# Diffusion-controlled phase transitions as a tool for tailoring Fe-Ga functional properties

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Fe-Ga alloys exhibit unique functional properties such as magnetostriction that can be varied from the highest positive values among iron-based alloys to negative values including zero magnetostriction, if proper compositions and heat treatments are chosen. This remarkable behavior is related to rather complex diffusion-controlled phase transformation sequences in this alloy family that are still unresolved. In earlier studies, the phase transformations in Fe-Ga alloys were studied by X-ray diffraction, which provides structural information limited to the near-surface sample area. In this work, we use electron back-scatter diffraction and *in situ* neutron diffraction to characterize the $D0_3$ and $L1_2$ phases that originate from the fcc and bcc phases in the Fe-27Ga type bulk alloy, respectively. Different ratios between these phases, characterized by magnetostriction values of different signs, were achieved using an isothermal annealing treatment that produces an intrinsic composite in the alloy. Depending on the relative fraction of the $D0_3$ and $L1_2$ phases, the magnetostriction values of the alloy, $\lambda_S$, vary from +100 to -50 ppm, including the value of $\lambda_S = 0$ for the alloy with $L1_2$:$D0_3$ = 2:1 achieved after 600 min annealing at 400°C, thus demonstrating the controlled adjustment of magnetostriction in these advanced alloys.

With respect to phase transitions, we demonstrate that the phase transition from a metastable ordered bcc-derivative $D0_3$ phase to an equilibrium fcc-derivative ordered $L1_2$ phase first leads to disordering of the $D0_3$ phase to obtain an A2 structure followed by an A2 to A1 transition with final A1 phase ordering to achieve the $L1_2$ structure. This transition sequence: $D0_3 \rightarrow A2 \rightarrow A1 \rightarrow L1_2$ is proven for the Fe-27Ga alloy at both instant heating and isothermal annealing between 400 and 475°C. Additional doping by Tb stabilizes bcc-derivative phases with respect to heating rate or annealing time and, therefore, fixes structures with high positive values of magnetostriction.

The results of this work present the details of the phase transformations occurring in Galfenol for the first time and they also pave the way for tuning the microstructure of the alloy in such a way that the magnetostriction of the material can be tuned in a controlled way to meet the demands of a given application.