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Thermal and spontaneous magnetic emission in Ni_2MnGa during austenite-martensite transition

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Abstract

Thermal and spontaneous magnetic emission signals in different types of single crystalline Ni_2MnGa ferromagnetic shape memory alloys have been investigated. The composition and the martensite structure of the samples are the same, but the twin structures and the twin boundary mobility of the martensite are different. We studied how can one get a set of thermal emission signals using a simple Differential Scanning Calorimeter, suitable for statistical analysis. Spontaneous magnetic emission signals (similar to magnetic Barkhausen noise, but different in origin) during A/M transitions in constant magnetic fields were also collected in the same type of samples.

I. Introduction

The formation and growth of the martensite nuclei in austenite/martensite transitions is a discontinuous process. The habit plate between the two phases can't move continuously, it stops due to thermo elastic effects and crystal defects. This behavior leads to different types of emission signals: thermal, magnetic and acoustic emission noise. If one can separate and measure these individual jumps, the statistical analysis is possible [1,2].

The measurements were carried out on 3 types of Ni_2MnGa. Each sample has the same composition close to 50at.% Ni, 28.5at.%Mn, 21.5at.%Ga and the same 5-layered modulated martensite structure (5M, but called also 10M modulated martensite structure). The first sample has no surface treatment, the twin fronts are forming more or less randomly. The second has stabilized fine twin microstructure (stabilized by shot peening). In the last one there are a few so called twin two fronts with lower internal stress, so the twin fronts can move faster. The A/M transformation temperatures are around 50 °C, the Curie point is close to 100 °C.

II. DSC measurements

The austenite/martensite structural transition is a diffusionless, first-order phase transition. Therefore we can investigate it using a Differential Scanning Calorimeter. In usual set up with usual heating rates (several K/min) the DSC peak are single peaks covered with average envelope curve. On the other hand the discontinuous character of the transformation suggests that this peak should be a result of overlapping of many smaller peaks, corresponding to the avalanche behavior of the transformation. Avalanches show criticality, where each avalanche leads to a spike in the calorimeter.

After an avalanche, the generated heat must reach the temperature sensor. This is a slow process compared to acoustic or magnetic emission signals, so we can measure individual peaks only at low heating or cooling rates. This low rate is around 0.1 - 0.01 K/min. (In [1] the heating/cooling rate was a few 10^{-3} K/h.) Below a given rate there are no additional peaks, there is an optimal rate, what depends on the properties of the system, and the mass of the sample. According to our preliminary measurements – using the observation that a bigger sample produces more individual peaks, but it needs lower heating/cooling rate – it was possible to optimize the conditions (heating/cooling rate, mass) to get individual DSC peaks.

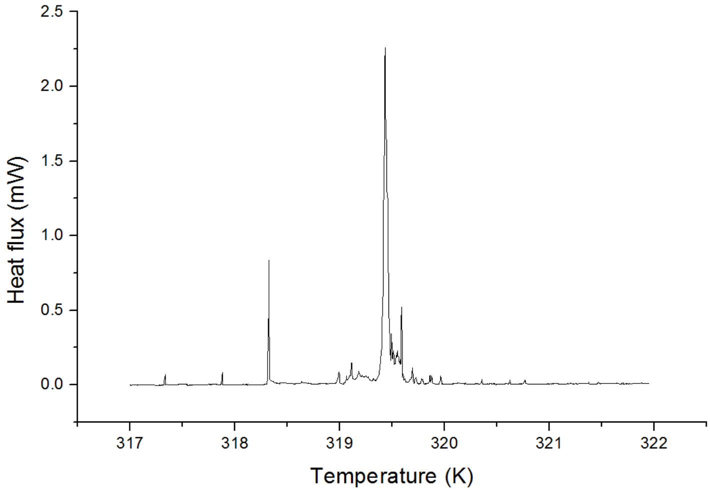

Figure 1: DSC curve, cooling of a Ni_2MnGa sample with 0.1 K/min

The quality of the sample surface is also important, because the A/M structural transition starts by nucleation on the surface. The surface defects and irregularities serve as nucleation points. Increasing the surface roughness, we can obtain more thermal emission signals in the calorimeter. Roughening of the surface is possible using an electric discharge machine. By cutting parallel lines into the sample, the surface can be increased.

As figure 1 shows, there are overlapping peaks, where the decay of a peak overlaps with the subsequent peaks. To investigate the decay of an individual peak, the response of the system to a square-shaped laser pulse has been measured. We found, that the decay is more or less exponential and it's time constant is about 7 seconds. Using this time constant the data processing program subtracts the contribution of the previous peaks from each peak.

Considering the findings above, we measured DSC curves like figure 1. With thermal cycling the statistics can be improved. The measurements were carried out for all of the 3 types of the samples, and the statistical analysis has been performed.

III. Magnetic emission

During martensitic transitions, large magnetic domain rearrangements take place due to the fact that the ferromagnetic Ni_2MnGa has different magnetic properties in the austenite and martensite phase. Therefore magnetic domain rearrangements and large magnetic emission can be observed without any external magnetic excitation.

This magnetic emission is suitable for statistical analysis and one can calculate the distribution of peak area, peak energy, duration, etc. These parameters also depend on the presence of an external, constant magnetic field [3].

To investigate the magnetic emission and its dependence on the external magnetic field, a unique measurement system has been compiled. The system based on an NI E series multifunctional DAQ board. The sample is heated by air flow between the yokes of an electromagnet. The temperature of the sample changes linearly between two given temperatures. The magnetic emission signals are detected by a detector coil and recorded by the DAQ board after amplification.

Figure 2 shows the result of a measurement on a test Ni_2MnGa sample (unknown exact composition and martensite structure) without magnetic field. The first half is the martensite → austenite transition, the second is the reverse transition.

Figure 3 shows the distribution of the peak energies. The distribution shows power-law behavior, with exponential cutoff:

$$P(E) = KE^{-\varepsilon} exp\left(\frac{-E}{E_C}\right)$$

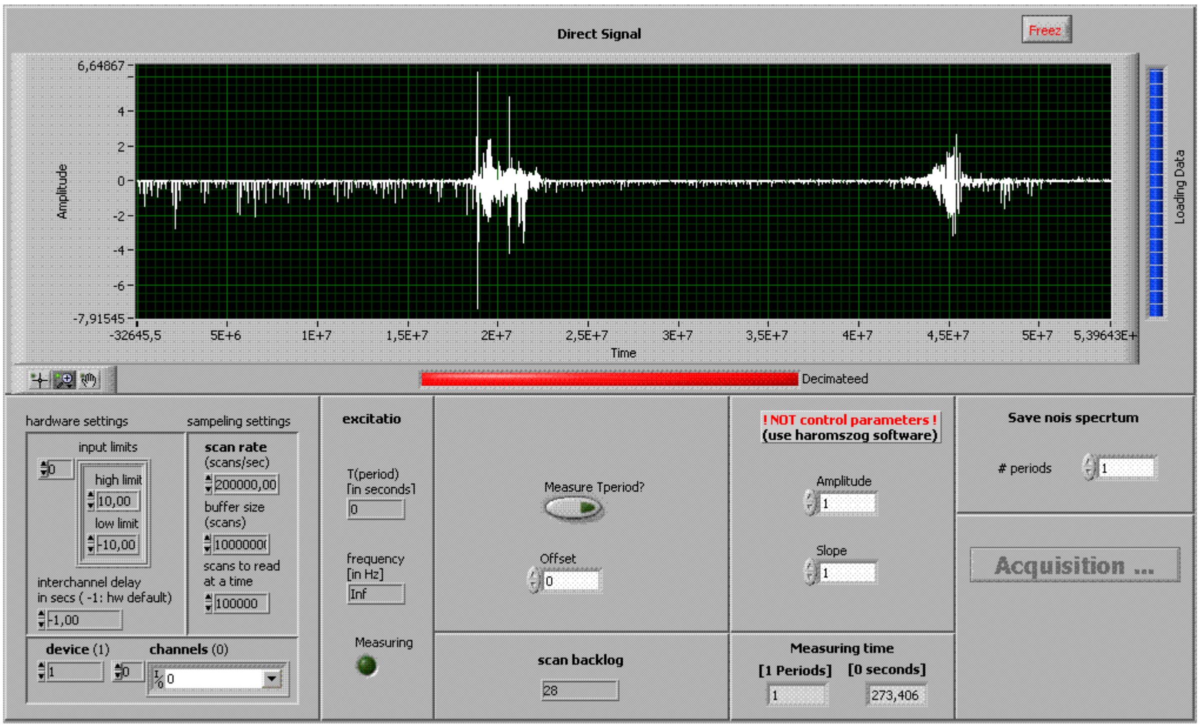

Figure 2: Test measurement on Ni2MnGa at 0 Tesla

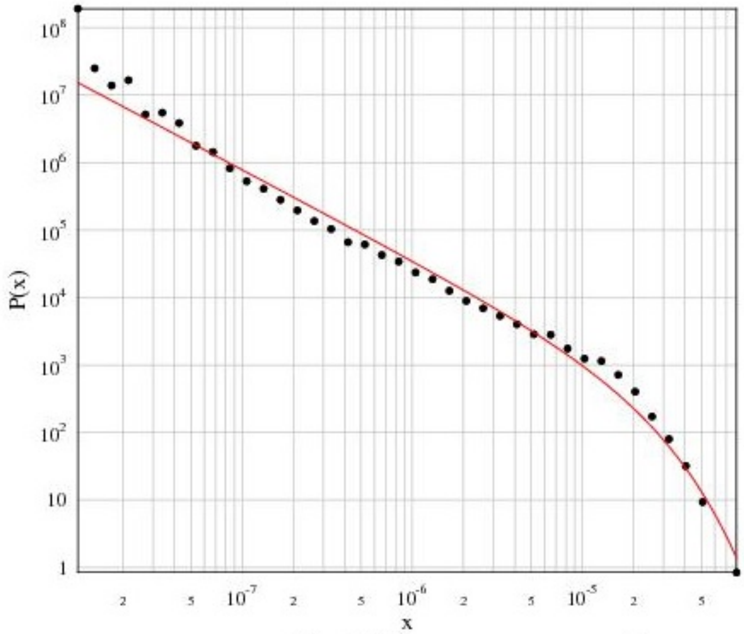

Figure 3: Energy distribution of magnetic emission signals in Ni_2MnGa

Conclusions

By optimization of the conditions for the DSC measurements (heating/cooling rates, mass) we were able - for the first time in Ni_2MnGa alloys - to obtain individual thermal peaks suitable for statistical noise analysis. in different types of Ni_2Mn Ga alloys. The calculation of the critical exponents is in progress and the results will be presented at the "International Conference on Martensitic Transitions" in Bilbao in July of 214.

The spontaneous magnetic emission signals during M/A transformation at different external magnetic field were detected and the statistical analysis of them is in progress.

The results of both types of measurements will be sent for publication in this year.

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