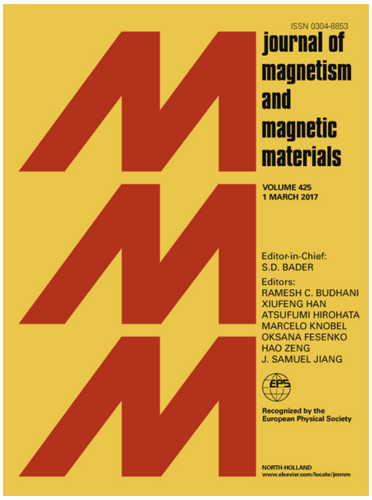

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PII: S0304-8853(18)31281-2
DOI: https://doi.org/10.1016/j.jmmm.2018.09.055
Reference: MAGMA 64337

To appear in: *Journal of Magnetism and Magnetic Materials*

Please cite this article as: Z. Zhang, W.J. Lu, S.Z. Dong, H.R. Bai, T.N. Yang, D.H. Wei, J.J. Ni, W. Li, C.C. Hu, Y.G. Shi, H.Y. Li, J.G. Hao, P. Fu, W.F. Rao, Design of high resistivity light-rare-earth-based $PrFe_{1.93}$ magnetostrictive alloys: Si doping and high-pressure annealing, *Journal of Magnetism and Magnetic Materials* (2018), doi: https://doi.org/10.1016/j.jmmm.2018.09.055

Design of high resistivity light-rare-earth-based $PrFe_{1.93}$ magnetostrictive alloys: Si doping and high-pressure annealing

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Abstract

Light-rare-earth-based $Pr(Fe_{1-x}Si_x)_{1.93}$ alloys ($0 \leqslant x \leqslant 0.1$) with pure cubic Laves phase were synthesized by high-pressure annealing method. Si substitution effects on magnetic, electrical and magnetostrictive properties of light-rare-earth-based $Pr(Fe_{1-x}Si_x)_{1.93}$ alloys were systematically investigated. It was found that the lattice parameter a and Curie temperature T_C of the cubic Laves phase in the alloys increase with the increasing Si content up to $x = 0.05$, which might be ascribed to the preferential occupation of Si in the Laves phase interstitial sites. The magnetization at the maximum available field of 15 kOe, σ_{15k}, decreases monotonically with the increasing x. A significant increase of 67% in electrical resistivity was observed in $Pr(Fe_{0.9}Si_{0.1})_{1.93}$ alloy at room temperature. The magnetostriction at the field of 3 kOe of $Pr(Fe_{0.95}Si_{0.05})_{1.93}$ is about 542 ppm, which is even larger than the saturation magnetostriction of heavy-rare-earth-based $Tb_{0.2}Dy_{0.22}Ho_{0.58}Fe_2$ single crystal (λ_s=530 ppm). The attractive price, lower eddy current loss, together with high magnetostrictive response suggest that the $Pr(Fe_{0.95}Si_{0.05})_{1.93}$ alloy might be a good candidate material for the potential magnetostrictive applications.

Keywords: Cubic Laves phase, $PrFe_2$, High-pressure annealing, Magnetostriction

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1. Introduction

Giant magnetostrictive materials (GMMs), as modern smart materials, are playing increasingly important roles in many applications, such as ultra-sensitive sensors, high energy density actuators, acoustic transducers, etc[1, 2, 3, 4]. In order to exploit the giant magnetostriction at low field, it is necessary to minimize the magnetocrystalline anisotropy by combining two RFe_2 (R=rare earth) with opposite anisotropy signs.[1] The pseudobinary compounds $Tb_{0.27}Dy_{0.73}Fe_2$ and $Tb_{0.15}Ho_{0.85}Fe_2$ were firstly proposed as candidate materials for the magnetostrictive application[5, 6]. Based on that, further interest has been paid to the element-doped and multicomponent pseudobinary systems, for the purpose of minimizing the magnetocrystalline anisotropy and improving their magnetic, magnetostrictive and electrical properties[7, 8, 9, 10, 11, 12]. Recently, Wutting *et al.* have experimentally found that the easy magnetic direction (EMD) boundary of $Tb_{1-x}Dy_xFe_2$ (Terfenol-D) between $\mathbf{Ms}||[111]$ and $\mathbf{Ms}||[100]$ indeed corresponds to the structure rhombohedral (R) and tetragonal (T) boundary, and the anisotropy compensation area could be physically analogous to ferroelectric **morphotropic phase boundary (MPB)**.[13] After that, many experimental and theoretical works on ferromagnetic MPB have being done.[14, 15, 16] However, the raw materials of these compounds mainly consist of expensive heavy-rare-earths Tb, Dy, or Ho. Hence, there is a need for searching new advanced magnetostrictive materials based on inexpensive light-rare-earths. According to the single ion model,[1] the spontaneous magnetostriction of $PrFe_2$ is as large as 5600 ppm at 0 K, which is even larger than that of $TbFe_2$ (4400 ppm) and $DyFe_2$ (4200 ppm). Many efforts were made for increasing the Pr content in magnetostrictive materials under ambient atmosphere. However, when the Pr content was over 30 at. %, many unanticipated $PrFe_3$ and Pr_2Fe_{17} phases appear, which

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Preprint submitted to Journal of Magnetism and Magnetic Materials *August 10, 2018*