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(54) **MAGNESIUM MOTHER ALLOY AND METAL ALLOY**

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(57) **ABSTRACT**

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Disclosed are a magnesium mother alloy, a manufacturing method thereof, a metal alloy using the same, and a method of manufacturing the metal alloy. In particular, there are provided a magnesium mother alloy with improved oxidation and ignition properties, and a manufacturing method thereof, and also provided a metal alloy with low cost that is suitable for design purposes using the magnesium mother alloy, and a method of manufacturing the metal alloy. The magnesium mother alloy includes a plurality of magnesium grains, and scandium dissolved in the magnesium grains, or a scandium compound crystallized at grain boundaries which are not inside but outside the magnesium grains. Also, the metal alloy suitable for design purposes is manufactured at low cost by adding the magnesium mother alloy containing scandium into a magnesium alloy or an aluminum alloy.

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Sep. 21, 2009 (KR) ..... 10-2009-0088959



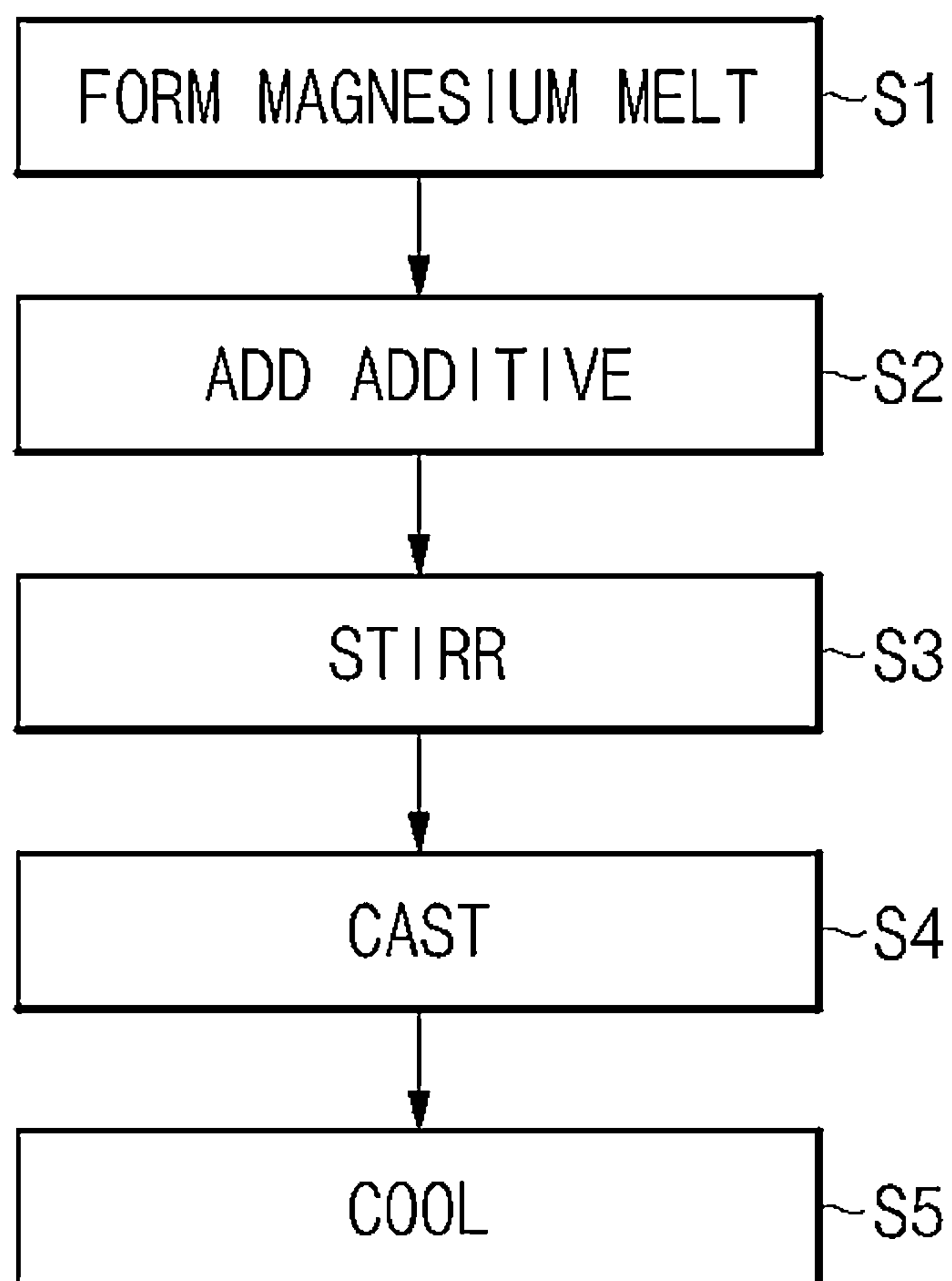


FIG. 1



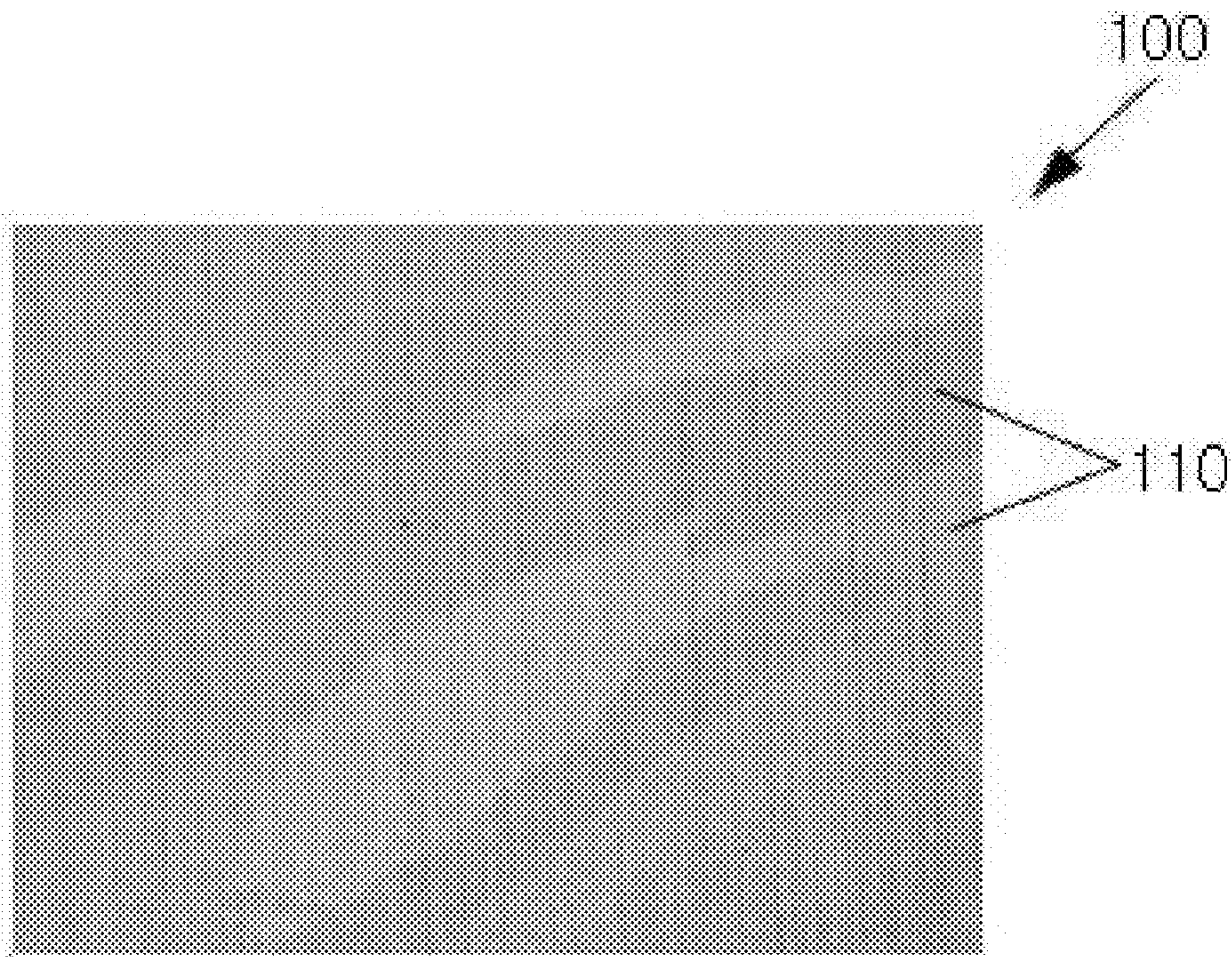


FIG. 2

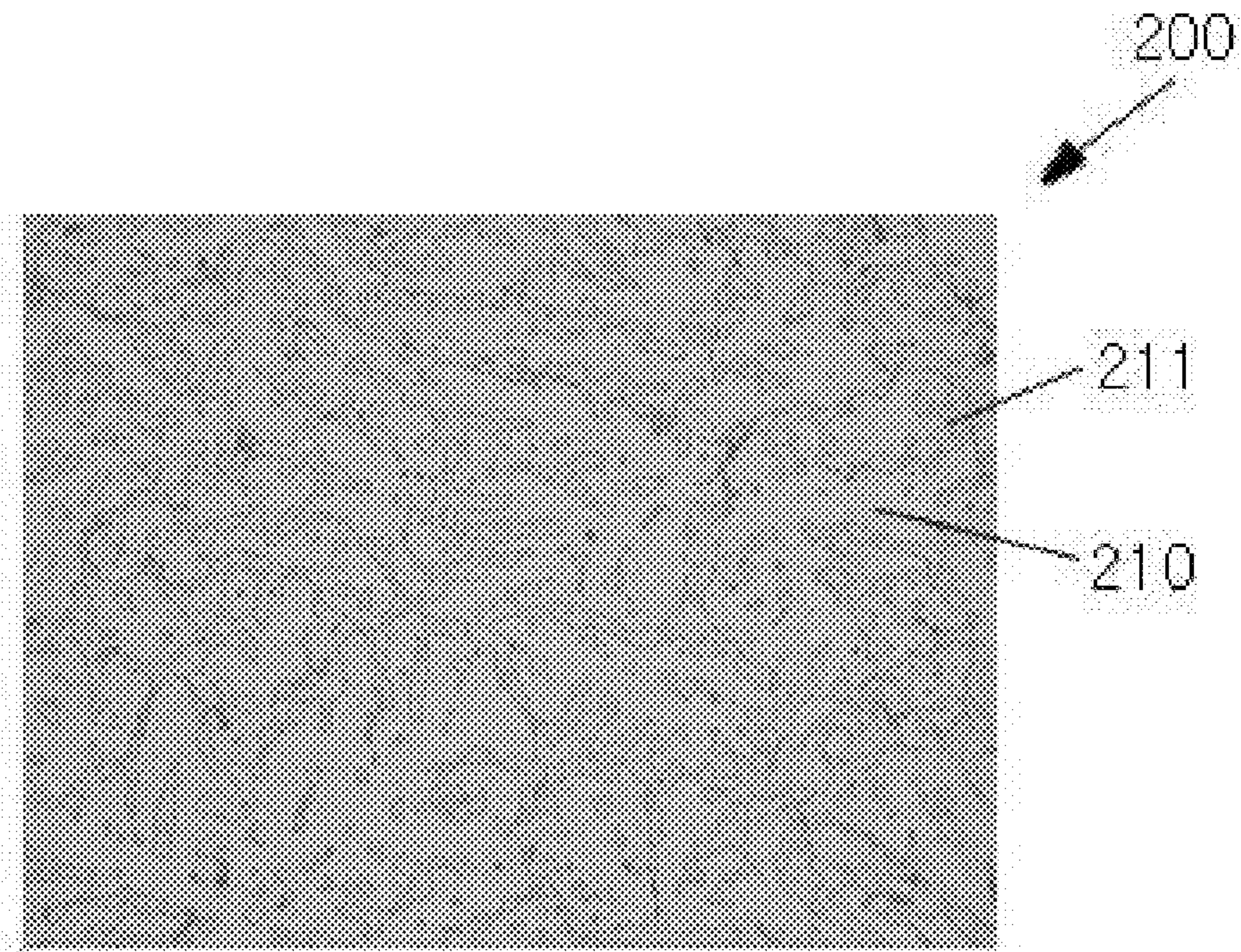


FIG. 3



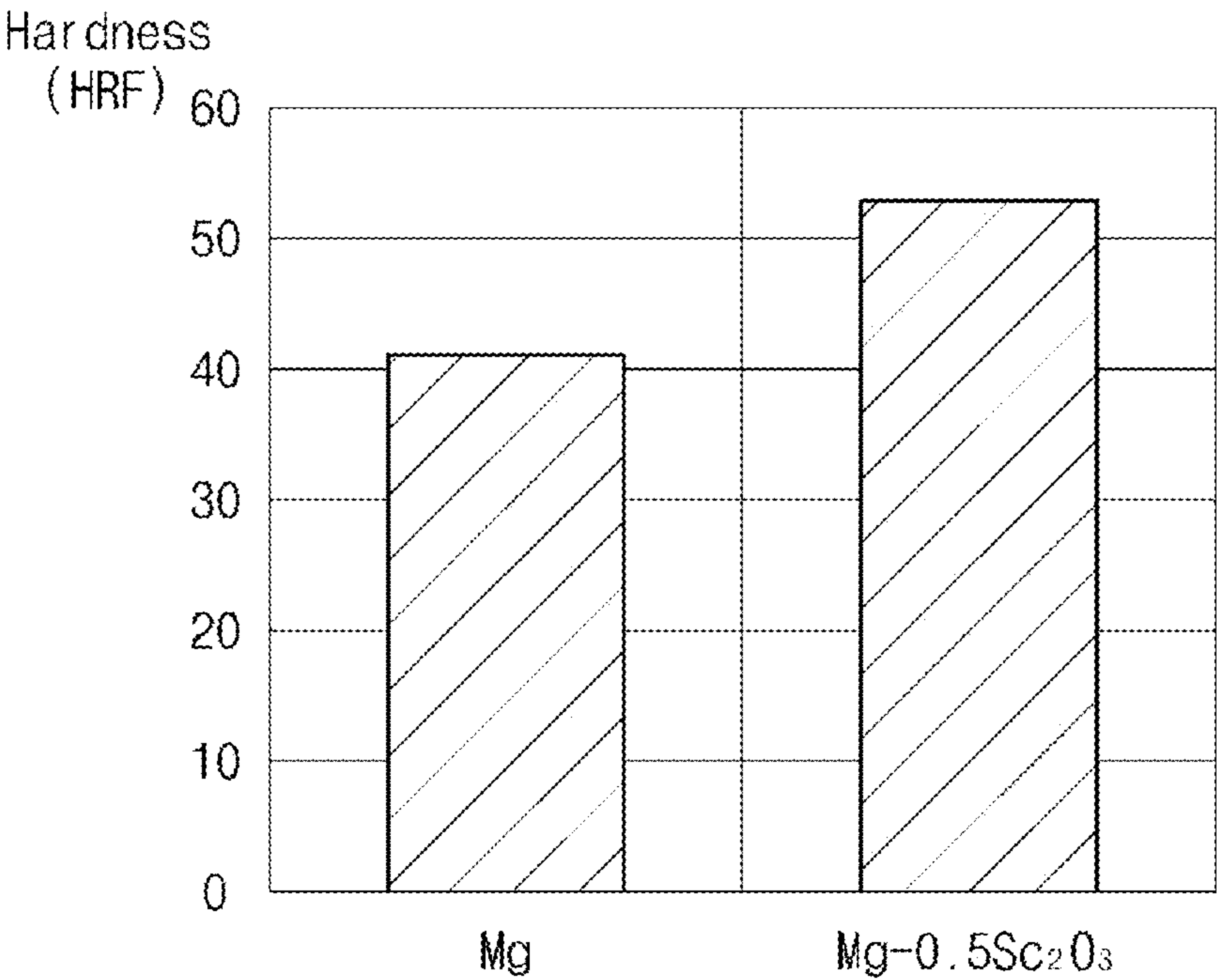


FIG. 4

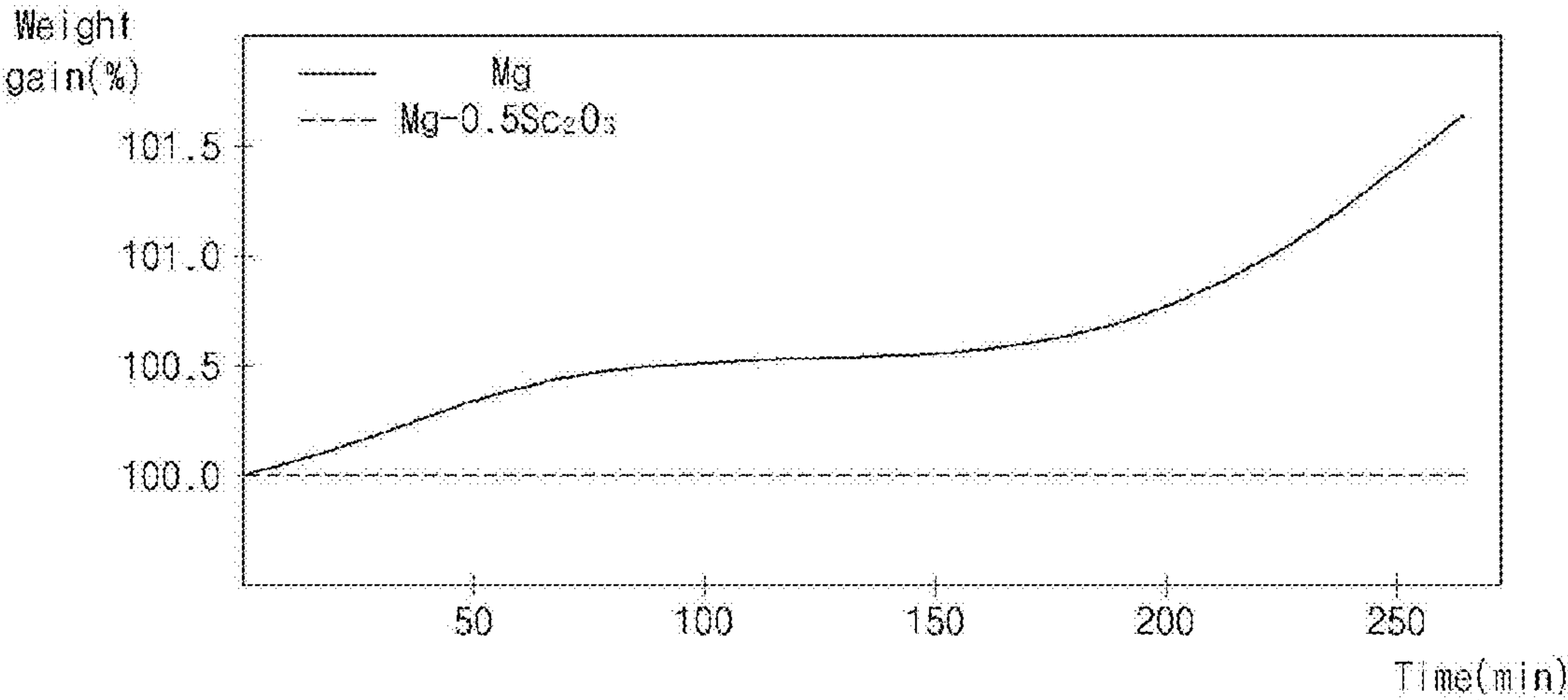


FIG. 5



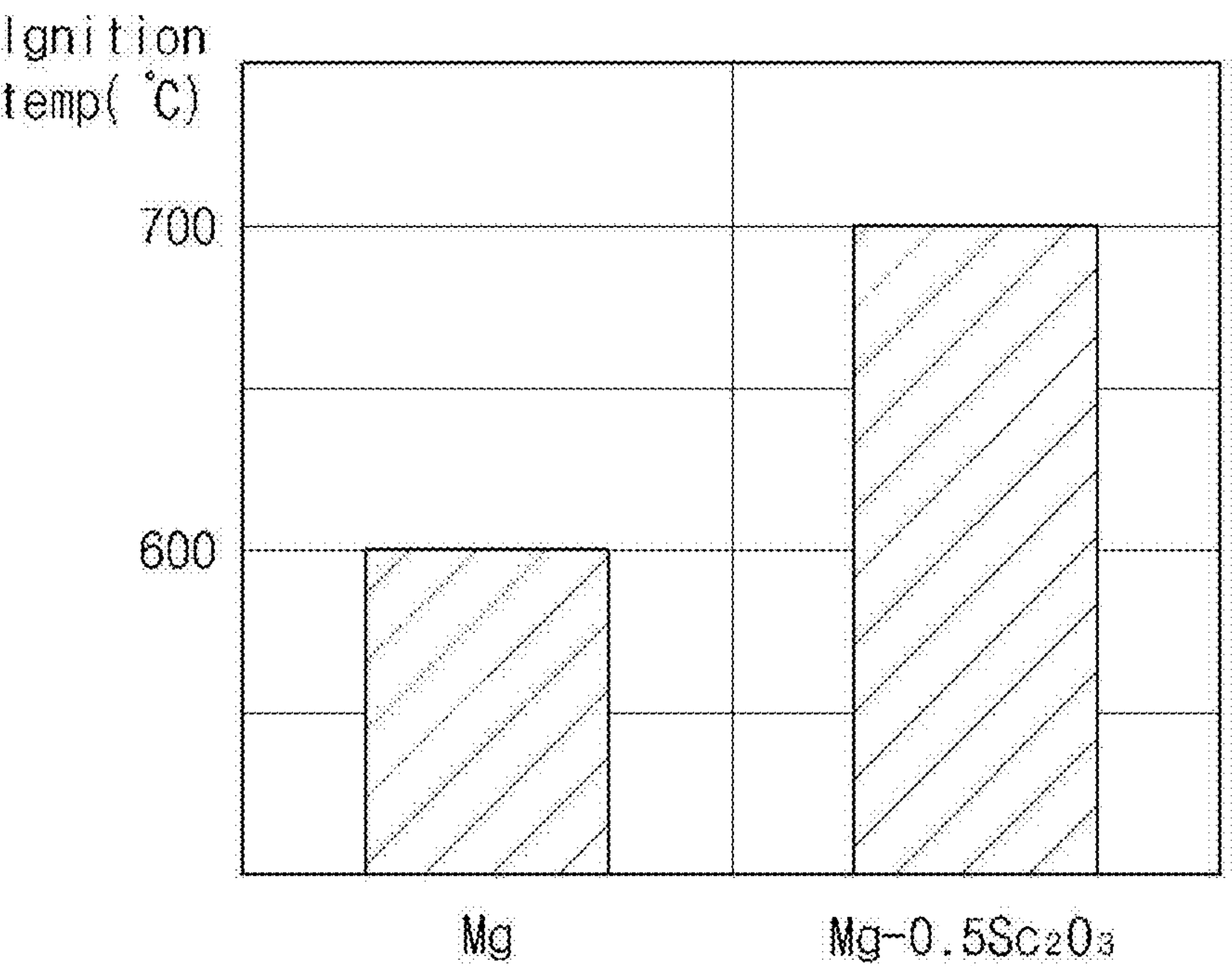


FIG. 6

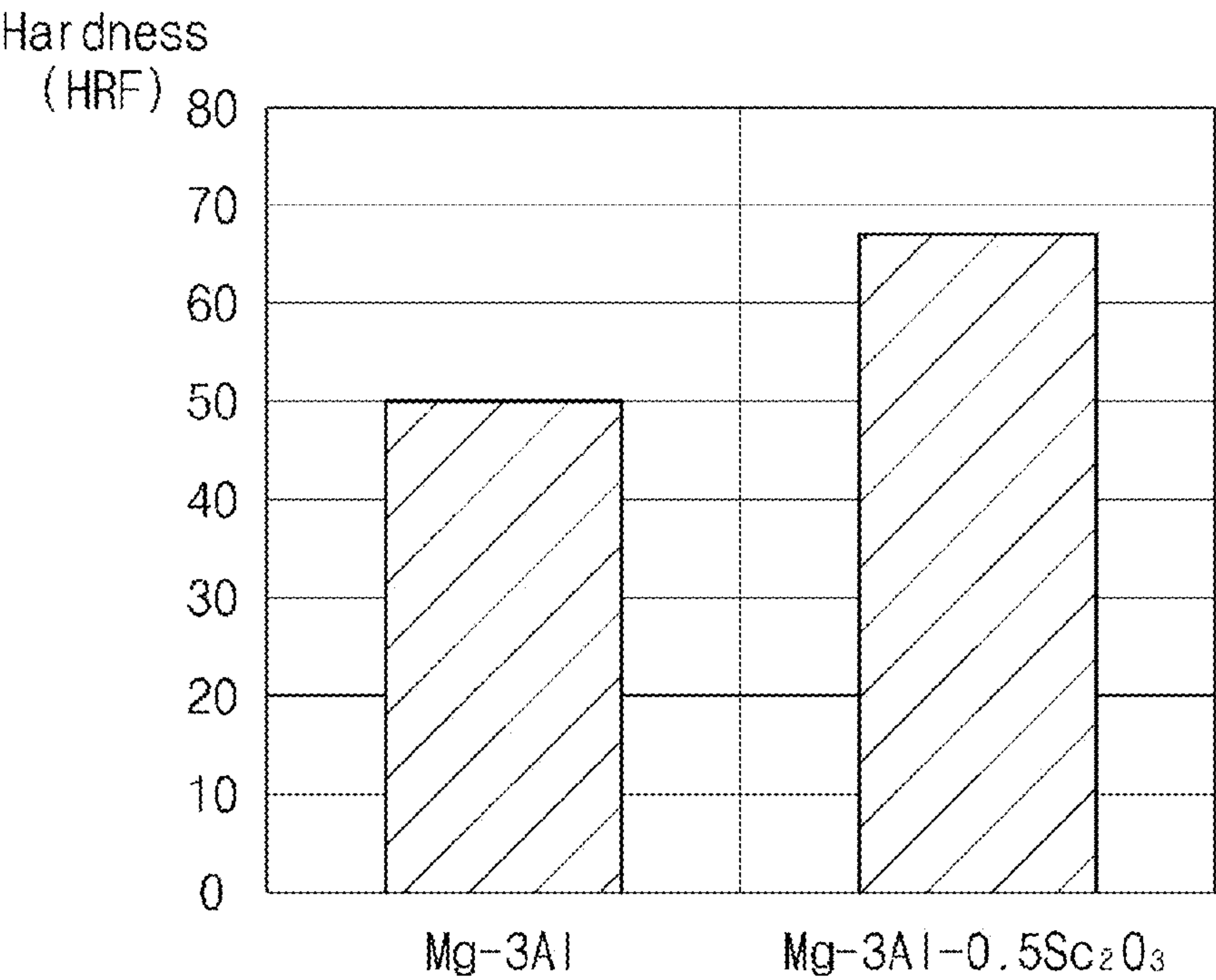


FIG. 7



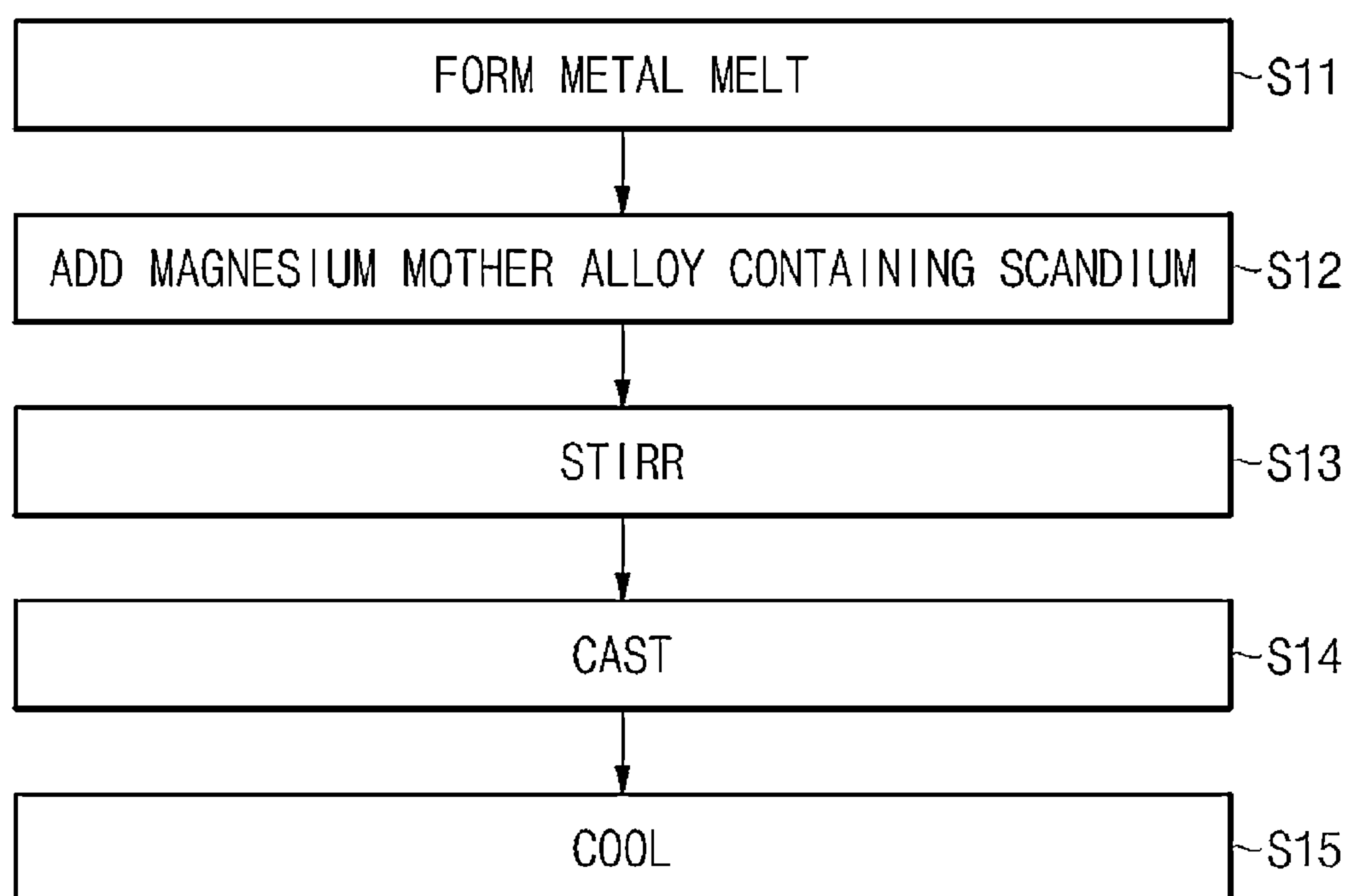


FIG. 8



## MAGNESIUM MOTHER ALLOY AND METAL ALLOY

### CROSS-REFERENCE TO RELATED APPLICATION

**[0001]** This application claims priority to and the benefit of Korean Patent Application No. 10-2009-0088959, filed on Sep. 21, 2009, which is herein incorporated by reference in its entirety.

### BACKGROUND OF THE INVENTION

**[0002]** 1. Field of the Invention

**[0003]** The present invention relates generally to a magnesium mother alloy, a manufacturing method thereof, a metal alloy using the same, and a method of manufacturing the metal alloy. More particularly, the present invention relates to a magnesium mother alloy with improved oxidation and ignition properties, and a manufacturing method thereof, and also relates to a metal alloy with low cost that is suitable for design purposes using the magnesium mother alloy, and a method of manufacturing the metal alloy.

**[0004]** 2. Description of the Related Art

**[0005]** Currently, using scandium (Sc) as an additive in super-hard aluminum alloys (for example, 2000-series, 5000-series, 6000-series, 7000-series aluminum alloys, etc.) have been researched and developed so as to improve alloy properties such as hardness, corrosion resistance and weldability. Aluminum alloys with scandium (Sc) added may be used for military purposes (for example, reinforcement for combat vehicles, rifle bodies, etc.) requiring good weldability and fatigue resistance, or may be used for private purposes (for example, a high-speed train, parts for an electric train, etc.).

**[0006]** However, scandium (Sc) is a rare earth material, and the amount of scandium (Sc) existing on the earth is too small. Furthermore, there is a difficulty in separating scandium (Sc) from a mineral, and thus scandium (Sc) is very expensive. Therefore, a method of adding scandium oxide ( $\text{Sc}_2\text{O}_3$ ) into aluminum alloys is now being considered because scandium oxide ( $\text{Sc}_2\text{O}_3$ ) is relatively cheaper than scandium (Sc) itself.

**[0007]** Unfortunately, when  $\text{Sc}_2\text{O}_3$  is directly added into aluminum alloys, various alloy properties such as hardness, corrosion resistance and weldability are deteriorated due to oxides of scandium (Sc).

### SUMMARY OF THE INVENTION

**[0008]** Embodiments are directed to a magnesium mother alloy, a manufacturing method thereof, a metal alloy using the same, and a method of manufacturing the metal alloy, which substantially overcome one or more of the problems due to the limitations and disadvantages of the related art.

**[0009]** It is therefore a feature of an embodiment to provide a magnesium mother alloy with improved oxidation and ignition properties, and a manufacturing method thereof.

**[0010]** It is therefore a feature of another embodiment to provide a metal alloy with low cost, which is adapted for design purposes and does not deteriorate alloy properties such as hardness, corrosion resistance and weldability, and a manufacturing method thereof.

**[0011]** At least one of the above and other features and advantages may be realized by providing a magnesium mother alloy including: a plurality of magnesium grains; and scandium (Sc) dissolved in the magnesium grains.

**[0012]** The scandium may exist in an amount of about 0.0001 wt % to about 30 wt % based on 100 wt % of the magnesium.

**[0013]** At least one of the above and other features and advantages may be realized by providing a magnesium mother alloy including: a plurality of magnesium-aluminum grains having grain boundaries; and a scandium compound crystallized at the grain boundaries which are not inside but outside of the magnesium-aluminum grains.

**[0014]** The scandium compound may include  $\text{Al}_2\text{Sc}$ ,  $\text{AlSc}$  and  $\text{Al}_3\text{Sc}$ .

**[0015]** The scandium of the scandium compound may exist in an amount of about 0.0001 wt % to about 30 wt % based on 100 wt % of the magnesium-aluminum.

**[0016]** At least one of the above and other features and advantages may be realized by providing a method of manufacturing a magnesium mother alloy including: forming a magnesium melt by putting magnesium into a crucible and melting the magnesium at a temperature ranging from about 600° C. to about 800° C.; adding scandium oxide ( $\text{Sc}_2\text{O}_3$ ) into the magnesium melt; stirring the magnesium melt for about 1 minute to about 400 minutes; pouring the magnesium melt into a mold having a temperature ranging from a room temperature to about 400° C. and casting the magnesium melt; and cooling the cast magnesium melt casting.

**[0017]** In the forming of the magnesium melt, the magnesium may be pure magnesium or magnesium-aluminum.

**[0018]** An added amount of the scandium oxide may be about 0.0001 wt % to about 30 wt % based on 100 wt % of pure magnesium or magnesium-aluminum.

**[0019]** At least one of the above and other features and advantages may be realized by providing a metal alloy including: a plurality of metal grains having grain boundaries; and scandium dissolved in the metal grains, or a scandium compound crystallized at the grain boundaries which are not inside but outside the metal grains.

**[0020]** The metal may include one selected from consisting of AZ91D, AM20, AM30, AM50, AM60, AZ31, AZ61, AZ80, AS41, AS31, AS21X, AE42, AE44, AX51, AX52, AJ50X, AJ52X, AJ62X, MRI153, MRI230, AM-HP2, Mg—Al, Mg—Al—Re, Mg—Al—Sn, Mg—Zn—Sn, Mg—Si, and Mg—Zn—Y.

**[0021]** The metal may include one selected from consisting of 1000-series, 2000-series, 3000-series, 4000-series, 5000-series, 6000-series, 7000-series and 8000-series wrought aluminum, and 100-series, 200-series, 300-series, 400-series, 500-series, and 700-series casting aluminum.

**[0022]** The scandium compound may include  $\text{Al}_2\text{Sc}$ ,  $\text{AlSc}$  and  $\text{Al}_3\text{Sc}$ .

**[0023]** The scandium dissolved in the metal grains or the scandium of the scandium compound may exist in an amount of about 0.0001 wt % to about 30 wt % based on 100 wt % of the metal.

**[0024]** At least one of the above and other features and advantages may be realized by providing a method of manufacturing a metal alloy including: forming a metal melt; adding a magnesium mother alloy containing dissolved scandium or scandium oxide ( $\text{Sc}_2\text{O}_3$ ) into the metal melt; stirring the metal melt for about 1 to about 400 minutes; pouring the metal melt into a mold having a temperature ranging from a room temperature to about 400° C. and casting the metal melt; and cooling the metal casting.



**[0025]** An added amount of the magnesium mother alloy containing scandium may be about 0.0001 wt % to about 30 wt % based on 100 wt % of the metal.

**[0026]** The magnesium mother alloy containing scandium may be manufactured by adding about 0.0001 wt % to about 30 wt % of scandium oxide ( $\text{Sc}_2\text{O}_3$ ) based on 100 wt % of pure magnesium.

**[0027]** The magnesium mother alloy containing scandium may be manufactured by adding about 0.0001 wt % to about 30 wt % of scandium oxide ( $\text{Sc}_2\text{O}_3$ ) based on 100 wt % of magnesium-aluminum.

**[0028]** The magnesium mother alloy containing scandium may include an alloy prepared by adding about 0.0001 wt % to about 30 wt % of scandium oxide ( $\text{Sc}_2\text{O}_3$ ) based on 100 wt % of pure magnesium, and an alloy prepared by adding about 0.0001 wt % to about 30 wt % of scandium oxide ( $\text{Sc}_2\text{O}_3$ ) based on 100 wt % of magnesium-aluminum.

**[0029]** The metal melt may be formed of one selected from consisting of AZ91D, AM20, AM30, AM50, AM60, AZ31, AZ61, AZ80, AS41, AS31, AS21X, AE42, AE44, AX51, AX52, AJ50X, AJ52X, AJ62X, MRI153, MRI230, AM-HP2, Mg—Al, Mg—Al—Re, Mg—Al—Sn, Mg—Zn—Sn, Mg—Si, and Mg—Zn—Y.

**[0030]** The metal melt may be formed of one selected from consisting of 1000-series, 2000-series, 3000-series, 4000-series, 5000-series, 6000-series, 7000-series and 8000-series wrought aluminum, and 100-series, 200-series, 300-series, 400-series, 500-series, and 700-series casting aluminum.

**[0031]** These and other features of the present invention will be more readily apparent from the detailed description set forth below taken in conjunction with the accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0032]** The above and other features and advantages will become more apparent to those of ordinary skill in the art by describing in detail exemplary embodiments with reference to the attached drawings, in which:

**[0033]** FIG. 1 is a flowchart illustrating a method of manufacturing a magnesium mother alloy according to an embodiment;

**[0034]** FIG. 2 is a micrograph illustrating a microstructure of a magnesium mother alloy in which scandium oxide is added into pure magnesium and scandium (Sc) exists in a solid-solution state;

**[0035]** FIG. 3 is a micrograph illustrating a microstructure of a magnesium mother alloy in which scandium oxide is added to magnesium-aluminum and a scandium compound is crystallized;

**[0036]** FIG. 4 is a graph illustrating hardness comparison results between a pure magnesium and a magnesium mother alloy with scandium oxide added according to an embodiment;

**[0037]** FIG. 5 is a graph illustrating oxidation experimental results between a pure magnesium and a magnesium mother alloy with scandium oxide added according to an embodiment;

**[0038]** FIG. 6 is a graph illustrating ignition experimental results between a pure magnesium and a magnesium mother alloy with scandium oxide added according to an embodiment;

**[0039]** FIG. 7 is a graph illustrating hardness comparison results between a magnesium-aluminum alloy and a magnesium-aluminum alloy with scandium oxide added according to an embodiment; and

**[0040]** FIG. 8 is a flowchart illustrating a method of manufacturing a metal alloy according to an embodiment.

**[0041]** In the following description, the same or similar elements are labeled with the same or similar reference numbers.

#### DETAILED DESCRIPTION

**[0042]** The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art.

**[0043]** The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used herein, the singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises” and/or “comprising,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

**[0044]** Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

**[0045]** Preferred embodiments of the present invention will now be described in detail with reference to the accompanying drawings.

**[0046]** FIG. 1 is a flowchart illustrating a method of manufacturing a magnesium mother alloy according to an embodiment.

**[0047]** The method of manufacturing the magnesium mother alloy includes forming a magnesium melt operation S1, adding an additive operation S2, stirring operation S3, casting operation S4, and cooling operation S5.

**[0048]** In the forming a magnesium melt operation S1, magnesium is put into a crucible and heated at a temperature ranging from about 600° C. to about 800° C. Then, the magnesium in the crucible is molten to form a magnesium melt. If the temperature is lower than about 600° C., it is difficult for forming the magnesium melt. If the temperature is higher than about 800° C., ignition may easily occur in the magnesium melt.

**[0049]** Additionally, a small amount of a shield gas may be provided to prevent the ignition of the magnesium melt. The shield gas may inhibit the ignition of the magnesium using  $\text{SF}_6$ ,  $\text{SO}_2$ ,  $\text{CO}_2$ , HFC-134a, Novec™612, inert gas or an equivalent thereof, or a mixture gas thereof. It should be noted that the listing of the above materials should not be seen as to



limit the scope of the present invention. Other materials may be used without departing from the spirit and scope of the present invention.

[0050] The magnesium used in operation S1 of forming the magnesium melt may be one selected from consisting of pure magnesium, magnesium-aluminum, and equivalents thereof. However, other types of material may be used without departing from the spirit and scope of the present invention.

[0051] In the adding an additive operation S2, a powdered additive is added to the magnesium melt. The additive used in operation S2 of adding the additive may not be pure scandium (Sc) of high price, but may be one selected from consisting of scandium oxide ( $\text{Sc}_2\text{O}_3$ ) which is relatively cheap, and equivalents thereof. The additive reduces the oxidation of a magnesium mother alloy, raises the ignition temperature, and remarkably reduces the required amount of the shield gas.

[0052] The additive used in operation S2 may be added in an amount of about 0.0001 wt % to about 30 wt % based on 100 wt % of the magnesium mother alloy. When the amount of the additive is less than 0.0001 wt %, the effect (increase in hardness, decrease in oxidation, increase in ignition temperature and decrease in shield gas) resulting from the addition of the additive may be little. When the amount of the additive exceeds 30 wt %, original magnesium properties or magnesium alloy properties may not appear.

[0053] The additive used in operation S2 may have a size ranging from about 0.1  $\mu\text{m}$  to about 500  $\mu\text{m}$ . If the additive is smaller than 0.1  $\mu\text{m}$ , it is difficult to manufacture the additive and it requires high manufacturing cost. When the size of the additive exceeds about 500  $\mu\text{m}$ , the additive may not react with the magnesium melt.

[0054] In the stirring operation S3, the magnesium melt is stirred for about 1 minute to about 400 minutes. If the stirring time is less than 1 minute, the additive is not sufficiently mixed with the magnesium melt. If the stirring time is greater than 400 minutes, the stirring time of the magnesium melt is unnecessarily lengthened.

[0055] The additive added into the magnesium melt does not exist in an oxide form. For example, when scandium oxide ( $\text{Sc}_2\text{O}_3$ ) is added into the magnesium melt, it does not exist in the form of  $\text{Sc}_2\text{O}_3$ . That is,  $\text{Sc}_2\text{O}_3$ , after being reduced, reacts with elements in the magnesium melt so that scandium (Sc) is dissolved in grains to exist in an alloy form, or crystallized to exist in a compound form.

[0056] It is generally expected that  $\text{Sc}_2\text{O}_3$  is not reduced in the magnesium melt because  $\text{Sc}_2\text{O}_3$  is thermodynamically more stable than magnesium. However, according to experiments conducted by the present inventors, it was found out that  $\text{Sc}_2\text{O}_3$  is reduced in the magnesium melt. This reduction mechanism is not discovered yet, and therefore the present inventors continue to study in order to diagnose the reduction mechanism.

[0057] When  $\text{Sc}_2\text{O}_3$  is added into pure magnesium, scandium (Sc) is dissolved in the pure magnesium. That is, scandium (Sc) forms an alloy element with magnesium. When  $\text{Sc}_2\text{O}_3$  is added into magnesium-aluminum, a scandium (Sc) compound is crystallized at a grain boundary of the magnesium-aluminum. That is, scandium (Sc) does not form an alloy element with magnesium but forms the Sc compound. Here, the scandium (Sc) compound is in the form of  $\text{Al}_2\text{Sc}$ ,  $\text{AlSc}$  or  $\text{Al}_3\text{Sc}$  typically.

[0058] The other element, oxygen ( $\text{O}_2$ ), of the additive all float on the surface of the magnesium melt, and thus can be removed manually or using an automatic equipment.

[0059] In the casting operation S4, the magnesium melt is poured into a mold having a room temperature (e.g., about 25° C.) to about 400° C., and then casted.

[0060] The mold may be one selected from group consisting of a metal type, a ceramic type, a graphite type and equivalents thereof. Also, a casting may be performed using gravity casting method, continuous casting method and equivalents thereof. It should be noted that other types of mold may be used without departing from the spirit and scope of the present invention. Further, it should be noted that the casting method is not limited to the above mentioned methods without departing from the spirit and scope of the present invention.

[0061] In the cooling operation S5, the mold is cooled down to a room temperature, and magnesium or magnesium-aluminum (e.g., ingot) is picked out of the mold.

[0062] The magnesium mother alloy prepared through the above-described method may include a plurality of magnesium grains having grain boundaries therebetween, and scandium (Sc) dissolved in the magnesium grains, or may include a scandium compound existing at the grain boundaries which are not inside but outside the magnesium grains.

[0063] FIG. 2 is a micrograph illustrating a microstructure of a magnesium mother alloy in which scandium oxide is added into pure magnesium and Sc exists in a solid-solution state. The microstructure shown in FIG. 2 is obtained by, for example, adding 0.5% scandium oxide into pure magnesium.

[0064] As shown in FIG. 2, a magnesium mother alloy 100 prepared according to an embodiment includes a plurality of magnesium grains 110, and scandium (Sc) dissolved in the magnesium grains 110. Here, the scandium is not discriminated from the magnesium grains 110 substantially because scandium (Sc) forms an alloy with magnesium.

[0065] The hardness of the magnesium mother alloy manufactured by adding scandium oxide is improved compared to that of pure magnesium. Since the scandium (Sc) does not change the original composition of the magnesium mother alloy and does not disappear during a process of recycling the magnesium mother alloy, the reusability of magnesium mother alloy is considerably enhanced. That is, it is unnecessary to add scandium (Sc) or scandium oxide again during the recycle of magnesium mother alloy.

[0066] In this embodiment, about 0.0001 wt % to about 30 wt % of scandium oxide may be added based on 100 wt % of magnesium. The scandium oxide may have a size ranging from about 0.1  $\mu\text{m}$  to about 500  $\mu\text{m}$ . The meaning of such a numerical range has already been described above.

[0067] FIG. 3 is a micrograph illustrating a microstructure of a magnesium mother alloy in which scandium oxide is added to magnesium-aluminum and a scandium compound is crystallized. For example, the microstructure in FIG. 3 is obtained by adding 0.5 wt % scandium oxide into magnesium-aluminum (Mg-3Al).

[0068] As shown in FIG. 3, a magnesium mother alloy 200 according to an embodiment includes a plurality of magnesium-aluminum grains 210, and a scandium compound 211.

[0069] The magnesium-aluminum grains 210 have grain boundaries therebetween, and the scandium compound 211 exists at the grain boundaries which are not inside the grains 210 but outside the magnesium-aluminum grains 210. Here, the scandium compound 211 exists in the form of  $\text{Al}_2\text{Sc}$ ,  $\text{AlSc}$  or  $\text{Al}_3\text{Sc}$ . That is, the scandium does not form an alloy with magnesium. Accordingly the hardness of the magnesium mother alloy 200 is enhanced, which will be described below.



**[0070]** Since the scandium (Sc) does not change the original composition of the magnesium mother alloy and does not disappear during a process of recycling the magnesium mother alloy, the reusability of magnesium mother alloy is considerably enhanced. For example, it is unnecessary to add scandium or scandium oxide again during the recycle of magnesium mother alloy.

**[0071]** Also, about 0.0001 wt % to about 30 wt % of the scandium compound **211** may be added based on 100 wt % of magnesium-aluminum. The scandium compound **211** may have a size ranging from about 0.1  $\mu\text{m}$  to about 500  $\mu\text{m}$ . The meaning of such a numerical range has been already described above.

**[0072]** The magnesium mother alloy may be used as one selected from consisting of an incombustible alloy, a wrought alloy, a creep alloy, a damping alloy, a degradable bio alloy, and a powder metallurgy. It should be noted that the listing of the above materials should not be seen as to limit the scope of the present invention. Other materials may be used without departing from the spirit and scope of the present invention.

**[0073]** For example, the casting alloy may be formed by mixing AZ91D, AM20, AM50, or AM60 with scandium oxide.

**[0074]** The wrought alloy may be formed by mixing AZ31, AM30, AZ61, or AZ80 with scandium oxide.

**[0075]** The creep alloy may be formed by mixing Mg—Al, or Mg—Al—Re with scandium oxide. Furthermore, the creep alloy may be formed by mixing Mg—Al—Sn or Mg—Zn—Sn with scandium oxide.

**[0076]** The damping alloy may be formed by mixing Mg, Mg—Si, or SiCp/Mg with scandium oxide.

**[0077]** The degradable bio alloy may be formed by mixing pure Mg with scandium oxide.

**[0078]** The powder metallurgy may be formed by mixing Mg—Zn—(Y) with scandium oxide.

**[0079]** Of course, in all the alloys, only scandium (Sc), which is obtained by removing  $\text{O}_2$  from scandium oxide, is crystallized and present at grain boundaries, or the scandium exists in the grains in a solid-solution state finally.

**[0080]** FIG. 4 is a graph illustrating hardness comparison results between a pure magnesium and a magnesium mother alloy with scandium oxide added according to an embodiment. In FIG. 4, the X-axis represents pure magnesium and magnesium into which 0.5 wt % scandium oxide is added, and the Y-axis represents hardness (HR).

**[0081]** Referring to FIG. 4, it can be observed that the hardness increases when scandium oxide is added during the manufacture of a magnesium mother alloy. That is, the hardness of the pure magnesium without scandium oxide is about HRF41, whereas the hardness of the magnesium mother alloy with scandium oxide added increases up to about HRF53.

**[0082]** FIG. 5 is a graph illustrating oxidation experimental results between pure magnesium and magnesium mother alloy with scandium oxide added according to an embodiment. In FIG. 5, the X-axis represents an elapse time (min.), and the Y-axis represents oxidation amount (%). A reference value of the Y-axis is set to 100.

**[0083]** Referring to FIG. 5, in the pure magnesium, it can be observed that the oxidation of the pure magnesium is accelerated with the lapse of time, and thus the value of the Y-axis increases gradually. However, in the magnesium mother alloy into which scandium oxide is added during manufacturing process, it can be observed that the oxidation does not increase even after the lapse of time. That is, the magnesium

mother alloy according to an embodiment is stable for various applications because it is not oxidized even after the lapse of time.

**[0084]** FIG. 6 is a graph illustrating ignition experimental results between pure magnesium and magnesium mother alloy with scandium oxide added according to an embodiment. In FIG. 6, the X-axis represents pure magnesium and magnesium into which 0.5 wt % scandium oxide is added, and the Y-axis represents an ignition temperature (C).

**[0085]** Referring to FIG. 6, it can be observed that the ignition temperature of the magnesium mother alloy with scandium oxide added is increased. That is, the ignition temperature of the pure magnesium without scandium oxide is about 600° C., whereas the ignition temperature of the magnesium mother alloy with scandium oxide added increases up to about 700° C.

**[0086]** FIG. 7 is a graph illustrating hardness comparison results between a magnesium-aluminum alloy and a magnesium-aluminum alloy with scandium oxide added according to an example embodiment. In FIG. 7, the X-axis represents a magnesium-aluminum alloy and a magnesium-aluminum alloy into which 0.5% scandium oxide is added, and the Y-axis represents hardness (HR).

**[0087]** Referring to FIG. 7, it can be observed that the hardness increases when scandium oxide is added during the manufacture of a magnesium-aluminum alloy. That is, the hardness of the magnesium-aluminum alloy without scandium oxide is about HRF50, whereas the hardness of the magnesium-aluminum alloy with scandium oxide added increases up to HRF68.

**[0088]** FIG. 8 is a flowchart illustrating a method of manufacturing a metal alloy according to an embodiment.

**[0089]** The method of manufacturing the metal alloy includes forming a metal melt operation S11, adding a magnesium mother alloy containing scandium (Sc) operation S12, stirring operation S13, casting operation S14, and cooling operation S15.

**[0090]** In the forming a metal melt operation S11, a magnesium alloy or an aluminum alloy is put into a crucible and heated at a temperature ranging from about 600° C. to about 800° C. Then, the metal in the crucible is molten to form a metal melt. There is a difficulty in forming the metal melt when the temperature is less than 600° C., whereas there is a danger that the metal melt is ignited when the temperature exceeds 800° C.

**[0091]** Here, the metal may be a magnesium alloy selected from consisting of AZ91D, AM20, AM30, AM50, AM60, AZ31, AZ61, AZ80, AS41, AS31, AS21X, AE42, AE44, AX51, AX52, AJ50X, AJ52X, AJ62X, MRI153, MRI230, AM-HP2, Mg—Al, Mg—Al—Re, Mg—Al—Sn, Mg—Zn—Sn, Mg—Si, and Mg—Zn—Y. It should be noted that the listing of the above materials should not be seen as to limit the scope of the present invention. Other materials may be used without departing from the spirit and scope of the present invention.

**[0092]** Also, the metal may be a metal alloy selected from consisting of 1000-series, 2000-series, 3000-series, 4000-series, 5000-series, 6000-series, 7000-series and 8000-series wrought aluminum, and 100-series, 200-series, 300-series, 400-series, 500-series, and 700-series casting aluminum. However, the present invention is not limited to such materials.

**[0093]** The aluminum alloys will be described in detail below. Various types of aluminum alloys have been developed



for their use, and most of countries currently classify the kinds of aluminum alloys according to the standard stipulated by the Aluminum Association of America. Main alloy elements for each of alloy series are listed in Table 1 below in which a serial number is only shown in units of thousand. In case of improving each of the alloy series by adding other elements, an alloy name is designated by subdividing four digits number more specifically.

TABLE 1

| Classification of aluminum according to alloy series |                           |
|------------------------------------------------------|---------------------------|
| Alloy Series                                         | Main alloy elements       |
| 1000-series Al                                       | Pure Al                   |
| 2000-series Al                                       | Al—Cu—(Mg)-based Al alloy |
| 3000-series Al                                       | Al—Mn-based Al alloy      |

indicated by a capital letter N. For example, 2xxx represents a basic alloy of Al—Cu series aluminum, 21xx-29xx represents alloys obtained by improving an Al—Cu basic alloy, and 2Nxx represents a newly developed alloy which is not stipulated in the standard of the Aluminum Association of America. The third and fourth numbers represent the purity of a pure aluminum or an alloy name of an aluminum alloy that Alcoa Inc. has used in the past. For example, in case of pure aluminum, 1080 indicates that the content of aluminum is 99.80% or higher, and 1100 indicates that the content of aluminum is 99.00% or higher.

**[0095]** Main compositions of wrought alloys are listed in Table 2 below. Properties of each alloy may significantly differ according to composition metals and their amounts, and working process. The main composition of the aluminum alloy is listed in Table 2 below.

TABLE 2

| Grade | Added metal(element symbol), Unit: % |      |      |      |      |     |                         | Use                                                |
|-------|--------------------------------------|------|------|------|------|-----|-------------------------|----------------------------------------------------|
|       | Si                                   | Cu   | Mn   | Mg   | Cr   | Zn  | Others                  |                                                    |
| 1100  |                                      | 0.12 |      |      |      |     | Si 1%, Abundant Fe      | Metal foils, cooking utensils                      |
| 1350  |                                      |      |      |      |      |     | About 0.5% others       | Conductive material                                |
| 2008  | 0.7                                  | 0.9  |      | 0.4  |      |     |                         | Metal plates for vehicles                          |
| 2014  | 0.8                                  | 4.4  | 0.8  | 0.5  |      |     |                         | Exterior of aircraft, truck frame                  |
| 2024  |                                      | 4.4  | 0.6  | 1.5  |      |     |                         | Exterior of aircraft, truck wheel                  |
| 2036  |                                      | 2.6  | 0.25 | 0.45 |      |     |                         | Metal plates for vehicles                          |
| 2090  |                                      | 2.7  |      |      |      |     | Li 2.2, Zr 0.12         | Metal for aircraft                                 |
| 2091  |                                      | 2.2  |      | 1.5  |      |     | Li 2.0, Zr 0.12         | Metal for aircraft                                 |
| 2219  |                                      | 6.3  | 0.3  |      |      |     | V 0.1, Zr 0.18, Ti 0.06 | Metal for spacecraft, weldable                     |
| 2519  |                                      | 5.9  | 0.3  | 0.2  |      |     | V 0.1, Zr 0.18          | Military equipment, metal for spacecraft, weldable |
| 3003  |                                      | 0.12 | 1.1  |      |      |     |                         | General use, cooking utensils                      |
| 3004  |                                      |      | 1.1  | 1.0  |      |     |                         | General use, metal can                             |
| 3105  |                                      |      | 0.6  | 0.5  |      |     |                         | Building materials                                 |
| 5052  |                                      |      |      | 2.5  | 0.25 |     |                         | General use                                        |
| 5083  |                                      |      | 0.7  | 4.4  | 0.15 |     |                         | Heat-/Pressure-resistant vessels                   |
| 5182  |                                      |      | 0.35 | 4.5  |      |     |                         | Metal can, metal for vehicles                      |
| 5252  |                                      |      |      | 2.5  |      |     |                         | For vehicle bodies                                 |
| 6009  | 0.8                                  | 0.33 | 0.33 | 0.5  |      |     |                         | Metal plates for vehicles                          |
| 6010  | 1.0                                  | 0.33 | 0.33 | 0.8  |      |     |                         | Metal plates for vehicles                          |
| 6013  | 0.8                                  | 0.8  | 0.5  | 1.0  |      |     |                         | Metal for spacecraft                               |
| 6061  | 0.6                                  | 0.25 |      | 1.0  | 0.20 |     |                         | General use                                        |
| 6063  | 0.4                                  |      |      | 0.7  |      |     |                         | General use, injection molding                     |
| 6201  | 0.7                                  |      |      | 0.8  |      |     |                         | Conductive material                                |
| 7005  |                                      |      | 0.45 | 1.4  | 0.13 | 4.5 | Zr 0.14                 | Truck body, train                                  |
| 7075  |                                      | 1.6  |      | 2.5  | 0.25 | 5.6 |                         | Metal for aircraft                                 |
| 7150  |                                      | 2.2  |      | 2.3  |      | 6.4 | Zr 0.12                 | Metal for spacecraft                               |
| 8090  |                                      | 1.3  |      | 0.9  |      |     | Li 2.4, Zr 0.12         | Metal for spacecraft                               |

TABLE 1-continued

| Classification of aluminum according to alloy series |                              |
|------------------------------------------------------|------------------------------|
| Alloy Series                                         | Main alloy elements          |
| 4000-series Al                                       | Al—Si-based Al alloy         |
| 5000-series Al                                       | Al—Mg-based Al alloy         |
| 6000-series Al                                       | Al—Mg—Si-based Al alloy      |
| 7000-series Al                                       | Al—Zn—Mg—(Cu)-based Al alloy |
| 8000-series Al                                       | Others                       |

**[0094]** The first number denotes an alloy series representing main alloy elements, and the second number denotes whether a basic alloy is improved or not. That is, the second number of 0 represents a basic alloy, and the second number of 1 to 9 represents alloys improved from the basic alloy. Further, when a new alloy is developed, the second number is

**[0096]** In the operation S12 of adding the magnesium mother alloy, a magnesium mother alloy containing scandium (Sc) is added to the metal melt. As described above, the metal melt may be a magnesium alloy or an aluminum alloy.

**[0097]** The magnesium mother alloy used in the operation S12 may be manufactured by adding one selected from consisting of scandium oxide ( $\text{Sc}_2\text{O}_3$ ), which is cheaper than pure scandium (Sc), and equivalents thereof, into magnesium or magnesium-aluminum. The magnesium and magnesium-aluminum, and methods thereof have been fully described above, and thus further description will be omitted herein.

**[0098]** In this way, according to an exemplary embodiment, magnesium or magnesium-aluminum alloy containing scandium (Sc) that is prepared at low cost is added into a metal melt, thus making it possible to solve several problems occurring when scandium oxide is directly put into the metal melt.



For example, the direct addition of scandium oxide ( $\text{Sc}_2\text{O}_3$ ) into aluminum causes the quality of an alloy to be deteriorated due to oxides. However, the quality of an alloy is not deteriorated by adding magnesium or magnesium-aluminum alloy containing scandium according to the embodiment. More specifically, alloy properties such as hardness, corrosion resistance and weldability are deteriorated when scandium oxide ( $\text{Sc}_2\text{O}_3$ ) is directly added into aluminum. However, alloy properties such as hardness, corrosion resistance and weldability in the metal alloy according to the embodiment are maintained without a change when magnesium or magnesium-aluminum already containing scandium (sc) is added into aluminum.

[0099] For instance, 5000-series metal alloys are strong, easy to be molded, and highly resistant to corrosion, in comparison with 3000-series metal alloys. Furthermore, 5000-series metal alloys are weldable. In particular, the 5182 alloy may be used for a cover of an aluminum can. In addition, 5005 and 5083 alloys, and 5052, 5056, 5086 and varieties thereof may widely be used for electric facilities, various cooking utensils, metal plate, pressure-resistant vessels, transmission towers of radio wave, welding structures, boats, reservoirs for chemicals, etc. Insect nets, nails, and fasteners may be made of 5000-series alloys. When magnesium or magnesium-aluminum alloy already containing scandium is added into such 5000-series metal alloys having the above properties, it is possible to obtain an aluminum alloy with good hardness, corrosion resistance and weldability at low cost.

[0100] The additive used in the operation S12 of adding the magnesium mother alloy may be added in an amount of about 0.0001 wt % to about 30 wt % based on 100 wt % of the metal. When the amount of the additive is less than 0.0001 wt %, the effect (hardness, corrosion resistance, and weldability) resulting from the addition of magnesium may be little. Also, when the amount of the additive exceeds 30 wt %, original metal properties may not appear.

[0101] Furthermore, the additive used in the operation S12 of adding the magnesium mother alloy may have a size ranging from about 0.1  $\mu\text{m}$  to about 500  $\mu\text{m}$ . It is difficult to manufacture an additive having a size of 0.1  $\mu\text{m}$  or smaller actually, leading to high manufacturing cost. When the size of the additive exceeds 500  $\mu\text{m}$ , the magnesium may not react with the metal melt.

[0102] Likewise, the additive used in the operation S12 of adding the magnesium-aluminum may be added in an amount of about 0.0001 wt % to about 30 wt % based on 100 wt % of the metal alloy. When the amount of the additive is less than 0.0001 wt %, the effect (hardness, corrosion resistance, and weldability) resulting from the addition of magnesium may be little. Also, when the amount of the additive exceeds 30 wt %, original metal properties may not appear.

[0103] Furthermore, the additive used in the operation S12 of adding the magnesium-aluminum may have a size ranging from about 0.1  $\mu\text{m}$  to about 500  $\mu\text{m}$ . It is difficult to manufacture an additive having a size of 0.1  $\mu\text{m}$  or smaller actually, leading to high manufacturing cost. When the size of the additive exceeds 500  $\mu\text{m}$ , the of adding the magnesium-aluminum may not react with the metal melt.

[0104] In the stirring operation S13, the metal melt is stirred for about 1 to about 400 minutes. When the stirring time is less than 1 minute, the additive is not sufficiently mixed with the metal melt. When the stirring time is greater than 400 minutes, the stirring time of the metal melt is unnecessarily lengthened.

[0105] Here, when the metal melt is aluminum melt, scandium (Sc) contained in the magnesium added into the aluminum melt exists in the form of  $\text{Al}_2\text{Sc}$ ,  $\text{AlSc}$  or  $\text{Al}_3\text{Sc}$  due to the high affinity between scandium (Sc) and aluminum (Al).

[0106] In the stirring operation S13,  $\text{Al}_2\text{Sc}$ ,  $\text{AlSc}$  or  $\text{Al}_3\text{Sc}$  does not exist in metal grains, but exists outside the metal grains, i.e., at grain boundaries, in the form of an intermetallic compound. That is, the metallic compound of  $\text{Al}_2\text{Sc}$ ,  $\text{AlSc}$  or  $\text{Al}_3\text{Sc}$  is formed in the stirring operation S13.

[0107] In the casting operation S14, the metal melt is poured into a mold at a room temperature (e.g., about 25° C.) to about 400° C., and then cast.

[0108] The mold may be one selected from consisting of a metal type, a ceramic type, a graphite type and equivalents thereof. Also, a casting may be performed using gravity casting method, continuous casting method and equivalents thereof. It should be noted that other types of mold may be used without departing from the spirit and scope of the present invention. Further, it should be noted that the casting method is not limited to the above mentioned methods without departing from the spirit and scope of the present invention.

[0109] In the cooling operation S15, the mold is cooled down to a room temperature, and a metal alloy (e.g., metal alloy ingot) is picked out of the mold.

[0110] The metal alloy manufactured through the above-described method includes a plurality of metal grains having grain boundaries therebetween, and an intermetallic compound (i.e.,  $\text{Al}_2\text{Sc}$ ,  $\text{AlSc}$  or  $\text{Al}_3\text{Sc}$ ) existing at the grain boundaries which are not inside but outside the metal grains. Of course, in case where the metal is pure magnesium, scandium (Sc) is dissolved in the metal grains.

[0111] As such, according to an exemplary embodiment, a magnesium mother alloy (Sc-containing magnesium or Sc-containing magnesium-aluminum) is added into a metal melt (magnesium alloy or aluminum alloy), thus making it possible to solve several problems occurring when scandium oxide is directly put into the metal melt. For example, the direct addition of scandium oxide ( $\text{Sc}_2\text{O}_3$ ) into aluminum causes the quality of an alloy to be deteriorated due to oxides, however, the addition of Sc-containing magnesium or scandium (Sc) containing magnesium-aluminum into aluminum according to an embodiment enables the aluminum alloy to be manufactured at low cost while not deteriorating the quality (hardness, corrosion resistance, weldability, etc.) of an alloy.

[0112] Table 3 below shows experimental data for strength of an aluminum alloy manufactured through the above-described method.

TABLE 3

|                                  |                  |             |
|----------------------------------|------------------|-------------|
| Strength of 7000-series Al alloy | Including Sc     | 650-700 MPa |
|                                  | Not including Sc | 550-600 MPa |
| Strength of 5000-series Al alloy | Including Sc     | 450-500 MPa |
|                                  | Not including Sc | 350-400 MPa |

[0113] As shown in Table 3, it can be understood that the strength increases up to about 650-700 MPa from about 550-600 MPa when magnesium or magnesium-aluminum, into which scandium (Sc) has been already added, is added into 7000-series Al alloy through the above-described method.

[0114] It can be also understood from Table 3 that the strength increases up to about 450-500 MPa from about 350-400 MPa when magnesium or magnesium-aluminum, into



which scandium (Sc) has been already added, is added into 5000-series Al alloy through the above-described method.

**[0115]** As such, in a metal alloy and a method thereof according to the embodiments, a magnesium mother alloy containing scandium (Sc) is added into a metal alloy such as a magnesium alloy or an aluminum alloy, and thus the metal alloy is manufactured at low cost. Furthermore, alloy properties of the metal alloy, e.g., hardness, corrosion resistance and weldability, are not deteriorated.

**[0116]** In addition, the magnesium mother alloy is manufactured in such a form that scandium (Sc) is dissolved in metal grains, or scandium (Sc) is crystallized at grain boundaries, which makes it possible to easily manufacture a metal alloy suitable for use or purpose. For example, when a metal alloy where scandium (Sc) is dissolved is required, a magnesium mother alloy where scandium (Sc) is dissolved in the metal grains may be used. Also, when a metal alloy where scandium (Sc) is crystallized is required, a magnesium mother alloy where scandium (Sc) is crystallized at the grain boundaries may be used. Of course, a metal alloy may be manufactured by adding both of the magnesium mother alloy where Sc is dissolved in metal grains and the magnesium mother alloy where Sc is crystallized at the grain boundaries.

**[0117]** As described above, according to foregoing embodiments, oxidation and ignition properties of a magnesium mother alloy are enhanced by adding scandium oxide into the magnesium mother alloy. Also, a metal alloy can be manufactured at low cost because the magnesium mother alloy containing scandium is added into a metal alloy such as a magnesium alloy and an aluminum alloy. In this case, alloy properties, e.g., hardness, corrosion resistance, and weldability, of the metal alloy are not deteriorated.

**[0118]** Moreover, it is possible to manufacture a metal alloy suitable for use and purpose by preparing two types of mother alloys of which one is a magnesium mother alloy containing scandium dissolved in grains, and the other is a magnesium mother alloy where scandium is crystallized. For example, when a metal alloy where Sc is dissolved is required, a magnesium mother alloy where Sc is dissolved in the metal grains may be used. Also, when a metal alloy where Sc is crystallized is required, a magnesium mother alloy where Sc is crystallized at the grain boundaries may be used. Of course, a metal alloy may be manufactured by adding both of the magnesium mother alloy where Sc is dissolved in metal grains and the magnesium mother alloy where Sc is crystallized at the grain boundaries. Accordingly, according to the embodiments, it is possible to manufacture metal alloys suitable for use and purpose through various methods.

**[0119]** A magnesium mother alloy, a manufacturing method thereof, a metal alloy using the same, and a method of manufacturing the metal alloy according to exemplary embodiments have been disclosed herein, and although specific terms are employed, they are used and are to be interpreted in a generic and descriptive sense only and not for purpose of limitation.

**[0120]** The drawings and the forgoing description gave examples of the present invention. The scope of the present invention, however, is by no means limited by these specific examples. Numerous variations, whether explicitly given in the specification or not, such as differences in structure, dimension, and use of material, are possible. The scope of the invention is at least as broad as given by the following claims.

1. A magnesium mother alloy comprising:  
a plurality of magnesium grains; and  
scandium (Sc) dissolved in the magnesium grains.
2. The magnesium mother alloy of claim 1 wherein the scandium (Sc) is contained in the magnesium mother alloy ranging from about 0.0001 wt % to about 30 wt % based on 100 wt % of the magnesium.
3. A magnesium mother alloy comprising:  
a plurality of magnesium-aluminum grains having grain boundaries; and  
a scandium compound crystallized at the grain boundaries which are not inside but outside of the magnesium-aluminum grains.
4. The magnesium mother alloy of claim 3 wherein the scandium compound is selected from the group consisting of  $\text{Al}_2\text{Sc}$ ,  $\text{AlSc}$  and  $\text{Al}_3\text{Sc}$ .
5. The magnesium mother alloy of claim 3 wherein the scandium (Sc) is contained in the scandium compound ranging from about 0.0001 wt % to about 30 wt % based on 100 wt % of the magnesium-aluminum.
- 6-8. (canceled)
9. A metal alloy comprising:  
a plurality of metal grains having grain boundaries; and  
a scandium compound crystallized at the grain boundaries which are not inside but outside the metal grains.
10. The metal alloy of claim 9 wherein the metal is selected from the group consisting of AZ91D, AM20, AM30, AM50, AM60, AZ31, AZ61, AZ80, AS41, AS31, AS21X, AE42, AE44, AX51, AX52, AJ50X, AJ52X, AJ62X, MRI153, MRI230, AM-HP2, Mg—Al, Mg—Al—Re, Mg—Al—Sn, Mg—Zn—Sn, Mg—Si, and Mg—Zn—Y.
11. The metal alloy of claim 9 wherein the metal is selected from the group consisting of 1000-series, 2000-series, 3000-series, 4000-series, 5000-series, 6000-series, 7000-series and 8000-series wrought aluminum, and 100-series, 200-series, 300-series, 400-series, 500-series, and 700-series casting aluminum.
12. The metal alloy of claim 9 wherein the scandium compound is selected from the group consisting of  $\text{Al}_2\text{Sc}$ ,  $\text{AlSc}$  and  $\text{Al}_3\text{Sc}$ .
13. The metal alloy of claim 9 wherein the scandium (Sc) is contained in the scandium compound ranging from about 0.0001 wt % to about 30 wt % based on 100 wt % of the metal.
- 14-20. (canceled)

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