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Barkhausen noise in the re-entrant system $Ni_{1-x}Mn_x$: A study of the power spectra

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In this article, the power spectra of the Barkhausen noise of $Ni_{1-x}Mn_x$ is presented. The measurements were made in the ferromagnetic phase at several temperatures and manganese concentrations in order to map the effects of the degree of disorder and of the temperature on domain wall dynamics. Measurements in standard ferromagnetic materials were also made to compare the dynamics in both cases.

I. INTRODUCTION

Barkhausen noise corresponds to the randomlike voltage pulses appearing at the extremes of a coil wound around a ferromagnetic sample when this sample sweeps on its hysteresis curve. The effect is connected to the interaction between magnetic domain walls and metallurgical defects on the material. However, several aspects remains to be clarified such as the stochastic versus deterministic character,[1-3] connections to self-organized criticality,[4,5] or the effect of microscopic parameters on domain wall dynamics.[6-8]

Recently, Senoussi and collaborators[9-11] showed that metallic re-entrant materials exhibit domain structure, as observed in amorphous $Fe_{90}Zr_{10}$ and crystalline $Ni_{0.81}Mn_{0.19}$; in insulating $Eu_xSr_{1-x}S$ a similar result was obtained.[12] Particularly, the results of Senoussi and collaborators showed that even below the freezing temperature the domain structure remains unchanged. Very recently,[6] Barkhausen noise experiments were performed on $Ni_{1-x}Mn_x$ in order to clarify the questions about the existence of domain wall motion in these kinds of materials. In these experiments, measurements of the rms value of the Barkhausen noise were taken at several temperatures and manganese concentrations, as described in Ref. 6. The main results were: (i) The magnetic noise disappears at temperatures greater than the freezing temperatures for each manganese concentration. (ii) The noise level was strongly depressed as concentration increases. At 23 at.%Mn or greater no magnetic noise was detected. This result confirms a previous one[7] where noise was not observed for this Mn concentration neither for as cast and laminated samples or quenched disordered ones.

Therefore, the degree of disorder has the effect of depressing the Barkhausen activity. In Ref. 6 this was interpreted as a consequence of the competition between two well-defined lengths: the domain wall width δ_w and the correlation length for the transverse components of the magnetic moments ξ_T. However, another question has to be inspected: how does the degree of disorder affect the dynamics of domain walls? In order to obtain some insight about this point, we performed several measurements of the Barkhausen noise power spectra for the same system: $Ni_{1-x}Mn_x$. Since this is in re-entrant materials, we need some kind of standard. We take then samples of Ni and FeSi classical ferromagnetic materials at room temperature.

II. EXPERIMENT

The samples and experimental procedure were the same as Ref. 6. From the manufactured samples with concentrations $x=18$, 19, 20, 21, 22, 23, and 25 at.%Mn, only the samples with x from 0.18 to 0.22 showed detectable magnetic noise[6] and only the samples with x from 0.18 to 0.20 were able to have their power spectra analyzed because of the signal to noise ratio. This is a consequence of the deviation from usual ferromagnetic ordering as the concentration increases.

The difference between the data reduction of that of Ref. 6 and that used here is the use of discrete fast Fourier transform (FFT) for the determination of the power spectra. Some care was taken on the deconvolution of the as sampled signal from the response of the preamplifier. The last was numerically performed using the amplifier response function (obtained by circuit analysis and experimentally confirmed) $r(f)$. The deconvoluted power spectra is given by

$$P(f_i)=\frac{|v(f_i)|^2}{|r(f_i)|^2}. \qquad (1)$$

It must be emphasized that the parameters of the experiment were at constant values along all measurements, in order to ensure reproductibility: $f_{\text{sampling}}=75$ kHz; $f_{\text{exc}}=0.4$ Hz; $H_{\max}=\pm 20$ Oe; $H_{\text{trigger}}=0.00\pm 0.05$ Oe.)

From the experimentally obtained data the power spectra were then calculated by using standard FFT routines.

In order to compare the power spectra obtained for the re-entrant samples to the classical ones, we tried a fit of the usually accepted function for power spectra description in ferromagnetic materials[2]

$$P(\omega)=C_1[\omega^2/(\omega^2+\tau_e^{-2})(\omega^2+\tau_\xi^{-2})], \qquad (2)$$

where C_1 depends linearly on the flux rate (Ref. 2), τ_e is a

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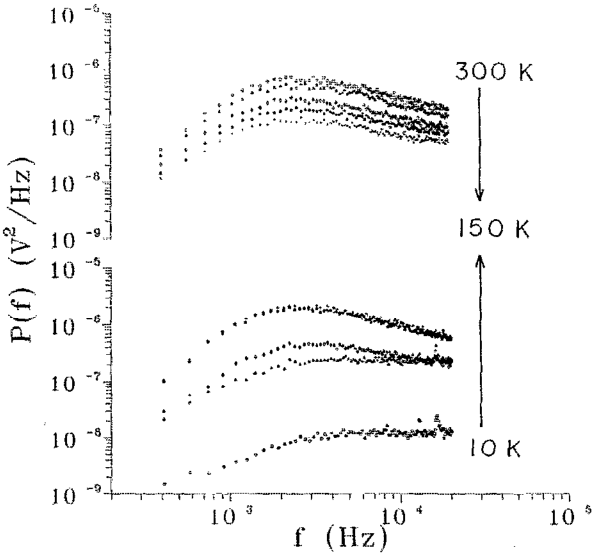

FIG. 1. Power spectra for the $x=0.18$ sample at several temperatures ($T_{fg}=23.5$ K): (a) (□)—10 K, (△)—20 K, (◇)—50 K, (*)—100 K, (+)—150 K; (b) (□)—150 K, (△)—200 K, (◇)—250 K, (*)—275 K, (×)—300 K.

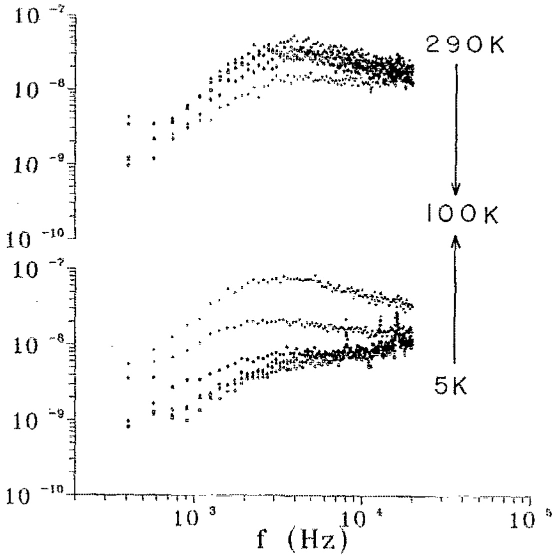

FIG. 3. Power spectra for the $x=0.20$ sample at several temperatures ($T_{fg}=35.2$ K): (a) (□)—5 K, (△)—20 K, (◇)—35 K, (*)—50 K, (+)—60 K, (×)—80 K; (b) (□)—100 K, (△)—150 K, (◇)—200 K, (*)—250 K, (+)—290 K.

time constant characteristic to eddy current attenuation, and τ_ξ is a time constant characteristic of the coupling between walls, etc.[2]

In this work the flux rate was maintained constant by the sample demagnetization factors. Thus, the parameter C_1 could be assumed constant.

III. RESULTS AND DISCUSSION

Figures 1–3 show the obtained power spectra (on log–log scales) for $Ni_{1-x}Mn_x$ with concentrations $x=0.18$, 0.19, and 0.20. All spectra seem to be similar in principle. Figures 4 and 5 show the power spectra obtained for Ni and $FeSi_{3\%}$ at the same experimental conditions. The structure of the spectra are similar to the $Ni_{1-x}Mn_x$ ones. The attempt to fit this spectra with Eq. (2) failed as can be seen in Fig. 5. The most striking feature of this fit was the difference in the inclination of the straight line (in the log–log scale) for frequencies above the maximum of the spectrum. A close inspection of Refs. 2, and 13–15 show that all fits are equally poor. The assumption that the power spectra behaves in this range as f^{-2} is no longer valid. This fact leads to the necessity of improvements in the description of the dynamics of domain walls in ferromagnetic materials. In fact, preliminary results obtained by us[8] using an alternative stochastic description[1] for these dynamics, confirm our experimentally obtained data. In view of the problems with the fittings, we use another procedure to compare the results obtained for $Ni_{1-x}Mn_x$ to the classical ferromagnets: the linear behavior of all the

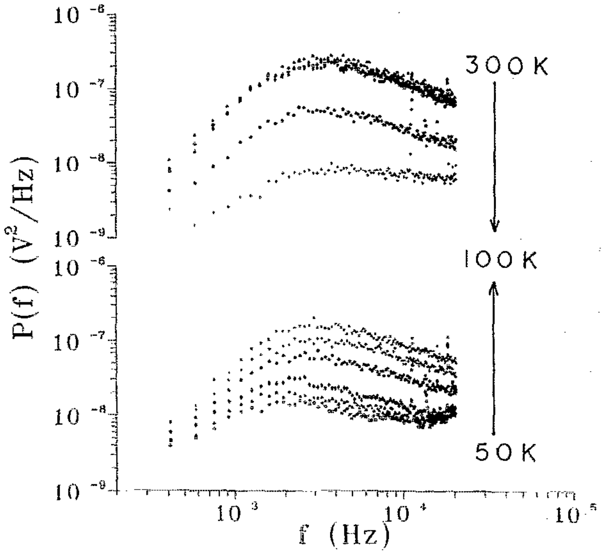

FIG. 2. Power spectra for the $x=0.19$ sample at several temperatures ($T_{fg}=27.6$ K): (a) (□)—50 K, (△)—52 K, (◇)—55 K, (*)—65 K, (+)—75 K, (×)—85 K; (b) (□)—100 K; (△)—150 K, (◇)—200 K, (*)—275 K, (+)—300 K.

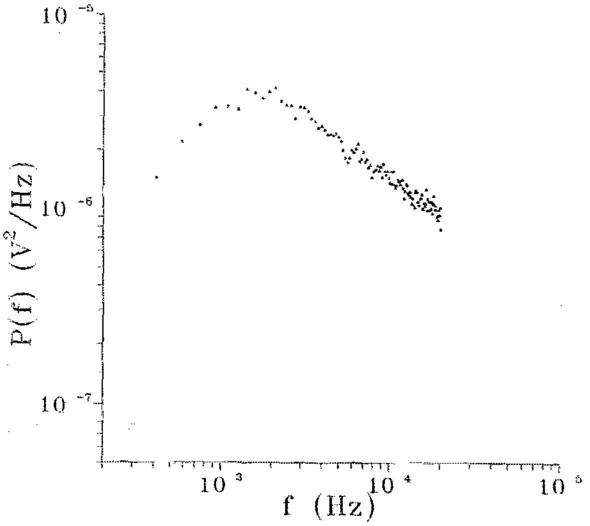

FIG. 4. Power spectra for the Ni(5 N) sample at room temperature.

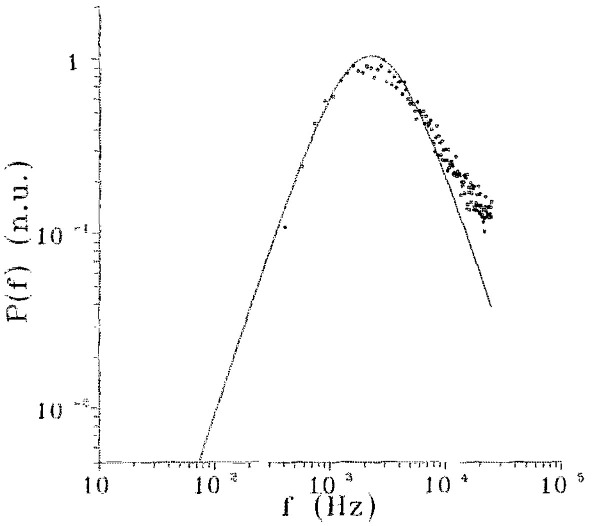

FIG. 5. Power spectra for the $FeSi_{3\%}$ sample at room temperature. The continuous line corresponds to the fit with the double Lorentzian function of Eq. (2). The data are normalized.

power spectra on a log–log scale, for frequencies higher than the frequency of maximum position enable us to fit the experimental data (in this range) using a simple power law f^{α}. A close inspection reveals slight changes in the exponent α with concentration enabling its use for characterization of the domain wall dynamics.

The result for all exponents are summarized in Fig. 6 where the values of α are plotted against the reduced temperature $t=(T-T_{fg})/T_{fg}$ for each concentration x. In this figure the horizontal lines are the values of the exponent α in Ni and $FeSi_{3\%}$. It is clear that the $\alpha(t)$ curves have "plateaus" defined by their maximum values. As manganese concentration x increases, the α value of the corresponding "plateaus" decreases from the horizontal lines values. This can be interpreted as a signature of the deviation from classical ferromagnetism. An interesting point which remains to be investigated is the effect of the excitation frequency on the power spectra (this work is presently being done). The trend observed in the exponent α corroborates the trend observed in the V_{rms} vs T (Ref. 6) curves.

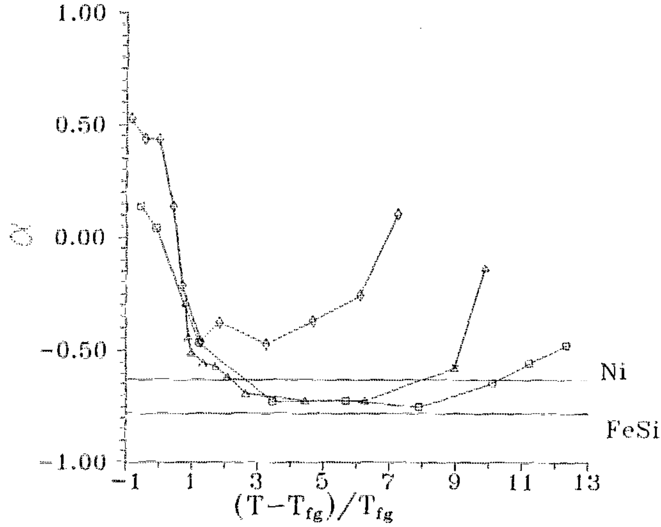

FIG. 6. Exponents α as a function of the reduced temperature $t=(T-T_{fg})/T_{fg}$. The values for Ni and $FeSi_{3\%}$ are indicated by horizontal lines. (□)—$x=0.18$; (△)—$x=0.19$, and (◇)—$x=0.20$

IV. CONCLUSIONS

In this work, an experimental detection of the Barkhausen noise in the $Ni_{1-x}Mn_x$ was performed and its power spectra obtained. The results corroborates previous ones[6,7] of V_{rms} vs T (Barkhausen activity) in the sense that an increase in the manganese concentration has the effect of altering the magnetic order from a classical ferromagnetism to a probable mixed state, characterized by longitudinal ferromagnetic ordering and spin glass like transverse freezing. This mixed state produces a strong damping on Barkhausen activity as can be seen from the curves in Ref. 6 and from the trend on the $P(f_i)$ values for the different temperatures. In our opinion, the changes in α values are a consequence of the modifications in the domain wall dynamics, naturally associated to the noise level but not a consequence of the noise level decrease.

On the other hand, the alterations of the dynamics are shown to occur at higher temperatures than detected by magnetization measurements and this is connected with the fact that the freezing process of the transversal component of the magnetic moments is already in course at such temperatures. It must be emphasized that the kind of measurement used in this work brought about information about the magnetic processes in a mesoscopic scale in the samples (neither volumetric or macro as in the case of standard magnetization measurements nor micro as in the case of NMR, Mössbauer or perturbed angular correlation measurements).

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