustable N content from 0 to 6. In 1999, Chen Aiping, Jin Hongming and others used $\text{NH}_3 + \text{H}_2$ for carburizing treatment. They found that pretreatment of $\text{Sm}_2\text{Fe}_{17}$ alloy with H_2 and controlling nitriding temperature and time can effectively control the soft magnetic phase produced in the nitriding process and inhibit the decomposition of $\text{Sm}_2\text{Fe}_{17}\text{N}_x$. In addition, H_2 has reducibility to prevent $\text{Sm}_2\text{Fe}_{17}$ from being oxidized during nitriding and the generation of incubation period [32-35].

3.3. Nitriding conditions

In order to obtain better carburizing effect in nitriding process, the pressure and temperature should be controlled in an appropriate range, and the parent alloy needs to be crushed into fine powder ($<40\mu\text{m}$), between the range of 1-10 μm , the coercivity increases with the decrease of particle size. The single domain particle size of $\text{Sm}_2\text{Fe}_{17}$ is about 300 nm when the particle size is about 1-3 μm , the magnetization is consistent with that of single domain. Thus, in this range, it is beneficial to the size of $\text{Sm}_2\text{Fe}_{17}\text{N}_x$ particles. In order to obtain fine and uniform powder, the nitriding layer needs to be ground, but the grinding process will increase the internal stress of the nitriding layer and destroy the crystal structure of the nitriding layer [36-37].

In order to obtain good carburizing effect, whether to choose flowing gas has also attracted people's research. Koeninger et al. showed that under high temperature conditions, the activity of N atoms in the closed system is much lower than that of nitrogen atoms decomposed from NH_3 flowing fast enough. T. Y. ILN et al. Believe that under closed conditions, heat accumulation

inside $\text{Sm}_2\text{Fe}_{17}$ particles increases the temperature, resulting in the decomposition of $\text{Sm}_2\text{Fe}_{17}\text{N}_x$ [38-39].

3.4. Crystal structure of $\text{Sm}_2\text{Fe}_{17}\text{N}_x$

At normal temperature, the crystal structures of $\text{Sm}_2\text{Fe}_{17}$ and $\text{Th}_2\text{Zn}_{17}$ are the same, belonging to the trilateral system [40]. It is rhombohedral. Each cell has three $\text{Sm}_2\text{Fe}_{17}$ molecules, including 57 atoms in total. Six samarium atoms exist in c crystal position, nine of 51 iron atoms exist in d crystal position, eighteen in f crystal position and six in c crystal position. However, because samarium ferroalloy is a precursor material, it is necessary to introduce interstitial atom n to obtain $\text{Sm}_2\text{Fe}_{17}\text{N}_x$. Usually, there are two gaps in the composition system of this compound: one is the octahedral gap, which exists on the surface of rare earth atoms, and the other is between two rare earth atoms along the c axis. The configuration of this compound itself is the same as that of samarium iron, but the atomic distribution is different, resulting in the increase of unit cell volume by 6% [41,42].

Generally speaking, when the octahedral 9e crystal position of $\text{Sm}_2\text{Fe}_{17}$ is completely occupied by nitrogen, its molecular formula is $\text{Sm}_2\text{Fe}_{17}\text{N}_3$, but when the nitrogen content exceeds 3 atoms, it has an adverse effect on magnetism. The value of nitrogen content can be up to 6. At this time, three nitrogen atoms occupy 9e crystal position, which enhances the magnetic properties, and the other three nitrogen atoms occupy half of 18e crystal position, which weakens the magnetic properties.

3.5. Sm-Fe based compounds

At present, the alloying elements added to Sm-Fe alloy mainly include: Ti (z = 22), V (z = 23), Cr (z = 24), Zr (z = 40), Nb (z = 41), Mo (z = 42), HF (z = 72), Ta (z = 73), w (z = 74). And Group B elements include: Mn (z = 25), Co (z = 27), Ni (z = 28), Cu (z = 29). Over the past decade, people have accepted the exact explanation of the magnetic properties and structure of Sm-Fe alloys, but there are many differences on the contribution of substituted elements in different Sm-Fe based nitrides, which need to be further studied, especially the phase-to-phase relationship of Sm-Fe based nitrides, the structure of nitrides and the magnetism of different methods. Therefore, the emergence of different branch magnetic materials also improves the performance requirements of $\text{Sm}_2\text{Fe}_{17}\text{N}_x$ [43-46].

3.6. Magnetic property test method

At present, the instruments for testing magnetic properties mainly include superconducting quantum interferometer (squid, with a maximum applied magnetic field of more than 5T), vertical sliding sample magnetometer (with a maximum applied magnetic field of more than 20T), magnetic balance, pulse magnetometer (with an applied magnetic field of more than 7-12T), vibrating sample magnetometer (VSM, with a maximum applied magnetic field of 2-3T), hysteresis meter (2T), flux diagram, permanent magnet measuring instrument, etc. Because the magnetic properties of powder cannot be detected directly, it can only be detected after mixing with wax, pressing and orientation. Squid and VSM belong to open circuit test, which can directly obtain the torque or magnetization of powder, but some researchers obtain the magnetization value by calculating the theoretical density. Hard magnetic materials cannot be saturated in an applied magnetic field of 2T, so the residual magnetization and coercivity are low. Some permanent magnet measuring instruments belong to closed-circuit test, which are only suitable for directional block samples to obtain magnetization. At present, due to the great difference of experimental conditions in different laboratories and the poor comparison of the same performance, there is no unified magnetic property testing instrument.

4. Summary

$\text{Sm}_2\text{Fe}_{17}\text{N}_x$ is favored by people for its excellent magnetic properties, high Curie temperature, good corrosion resistance and oxidation resistance. It has a high possibility to become the fourth generation permanent magnet material. However, at present, there is no mature industrial method to prepare $\text{Sm}_2\text{Fe}_{17}\text{N}_x$ magnetic materials with excellent properties. There are still urgent problems to be solved in the precursor material $\text{Sm}_2\text{Fe}_{17}$, the control of nitriding process and the detection of properties.

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