SPINODAL DECOMPOSITION IN Fe-Ga ALLOYS

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Fe-*x*Ga alloys demonstrate a phenomenon known as giant magnetostriction. What makes them unique is that magnetostriction has two peaks, at $x \approx 19$ and 27 at.%. While the nature of the first peak is more or less understood, there is active debate in the literature regarding the second one. To date, no structural element or set of elements has been reliably identified as the unequivocal cause of the second magnetostriction peak. In Ref. [1], it was found that an ω-like phase, designated by the authors as the X-phase, is observed in the as-cast Fe-27Ga alloy. A detailed analysis of the electron diffraction patterns [2], carried out by A. Leineweber, demonstrated that this phase is the $Fe_{13}Ga_9$ intermetallic compound. The same study also established that the ω-like phases observed by the authors of references [3, 4] in the $Fe_{73.1}Ga_{26.9}$ and $Fe_{73}Ga_{27}$ alloys, respectively, in the quenched and subsequently annealed states, are also the $Fe_{13}Ga_9$ intermetallic compound.

Using transmission electron microscopy, it was found in [4] that the ω-like phase forms via a spinodal decomposition mechanism. A similar conclusion was reached in [5], where a mechanism was proposed to explain the sharp increase in the volume fraction of the metastable $Fe_{13}Ga_9$ intermetallic compound at ~400 °C during continuous heating of alloys with a high gallium content (31–35 at.%). Thus, there arose a need for experimental confirmation of this conclusions.

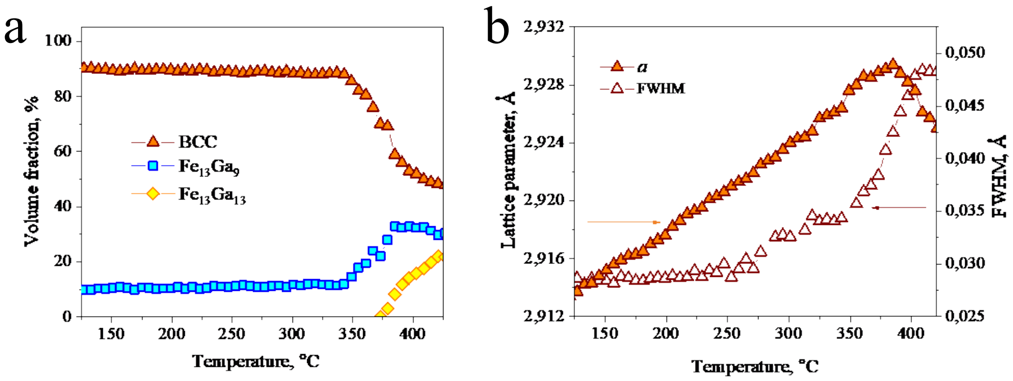

Figure 1. Evolution of the phase composition of the Fe66Ga34 alloy from the initial quenched state upon heating to 420°C (a) and lattice parameter of B2 phase and FWHM of (200) peak (b).

In this study, *in situ* investigations of the $Fe_{66}Ga_{34}$ alloy were carried out using neutron diffraction on a high-resolution Fourier diffractometer (HRFD, IBR-2). This instrument is distinguished by its ability to operate in two modes: high resolution ($\Delta d/d \approx 0.0015$) and high intensity ($\Delta d/d \approx 0.015$).

The initial state of the $Fe_{66}Ga_{34}$ alloy was achieved by quenching it in water at 900 °C. This heat treatment resulted in a two-phase structure consisting of 90% B2 and 10% $Fe_{13}Ga_9$ intermetallic phases. The alloy sample was then subjected to continuous heating at a rate of 2 °C/min up to a temperature of 420 °C. Measurements were carried out in high-intensity mode. Within the 350–380 °C range, a sharp increase in the volume fraction of the $Fe_{13}Ga_9$

intermetallic phase was observed (Fig.1a), accompanied by a decrease in the lattice parameter of the B2 phase (see Fig. 1b). At 375 °C, a phase transition B2 → $Fe_{13}Ga_{13}$ also occurs. A detailed analysis of the peak shapes revealed that, at a temperature of ~250 °C, the full width at half maximum (FWHM) begins to increase. We believe this is associated with the spinodal decomposition process, given that no other changes in phase composition were observed within this temperature range. The FWHM then levels off at ~310 °C and a sharp increase begins again at 350 °C, which is associated with the formation of the $Fe_{13}Ga_9$ intermetallics.

To confirm that a spinodal decomposition process occurs in the 250–310 °C range, an *in situ* experiment was conducted in high-resolution mode (Fig. 2). A sample of the $Fe_{66}Ga_{34}$ alloy was heated to 270 °C at a rate of 10 °C/min and then held at that temperature for 30 hours. As can be seen from Fig. 2b, upon reaching the set temperature, satellites had already formed to the right and left sides of (200) peak, corresponding to the formation of BCC phases with lower (BCC_I) and higher (BCC_{II}) gallium content, respectively. Subsequently, as the holding time increases, the intensity of the satellites grows, confirming the continued progression of the spinodal decomposition process.

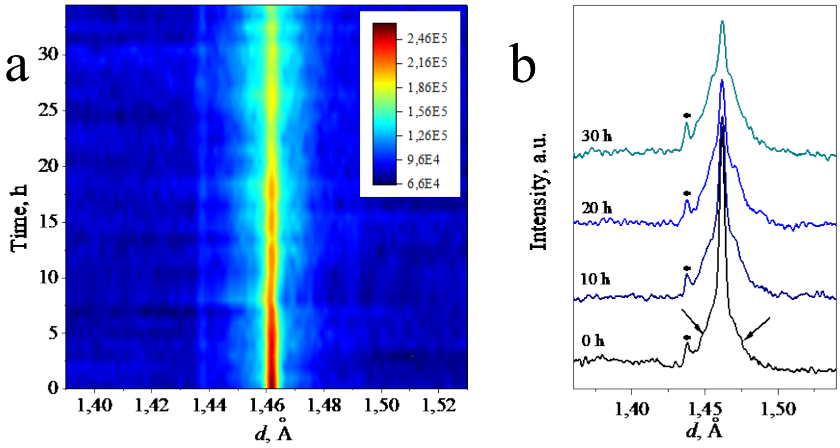

Figure 2. 2D visualization of the evolution of (200) peak of B2 phase of $Fe_{66}Ga_{34}$ alloy in a quenched state measured upon slow heating up to 270 °C (a) and profiles of (200) peak of B2 phase obtained at different temperatures. The arrows indicate the satellites. The peak from the furnace is marked with a sticker.

Since continuous heating results in a significant reduction in the B2 lattice parameter when the $Fe_{13}Ga_9$ intermetallic compound forms, it can be inferred that the gallium-rich phase with a BCC-based lattice structure transforms into the $Fe_{13}Ga_9$ intermetallic compound.

Experiments have thus confirmed that a spinodal decomposition process BCC → BCC_I + BCC_{II} occurs in Fe-Ga alloys, followed by a transition BCC_{II} → $Fe_{13}Ga_9$.

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[4] C. Guan et.al. (2021) Atomic-scale insights into ω-variants in galfenol triggered by displacive-diffusive transformation, Materials Design, 205, 109745.

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