Nonresonant microwave absorption in nickel near the Curie point

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Anomalies have been detected in the nonresonant absorption spectrum of nickel near T_C. These anomalies have been studied, and the critical index for the width of the nonresonant-absorption line has been determined.

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Ferromagnetic resonances near critical temperatures have recently been the object of active research. Several interesting results have been obtained[1–3] on the ferromagnetic resonance in nickel near T_C. The microwave ferromagnetic resonance near T_C, however, occurs at rather strong magnetic fields, such that the sample is in a single-domain state. This circumstance strongly affects the dynamics of the magnet. The dynamic effects can be studied in weak magnetic fields by studying the nonresonant absorption, which is due entirely to the presence of a domain structure in the sample.

A simple model will suffice to explain the ocurrence of a nonresonant microwave absorption. We introduce the concept of the number of "effective" spins. Those spins which are oriented perpendicular to the alternating magnetic field **h** are "effective,"

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while those which are parallel to **h** are "ineffective." If the constant magnetic field is perpendicular to the alternating field, **H⊥h**, then the number of effective spins will increase with increasing H as the sample is magnetized, and there will also be an increase in the microwave absorption. In other words, the absorption will be at a minimum in a zero magnetic field (the nonresonant-absorption line is inverted with respect to the ferromagnetic-resonance line). In the other geometry, **h**‖**H**, the absorption will be at a maximum in a zero magnetic field. The nonresonant absorption was first observed in Ref. 4; it has been studied in detail in thin magnetic films.[5,6] All the measurements in Refs. 4–6 were carried out at room temperature; in the present experiments we studied the nonresonant absorption near T_C.

The measurements were carried out at a frequency of 9.16 GHz with a direct-amplification ESR spectrometer, fitted with an automatic-frequency-control system through the working resonance. This resonator was a rectangular waveguide in which the H_{102} mode was excited. The external field **H** was directed parallel to the surface of the sample. The sample was mounted on the tuning plug of the resonator without cement, in order to avoid deformation. The heating was carried out in pure helium to prevent oxidation of the sample and to reduce the temperature gradient. The temperature was measurd with a Pt–Pt/10% Rh thermocouple calibrated at the solidification point of several pure metals (In, Cd, and Zn). The measuring thermocouple was introduced through the resonator tuning piston in such a manner that it touched the lower surface of the sample. The temperature was regulated within $\pm 0.01°$. The absolute error of the temperature measurements was $\pm 0.5°$. The single-crystal nickel samples were ground with diamond pastes and then electropolished. The samples had a resistance ratio R (300 K)/R (4.2 K)$\cong$300. While recording the nonresonant absorption, we also recorded the ferromagnetic-resonance line. The ferromagnetic-resonance results agreed with those of Ref. 3.

Figure 1 shows the experimental recordings of the derivative of the absorption, dP/dH, during the magnetization reversal of a sample with a diameter $D = 8$ mm and a thickness $d = 0.2$ mm; the normal to the surface of this sample was in the orientation **n**‖⟨110⟩ with **h⊥H**‖⟨$\bar{1}$10⟩. The results shown here correspond to various temperatures. The horizontal lines show the zero value of the derivative. The nonresonant-absorption lines have a hysteresis in the magnetic field, but this is not shown in Fig. 1.

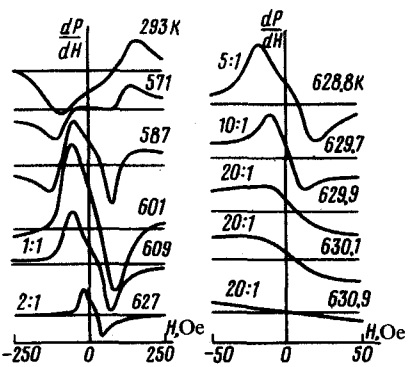

FIG. 1.

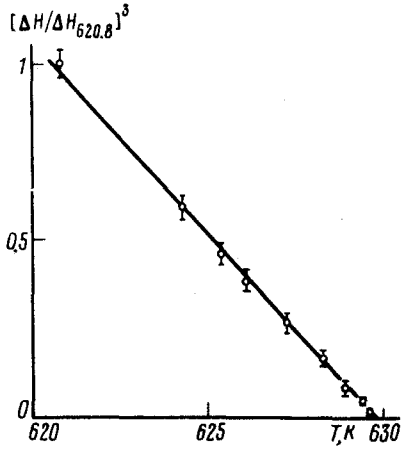

FIG. 2.

It can be seen from this figure that the model described above breaks down at $T \cong 570$ K. The nonresonant-absorption line is highly distorted at $T = 568$ K, and at $T = 595$ K it is completely inverted. At $T = 600$ K the line intensity reaches its maximum (remaining lower than at room temperature). A further increase in the temperature leads to decreases in both the intensity and the width of the line. At $T = T_k \cong 629.8$ K, the line extrema become difficult to resolve, and they essentially vanish when the temperature is increased another 0.1°. At $T = 633$ K the nonresonant-absorption line becomes unresolvable. The temperature measured by us, $T_k = 629.8 \pm 0.5$ K, agrees well with the value of T_C given in the literature for nickel, $\cong 630$ K. Figure 2 shows the behavior of the relative width ΔH of the nonresonant-absorption line. We see that the "one-third law" holds well for ΔH. For a sample with $D = 5$ mm and $d = 0.6$ mm, ΔH is much larger than for the first sample, i.e., the dipole–dipole interaction strongly affects the value of ΔH. The one-third law still holds for the thicker sample, however. Thus we find $\Delta H \sim (T_c - T)^{\beta}$. According to our measurements, the value of β is 0.35 ± 0.02, in good agreement with the critical index for the saturation magnetization,[7,8] M_0. Thus we may conclude that $\Delta H \sim M_0$. This result would be expected, since it is completely natural to suggest that ΔH for the nonresonant absorption is determined by the magnetic anisotropy field and by the demagnetizing field. In the geometry $\mathbf{h} \| \mathbf{H}$, however, the behavior of the nonresonant absorption is quite different from that described above. In this case the nonresonant-absorption line also inverts with increasing temperature, but this inversion begins at a temperature 50° lower than in the geometry $\mathbf{h} \perp \mathbf{H}$. After the line inversion, the extrema of dP/dH remain visible until the line disappears completely. At $T \cong T_C$, the line becomes unresolvable. The critical index for ΔH of the nonresonant absorption in the geometry $\mathbf{h} \| \mathbf{H}$ is different: $\beta = 0.44$.

We have observed the inversion of the nonresonant-absorption line in an amorphous alloy[9] and in an insulator, yttrium iron garnet (these results have not been published). It may thus be concluded that this is a general effect for all ferromagnets. A study of this effect can apparently yield the range of applicability of the Landau-

Lifshitz equation (the model described above is based on that equation). At present, however, no theory has been derived to describe these effects.

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