EMR study of NiMnGa-based powders for additive manufacturing applications

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Introduction

Ni-Mn-Ga-based alloys have been the subject of extensive research due to the strong coupling between their structural ordering, stoichiometry, and mechanical as well as magneto-mechanical properties [1,2]. Of particular interest is the magnetic-field-induced shape memory effect, first reported by Ullakko [3], which makes these materials promising for functional applications. While single-crystal Ni-Mn-Ga alloys are the most thoroughly investigated and exhibit excellent properties, their use in large-scale industrial applications remains limited due to high production costs and manufacturing constraints. As a result, interest has shifted toward polycrystalline forms, including melt-spun ribbons and powders, especially in the context of additive manufacturing technologies.

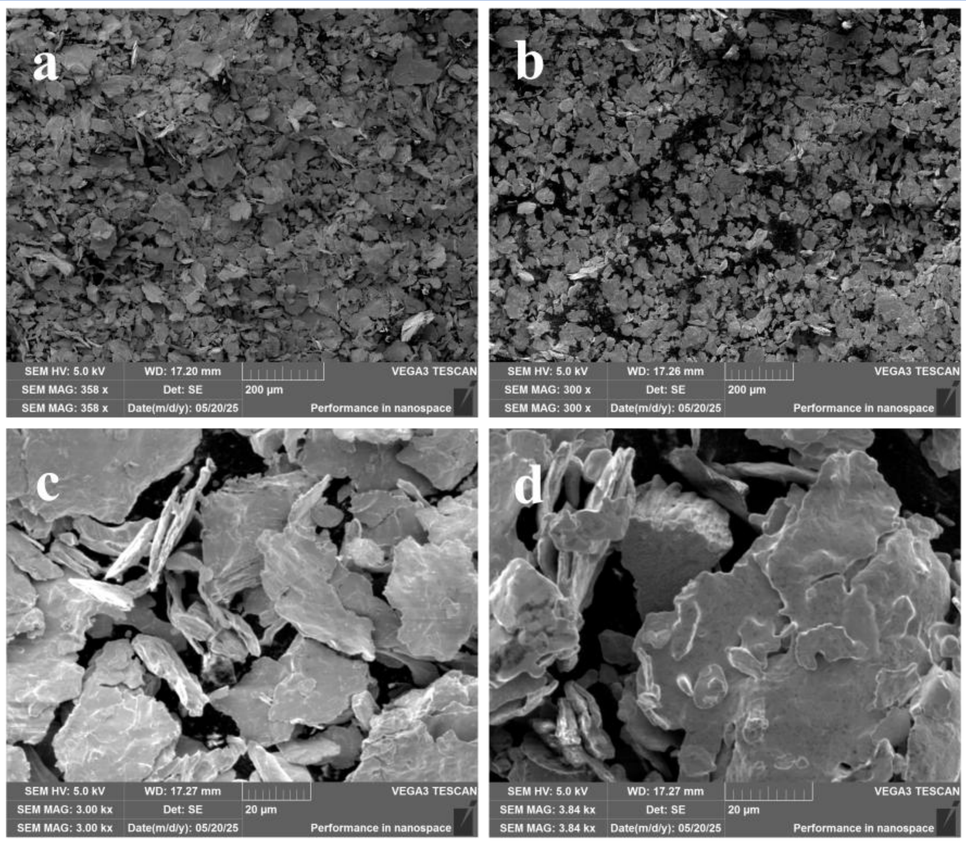
Materials and Methods

The $Ni_{45}Mn_{25}Ga_{20}Co_5Cu_5$ alloy was prepared using induction melting from high-purity metals in an argon atmosphere. The melt-spun ribbons were produced by ejecting molten alloys with argon overpressure (0.25~MPa) onto the surface of a copper wheel rotating at a linear speed of 20 ms^{-1}. The powder was produced by mechanical milling of melt-spun ribbons in a vibration mill with 1 ball 50 mm in diameter and under 0.5 mm vibration amplitude for 8 h. Before the measurements, the samples were annealed at 900 K for 1 hour.

Electron magnetic resonance (EMR) measurements were performed using the Bruker ELEXYS E580 spectrometer equipped with the Bruker liquid N gas flow cryostat with the 41131 VT digital controller in the X-band (9.44 GHz). In the X-band, the spectra were registered using a standard super-high-Q resonator (ER 4123D) at a 100 kHz magnetic field modulation with an amplitude of 1 G.

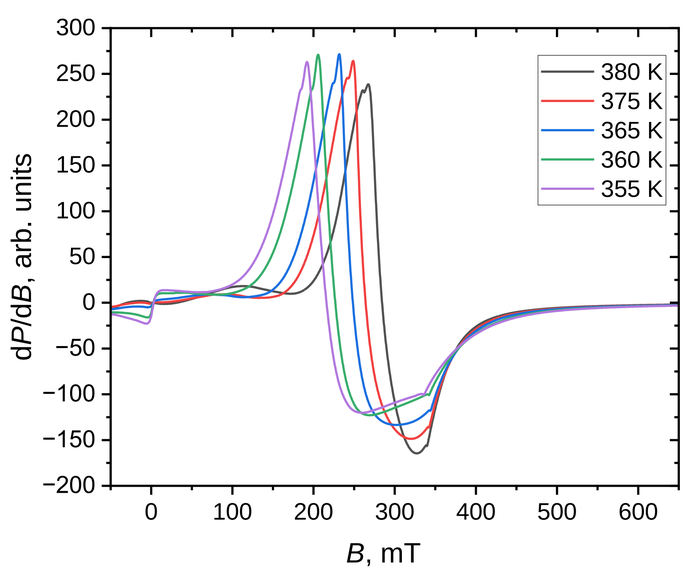
Morphology and composition of samples were examined using a Tescan Vega 3 scanning electron microscope equipped with the EDX Bruker Quantax microanalysis system.

Results

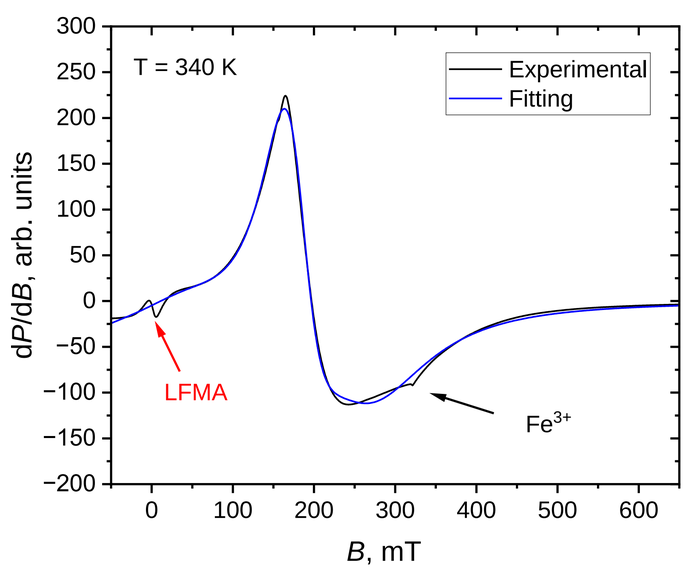


Morphology of in-situ powder (a), (c) and annealed powder at 900 K for 1 hour (b), (d).

The sample EMR spectra for $Ni_{45}Mn_{25}Ga_{20}Co_5Cu_5$ were recorded in the high-temperature region (austenite phase)



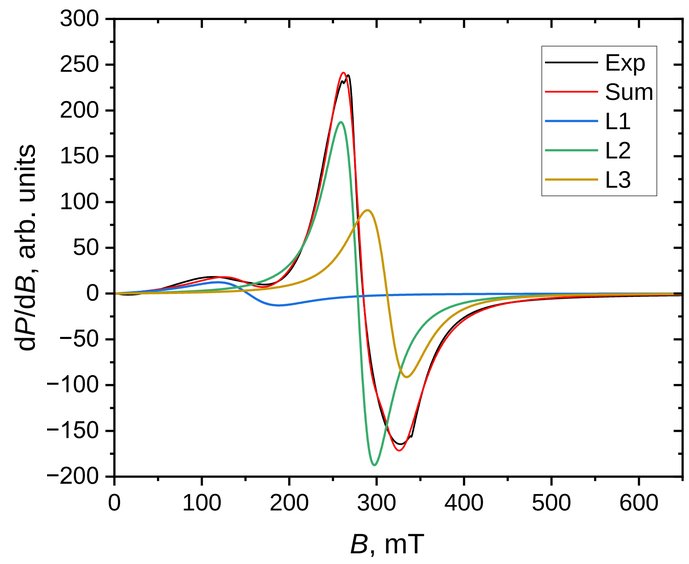
The EMR signal shows a characteristic shift toward lower fields with decreasing temperature



Below Curie temperature, the EMR lines contain a low-field microwave absorption signal (LFMA), and a weak, narrow line connected to Fe ions, originating from milling-induced contamination

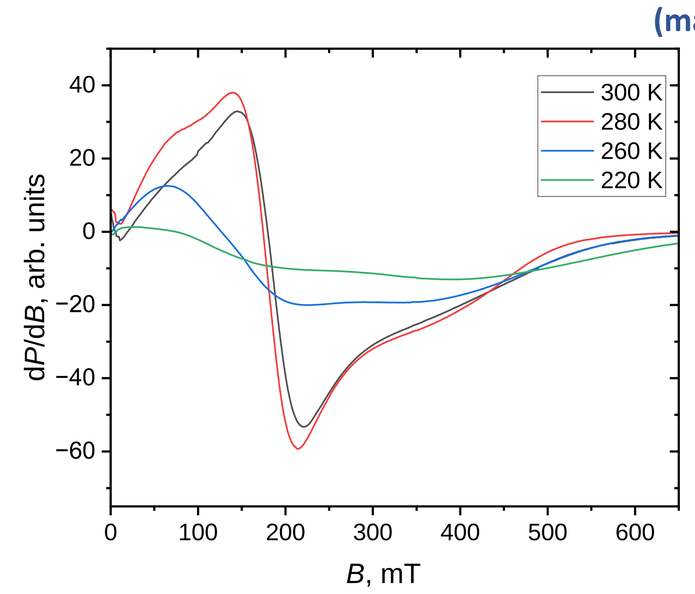
Dyson formula

$$\frac{dP}{dB} \propto \frac{d}{dB}\left(\frac{\Delta B + \alpha(B - B_R)}{(B - B_R) + \Delta B^2} + \frac{\Delta B + \alpha(B + B_R)}{(B + B_R) + \Delta B^2}\right)$$

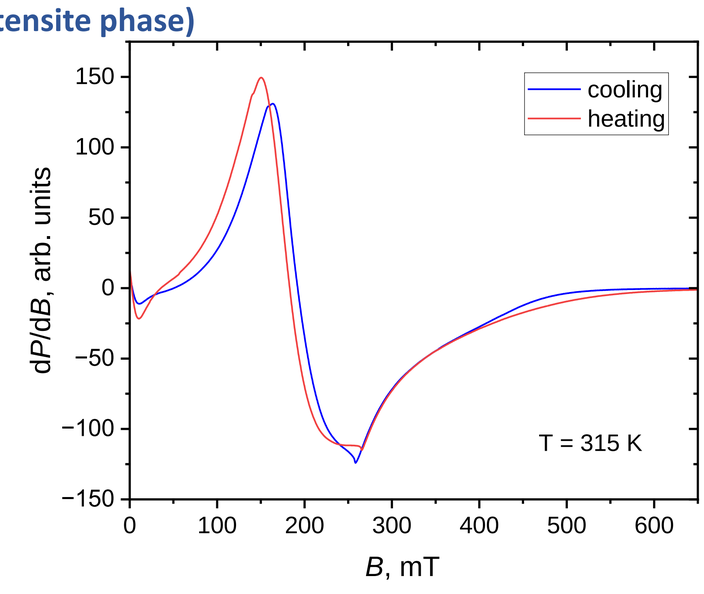


The EMR line recorded at 340 K, which is decomposed into three Dyson-type lines.

The sample EMR spectra for $Ni_{45}Mn_{25}Ga_{20}Co_5Cu_5$ were recorded in the low-temperature region (martensite phase)



The temperature dependence of EMR signal



The spectra recorded during the sample's cooling and heating show a clear difference. Such intensity hysteresis indicates the occurrence of a first-order phase transition (structural transformation)

Conclusion

1. The powder, which has an average particle size of about 15.8 µm, was produced by milling of as-melt-spun ribbons.
2. Each of the investigated lines is decomposed into three Dyson-type.
3. In the high-temperature region, the EMR signal is typical of NiMn-based Heusler alloys.
4. For samples in the parent phase (austenite), below the Curie temperature, an additional LFMA *(low-field microwave absorption)* signal is also observed.
5. A difference in the integrated intensity is observed between the spectra recorded during heating and cooling.

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Reference

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