

## Title (en)

METHOD OF FORMING A STARTING MATERIAL FOR PRODUCING RARE EARTH PERMANENT MAGNETS FROM RECYCLED MATERIALS AND CORRESPONDING STARTING MATERIAL

## Title (de)

VERFAHREN ZUR HERSTELLUNG EINES AUSGANGSMATERIALS ZUR HERSTELLUNG VON SELTENERD-DAUERMAGNETEN AUS RECYCELTEN MATERIALIEN UND ENTSPRECHENDES AUSGANGSMATERIAL

## Title (fr)

PROCÉDÉ DE FORMATION D'UN MATÉRIAU DE DÉPART POUR PRODUIRE DES AIMANTS PERMANENTS AUX TERRES RARES À PARTIR DE MATÉRIAUX RECYCLÉS ET MATÉRIAU DE DÉPART CORRESPONDANT

## Publication

**EP 4066963 A1 20221005 (EN)**

## Application

**EP 21165521 A 20210329**

## Priority

EP 21165521 A 20210329

## Abstract (en)

The present invention relates to a method of forming a starting material for producing rare earth permanent magnets from recycled materials. The method comprises at least the steps of providing single Nd<sub>2</sub>Fe<sub>14</sub>B grains of end-of-life Nd<sub>2</sub>Fe<sub>14</sub>B magnets and/or magnet scraps and coating the grains with a single layer or with a layer sequence of one or several grain boundary materials such that said single layer or layer sequence is covering each individual grain. The grain boundary material of said single layer or of a lowermost layer of said layer sequence is selected from one or several metals or metal compounds or alloys. The coated grains are then condensed to bulk Nd-Fe-B permanent magnets, optionally via subsequent thermal treatments.

## IPC 8 full level

**B22F 1/00** (2022.01); **B22F 8/00** (2006.01); **B22F 9/02** (2006.01); **C22B 7/00** (2006.01); **C22B 59/00** (2006.01); **C22C 38/00** (2006.01); **C23C 16/00** (2006.01); **C30B 29/52** (2006.01); **H01F 1/057** (2006.01); **H01F 41/02** (2006.01); **B22F 9/00** (2006.01)

## CPC (source: EP)

**B22F 1/05** (2022.01); **B22F 1/145** (2022.01); **B22F 1/16** (2022.01); **B22F 1/17** (2022.01); **B22F 8/00** (2013.01); **B22F 9/023** (2013.01); **C23C 28/00** (2013.01); **H01F 1/0572** (2013.01); **H01F 1/0578** (2013.01); **H01F 41/0253** (2013.01); **B22F 2009/001** (2013.01); **B22F 2998/10** (2013.01); **B22F 2999/00** (2013.01); **C22C 2200/00** (2013.01); **C22C 2202/02** (2013.01); **H01F 1/0573** (2013.01)

## C-Set (source: EP)

1. **B22F 2999/00** + **C22C 2202/02** + **B22F 2009/001**
2. **B22F 2999/00** + **C22C 2202/02** + **B22F 8/00**
3. **B22F 2998/10** + **B22F 1/145** + **B22F 9/023** + **B22F 8/00**
4. **B22F 2999/00** + **B22F 1/145** + **C22C 2202/02** + **C22C 2200/00** + **B22F 1/05**
5. **B22F 2999/00** + **B22F 1/145** + **B22F 1/17**
6. **B22F 2999/00** + **B22F 1/145** + **B22F 1/17** + **B22F 1/102** + **B22F 1/16**

## Citation (applicant)

- CN 104959618 A 20151007 - UNIV ZHEJIANG
- CN 110853854 A 20200228 - UNIV BEIJING TECHNOLOGY
- US 2006022175 A1 20060202 - KOMURO MATAHIRO [JP], et al
- US 2006191601 A1 20060831 - KOMURO MATAHIRO [JP], et al
- US 2014291296 A1 20141002 - JIN SUNGHO [US], et al
- SAGAWA, M. ET AL.: "Permanent magnet materials based on the rare earth-iron-boron tetragonal compounds", IEEE TRANSACTIONS ON MAGNETICS, vol. 20, no. 5, 1984, pages 1584 - 1589
- YANG, Y. ET AL.: "REE recovery from end-of-life NdFeB permanent magnet scrap: a critical review", JOURNAL OF SUSTAINABLE METALLURGY, vol. 3, no. 1, 2017, pages 122 - 149
- BETANCOURT, R.J.R.M.D.F., NANOCRYSTALLINE HARD MAGNETIC ALLOYS, vol. 48, no. 4, 2002, pages 283 - 289
- STRAUMAL, B. ET AL.: "Grain boundary wetting in the NdFeB-based hard magnetic alloys", JOURNAL OF MATERIALS SCIENCE, vol. 47, no. 24, 2012, pages 8352 - 8359, XP035124236, DOI: 10.1007/s10853-012-6618-5
- HONO, K.H. SEPEHRI-AMIN: "Strategy for high-coercivity Nd-Fe-B magnets", SCRIPTA MATERIALIA, vol. 67, no. 6, 2012, pages 530 - 535
- HERBST, J.: "R 2 Fe 14 B materials: Intrinsic properties and technological aspects", REVIEWS OF MODERN PHYSICS, vol. 63, no. 4, 1991, pages 819
- NAKAMURA, H. ET AL.: "Magnetic properties of extremely small Nd-Fe-B sintered magnets", IEEE TRANSACTIONS ON MAGNETICS, vol. 41, no. 10, 2005, pages 3844 - 3846, XP011140907, DOI: 10.1109/TMAG.2005.854874
- KOMATSU, T. ET AL.: "IOP Conference Series: Materials Science and Engineering", 2009, IOP PUBLISHING, article "IUMRS-ICA 2008 Symposium'AA. Rare-Earth Related Material Processing and Functions"
- LI, D. ET AL.: "Grain interface modification and magnetic properties of Nd-Fe-B sintered magnets", JAPANESE JOURNAL OF APPLIED PHYSICS, vol. 47, no. 10R, 2008, pages 7876
- ZAPF, L. ET AL., PROCEEDINGS OF 20TH INTERNATIONAL WORKSHOP ON RARE EARTH PERMANENT MAGNET & THEIR APPLICATIONS
- SODERZNIK, M. ET AL.: "The grain-boundary diffusion process in Nd-Fe-B sintered magnets based on the electrophoretic deposition of DyF<sub>3</sub>", INTERMETALLICS, vol. 23, 2012, pages 158 - 162, XP055203877, DOI: 10.1016/j.intermet.2011.11.014
- HIROTA, K. ET AL.: "Coercivity enhancement by the grain boundary diffusion process to Nd-Fe-B sintered magnets", IEEE TRANSACTIONS ON MAGNETICS, vol. 42, no. 10, 2006, pages 2909 - 2911, XP002463459, DOI: 10.1109/TMAG.2006.879906
- LOEWE, K. ET AL.: "Temperature-dependent Dy diffusion processes in Nd-Fe-B permanent magnets", ACTA MATERIALIA, vol. 83, 2015, pages 248 - 255
- SODERZNIK, M. ET AL.: "High-coercivity Nd-Fe-B magnets obtained with the electrophoretic deposition of submicron TbF<sub>3</sub> followed by the grain-boundary diffusion process", ACTA MATERIALIA, vol. 115, 2016, pages 278 - 284, XP029631563, DOI: 10.1016/j.actamat.2016.06.003
- SODERZNIK, M. ET AL.: "The grain-boundary diffusion process in Nd-Fe-B sintered magnets based on the electrophoretic deposition of DyF<sub>3</sub>", INTERMETALLICS, vol. 23, 2012, pages 158 - 162, XP055203877, DOI: 10.1016/j.intermet.2011.11.014
- MCGUINNESS, P. ET AL.: "Replacement and Original Magnet Engineering Options (ROMEOS): A European Seventh Framework Project to Develop Advanced Permanent Magnets Without, or with Reduced Use of, Critical Raw Materials", JOM, vol. 67, no. 6, 2015, pages 1306 - 1317
- GUTFLEISCH, O.: "Controlling the properties of high energy density permanent magnetic materials by different processing routes", JOURNAL OF PHYSICS D: APPLIED PHYSICS, vol. 33, no. 17, 2000, pages R157

- SEPEHRI-AMIN, H. ET AL.: "Grain boundary and interface chemistry of an Nd-Fe-B-based sintered magnet", ACTA MATERIALIA, vol. 60, no. 3, 2012, pages 819 - 830, XP028445602, DOI: 10.1016/j.actamat.2011.10.043
- MATSUURA, Y. ET AL.: "Phase diagram of the Nd-Fe-B ternary system", JAPANESE JOURNAL OF APPLIED PHYSICS, vol. 24, no. 8A, 1985, pages L635, XP001033985, DOI: 10.1143/JJAP.24.L635
- FUKAGAWA, T.S. HIROSAWA: "Coercivity generation of surface Nd<sub>2</sub>Fe<sub>14</sub>B grains and mechanism of fcc-phase formation at the Nd/Nd<sub>2</sub>Fe<sub>14</sub>B interface in Nd-sputtered Nd-Fe-B sintered magnets", JOURNAL OF APPLIED PHYSICS, vol. 104, no. 1, 2008, pages 013911, XP012116342, DOI: 10.1063/1.2952556
- WALTON, A. ET AL.: "The use of hydrogen to separate and recycle neodymium-iron-boron-type magnets from electronic waste", JOURNAL OF CLEANER PRODUCTION, vol. 104, 2015, pages 236 - 241
- XU, X. ET AL.: "Direct Recycling of Nd-Fe-B Magnets Based on the Recovery of Nd<sub>2</sub>Fe<sub>14</sub>B Grains by Acid-free Electrochemical Etching", CHEMSUSCHEM, vol. 12, no. 21, 2019, pages 4754 - 4758
- KIMURA, M. ET AL.: "Fabrication of Anisotropic Nd-Fe-B Powders by Ta Sputtering", MATERIALS TRANSACTIONS, vol. 60, no. 5, 2019, pages 830 - 836
- XU, X. ET AL., DIRECT RECYCLING OF ND-FE-B MAGNETS BASED ON THE RECOVERY OF ND<sub>2</sub>FE<sub>14</sub>B GRAINS BY ACID-FREE ELECTROCHEMICAL ETCHING, vol. 12, no. 21, 2019, pages 4754 - 4758

Citation (search report)

- [XY] CN 104036944 A 20140910 - UNIV BEIJING TECHNOLOGY
- [Y] JP 2020521339 A 20200716
- [Y] FR 3069096 A1 20190118 - COMMISSARIAT ENERGIE ATOMIQUE [FR]
- [Y] CN 112375914 A 20210219 - WEIFANG JIUTIAN STRONG MAGNETIC CO LTD
- [AD] US 2006191601 A1 20060831 - KOMURO MATAHIRO [JP], et al
- [A] WO 2017132075 A1 20170803 - URBAN MINING COMPANY [US]
- [A] US 2015294787 A1 20151015 - ZLATKOV BRANISLAV [AT]
- [A] US 2014366687 A1 20141218 - ZAKOTNIK MIHA [US], et al

Designated contracting state (EPC)

AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR

Designated extension state (EPC)

BA ME

DOCDB simple family (publication)

**EP 4066963 A1 20221005**

DOCDB simple family (application)

**EP 21165521 A 20210329**