World Academy of Science, Engineering and Technology
International Journal of Materials and Metallurgical Engineering
Vol:12, No:07, 2018

Morphotropic Phase Boundary in Ferromagnets: Unusual Magnetoelastic Behavior In $Tb_{1-x}Nd_xCo_2$

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Abstract : The morphotropic phase boundary (MPB); a boundary between two different crystallographic symmetries in the composition–temperature phase diagram has been widely studied in ferroelectrics and recently has drawn interest in ferromagnets for obtaining enhanced large field-induced strain. At MPB, the system gets a compressed free energy state, which allows the polarization to freely rotate and hence results in a high magnetoelastic response (e.g., high magnetization, low coercivity, and large magnetostriction). Based on the same mechanism, we designed MPB in a ferromagnetic $Tb_{1-x}Nd_xCo_2$ system. The temperature-dependent magnetization curves showed spin reorientation (SR); which can be explained by a two-sublattice model. Contrary to previously reported MPB involved ferromagnetic systems, the MPB composition of $Tb_{0.35}Nd_{0.65}Co_2$ exhibits a low saturation magnetization (MS), indicating a compensation of the Tb and Nd magnetic moments at MPB. The coercive field (HC) under a low magnetic field and first anisotropy constant (K_1) shows a minimum value at MPB composition of x=0.65. A detailed spin configuration diagram is provided for the $Tb_{1-x}Nd_xCo_2$ around the composition for the anisotropy compensation; this can guide the development of novel magnetostrictive materials. The anisotropic magnetostriction (λS) first decreased until x=0.8 and then continuously increased in the negative direction with further increase of Nd concentration. In addition, the large ratio between magnetostriction and the absolute values of the first anisotropy constant ($λS/K_1$) appears at MPB, indicating that $Tb_{0.35}Nd_{0.65}Co_2$ has good magnetostrictive properties. Present work shows an anomalous type of MPB in ferromagnetic materials, revealing that MPB can also lead to a weakening of magnetoelastic behavior as shown in the ferromagnetic $Tb_{1-x}Nd_xCo_2$ system. Our work shows the universal presence of MPB in ferromagnetic materials and suggests the differences between different ferromagnetic MPB systems that are important for substantial improvement of magnetic and magnetostrictive properties. Based on the results of this study, similar MPB effects might be achieved in other ferroic systems that can be used for technological applications. The finding of magnetic MPB in the ferromagnetic system leads to some important significances. First, it provides a better understanding of the fundamental concept of spin reorientation transitions (SRT) like ferro-ferro transitions are not only reorientation of magnetization but also crystal symmetry change upon magnetic ordering. Second, the flattened free energy corresponding to a low energy barrier for magnetization rotation and enhanced magnetoelastic response near MPB. Third, to attain large magnetostriction with MPB approach two terminal compounds have different easy magnetization directions below Curie temperature Tc in order to accomplish the weakening of magnetization anisotropy at MPB (as in ferroelectrics), thus easing the magnetic domain switching and the lattice distortion difference between two terminal compounds should be large enough, e.g., lattice distortion of R symmetry ˃˃ lattice distortion of T symmetry). So that the MPB composition agrees to a nearly isotropic state along with large ‘net’ lattice distortion, which is revealed in a higher value of magnetostriction.

Keywords : magnetization, magnetostriction, morphotropic phase boundary (MPB), phase transition
Conference Title : ICMMSE 2018 : International Conference on Metallurgy, Materials Science and Engineering
Conference Location : Dublin, Ireland
Conference Dates : July 23-24, 2018