

Wall Contraction in Bloch Wall Films\*  
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Abstract - The phenomena of wall contraction characterized by a peak in the velocity-field relationship and a region of negative differential mobility is observed. Uniaxial magnetic thin films of various compositions and magnetic properties are studied in careful interrupted pulse experiments. The observed results agree quite well with the theory for bulk samples.

Introduction

Previous experimental investigations of planar 180° wall motion in thin magnetic films have been limited to drives less than 5 oe [1-4]. The motion for fields of such magnitude is apparently understood, and an appropriate coercive force model together with the classical Galt [5] description which assumes a structure invariant wall agrees with previous wall velocity data.

For drives of greater magnitude, the static wall structure cannot be preserved and it seems appropriate to review a previously developed wall motion theory. In Walker's analytic solution of a planar Bloch wall in a bulk material [6], the steady-state wall velocity is of the form

$$v = \gamma \left( \frac{2A}{\mu_0} \right)^{\frac{1}{2}} \cdot \frac{h_z}{\alpha} \left[ h_k + \frac{1}{2} \left( 1 - \left( 1 - \left( \frac{2h_z}{\alpha} \right)^2 \right)^{\frac{1}{2}} \right) \right] \quad (1)$$

with  $0 \leq \left| \frac{2h_z}{\alpha} \right| \leq 1$ ,

where  $h_z = \mu_0 H_z / M_s$  is the normalized drive field,  $h_k = \mu_0 H_k / M$  is the normalized anisotropy field ( $H_k = 2K / M_s$ ), and  $M_s$  is the saturation magnetization. The exchange and anisotropy constants are A and K, the phenomenological wall damping parameter is  $\alpha$ , and  $\gamma$  the gyromagnetic ratio.

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The velocity-field relationship of eqn. 1 is shown in Fig. 1 for various anisotropy conditions. For low  $h_k$  materials a prominent peak in the velocity together with a region of negative differential mobility ( $\frac{\partial v}{\partial H_z} < 0$ ) is predicted. The coordinates of the velocity peak are given as:

$$v_{pk} = \gamma \left( \frac{2A}{\mu_0} \right)^{\frac{1}{2}} \left[ (1 + h_k)^{\frac{1}{2}} - h_k^{\frac{1}{2}} \right], \quad (2a)$$

$$h_z|_{v_{pk}} = \alpha h_k^{\frac{1}{4}} (1 + h_k)^{\frac{1}{4}} \left[ (1 + h_k)^{\frac{1}{2}} - h_k^{\frac{1}{2}} \right]. \quad (2b)$$

The negative differential mobility region occurs for fields  $h_z|_{v_{pk}} \leq h_z \leq \frac{1}{2} \alpha$ .

For permalloy,  $M_s = 1 \text{ wb/m}^2$ ,  $\alpha = 0.01$ ,  $A = 10^{-11} \text{ J/M}$  and  $K = 200 \text{ J/M}^3$ .

Using these values in a sample calculation,

$$h_k = .005 \quad (H_k = 5 \text{ oe}), \quad v_{pk} = 8.2 \times 10^4 \text{ cm/sec}, \quad 2h_z/\alpha|_{v_{pk}} = .496 \quad (H_z|_{v_{pk}} = 24.8 \text{ oe})$$

and  $2h_z/\alpha = 1$  corresponds to  $H_z = 50 \text{ oe}$ .

The wall in a real material may not have a stable planar configuration in the negative differential mobility region as discussed in the literature [7,8]. Even so, if short duration, interrupted pulses are used to drive an initially planar wall, then the rate of growth of the unstable motion may be suppressed if the amount of flexure during a single pulse is comparable to the randomizing influence of the sample inhomogeneities acting on the wall after the pulse. The transient behavior of wall contraction is considered in ref [9].

#### Experimental Technique

The velocity-field data of this report is obtained by interrupted pulse techniques. Pulses of short duration are used to reduce local nucleation and diffuse boundary propagation [10] at drives sometimes exceeding  $H_k$ .

The velocity data is invariant to changes in pulse width although short pulses (35 ns width, 10 ns rise and fall times) tend to enhance the repeatability of the data, particularly at high drives. If the pulse widths are too large ( $\sim 100$  ns), nucleation and tip motion obscure meaningful data.

To reduce the effects of sample inhomogeneities, the wall is made to travel in a given direction, over a specified distance ( $\sim 140$   $\mu\text{m}$ ), and the number of applied pulses counted. After the displacement is completed, the wall is reset to its initial position using low frequency creep [11] with small values of hard axis excitation ( $< 0.3H_k$ ). Data is taken in this way several times for each field setting, and the results are averaged.

Only planar walls parallel to the easy axis and near the center of the film are studied and care is exercised to avoid domain tip motion and other nucleation processes that interfere with the much slower, planar wall motion. Further, the ambient stray field at the sample location is canceled or reduced to less than one millioersted.

The Kerr effect is used to observe the movement of the domain boundaries which extend across the entire sample (1 cm dia.).

The drive fields are produced in a shorted strip line with optical access windows. This line is excited by a thyratron, charged-line, pulse generator with the pulse output taken at the cathode. The entire system is calibrated according to a technique described by Middlehoek [3] with a value of 0.704 oe per KV of charging potential. The strip line is in a parallel plate configuration with a 2.54 cm plate separation and a 1:6 spacing to width ratio; the access windows are approximately 9 cm apart. The strip line is usable for subnanosecond risetimes; however, to achieve a matched load for single pulse operation, a resistor (50 ohms) is placed in series with the shorted line. The combination is useful for risetimes down to 2 nsec.

The thin film samples are fabricated by conventional vacuum techniques and are condensed on heated glass substrates. The properties of the nonmagnetostrictive CoNiFe films used in the experiment are extensively reported in the literature [12]. The samples contain from 0% to 40% Cobalt with measured (Talysurf) thicknesses from 1100Å to 2000Å. These films are characterized by low dispersion ( $\alpha_{90} < 2^\circ$ ) and a well defined uniaxial anisotropy.

### Experimental Results

Several observed velocity-field curves are shown in Fig. 2 and Fig. 3. The sample properties are indicated in each figure. As the wall coercivity increases (see Fig. 2), the value of the field corresponding to  $V_{pk}$  shifts only slightly and for sufficiently high values of coercive force the peak disappears. A conservative coercive force model [1,2] is consistent with such results. For those samples with a coercivity below the position of the velocity peak, a region of negative differential mobility is observed.

The observed dependence of  $H_z/H_k|_{V_{pk}}$  ( $= h_z/h_k|_{V_{pk}}$ ) on  $H_k$  is shown in Fig. 4 and is in excellent qualitative agreement with eqn. 3 which is derived from eqn. 2 with  $h_k \ll 1$ .

$$\frac{h_z}{h_k} \Big|_{V_{pk}} = \alpha h_k^{-3/4} = \alpha \left( \frac{\mu_0 H_k}{M_s} \right)^{-3/4} \quad (3)$$

The slight shift of the velocity peak to higher values of  $h_z/h_k$  that occurs with a conservative coercive force model is compensated by the fact that in high anisotropy films the approximation of  $h_k \ll 1$  is somewhat violated.

In low coercive force samples,  $V_{pk} \sim 10^4$  cm/sec and is well below the value expected in bulk materials. In high coercive force samples,  $V_{pk}$  is reduced by the proximity of the motion threshold.

Discussion

According to Galt's description of wall motion, the spins in the wall precess about a demagnetizing field  $H_d$  such that

$$V = \frac{\gamma H_d}{\frac{\partial \theta}{\partial y}} \quad (4)$$

In Walker's analysis,  $H_d$  and  $\frac{\partial \theta}{\partial y}$  are both functions of the applied field.

Because of the flux closure characteristic of static thin film walls [13-15], it might be argued that moving walls in thin films are also characterized by extensive flux closure. Hence, a given applied field produces a smaller  $H_d$  in a thin film wall than in a bulk wall.

Due to the similarity between the theory derived for bulk materials and the observed thin film velocity-field data, it seems appropriate to introduce an empirical scaling factor,  $\beta$ , which is a measure of the difficulty in producing the demagnetizing field required for a given wall velocity. Eqns. 1-3 are consistently modified if  $M_s/\mu_0$  is replaced by  $\beta M_s/\mu_0$ . For example, the normalized anisotropy parameter becomes  $h_k = \mu_0 H_k / \beta M_s$ . The bulk solution corresponds to  $\beta = 1$ .

The velocity peak is a convenient point to evaluate  $\beta$ ; however, before  $\beta$  can be determined the wall width and wall damping parameter must be estimated.

For a 1500Å permalloy film, Suzuki [16] observed a wall width,  $a = 1500\text{Å}$  using a 650 KV electron microscope. His wall width value is in excellent agreement with Hubert's pole-free wall calculations [15].

The wall damping parameter can be estimated using the approximate expression for wall mobility discussed elsewhere [2]. With  $G = 2 \times 10^3$  cm/oe-sec,

$$\alpha = \gamma a/G\pi = 0.042. \quad (5)$$

From the results in Fig. 4 and from eqn. (3) together with the estimated wall damping parameter,  $\beta = .0385$ . The corresponding normalized anisotropy

field for permalloy is  $h_k = 0.013$ .

The peak velocity is determined as

$$v_{pk} = \gamma \left( \frac{2A}{\mu_0} \right)^{\frac{1}{2}} \beta^{\frac{1}{2}} \left[ (1 + h_k)^{\frac{1}{2}} - h_k^{\frac{1}{2}} \right] \quad (6)$$
$$= 1.54 \times 10^4 \text{ cm/sec,}$$

and this value agrees with observed peak velocities in low coercive force samples. Also, compare the shape of experimentally observed velocity curves with Fig. 1 for  $h_k \approx .005$ .

The significance of the remarkable correspondence between the theory for bulk and the observed data in thin film samples is that the thin film walls behave very much like bulk walls. The extensive flux closure predicted by two-dimensional wall calculations [13-15] may be responsible for this similarity. These results should be compared to Schlömann's calculations [17] of the velocity characteristics of one-dimensional thin film walls.

#### Conclusions

A peak in the observed velocity-field relationship of Bloch walls in thin films is well described by the theory derived for bulk materials together with a conservative coercive force model. A region of negative differential mobility is also observed although the motion in this region may not have a true steady-state velocity.

The agreement of the bulk wall theory with the data shows that a moving thin film Bloch wall is very similar to its bulk material counterpart.

### Figure Captions

Fig. 1. The normalized velocity versus normalized drive field predicted for bulk samples with  $h_k$  as a parameter (From [9]).

Fig. 2. Observed velocity-field relationship of several low coercive force samples. The anisotropy field and film thickness are indicated in the legend.

Fig. 3. Observed velocity-field relationship of several high coercive force samples. The anisotropy field and film thickness are indicated in the legend.

Fig. 4. Observed dependence of  $H_z/H_k | v_{pk}$  on  $H_k$ .  
The sample composition is indicated in the legend.

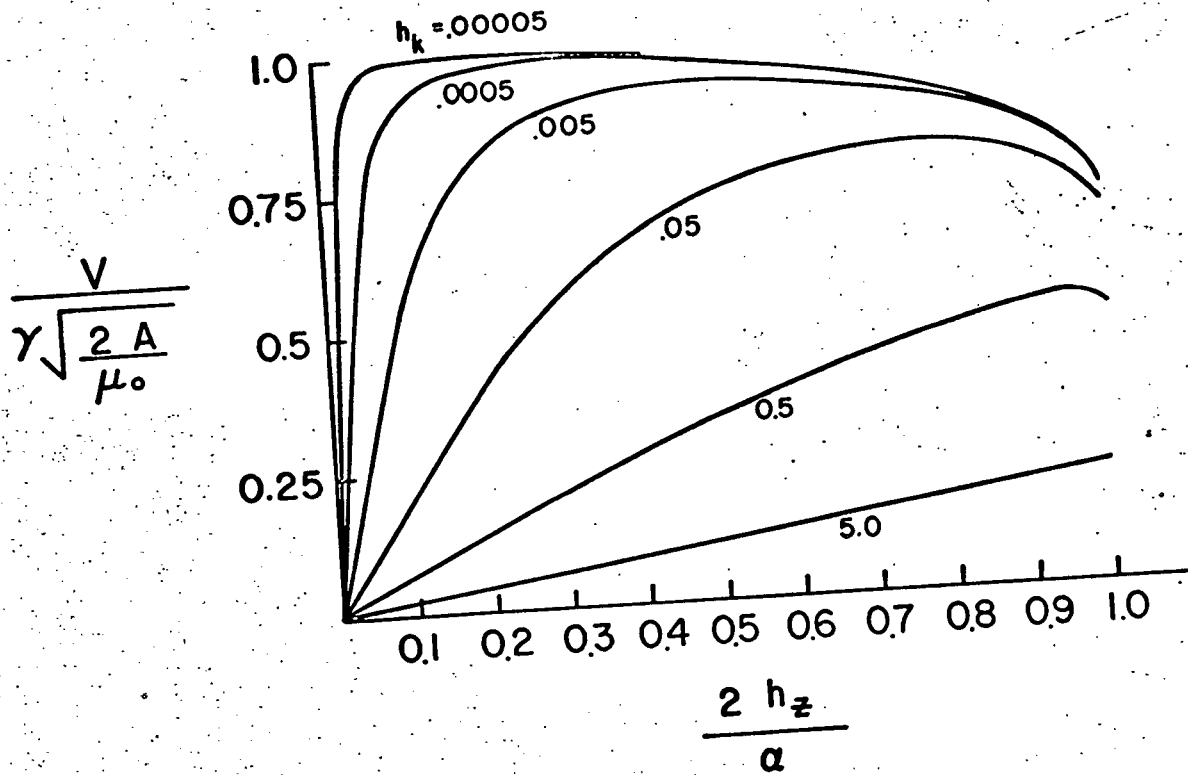
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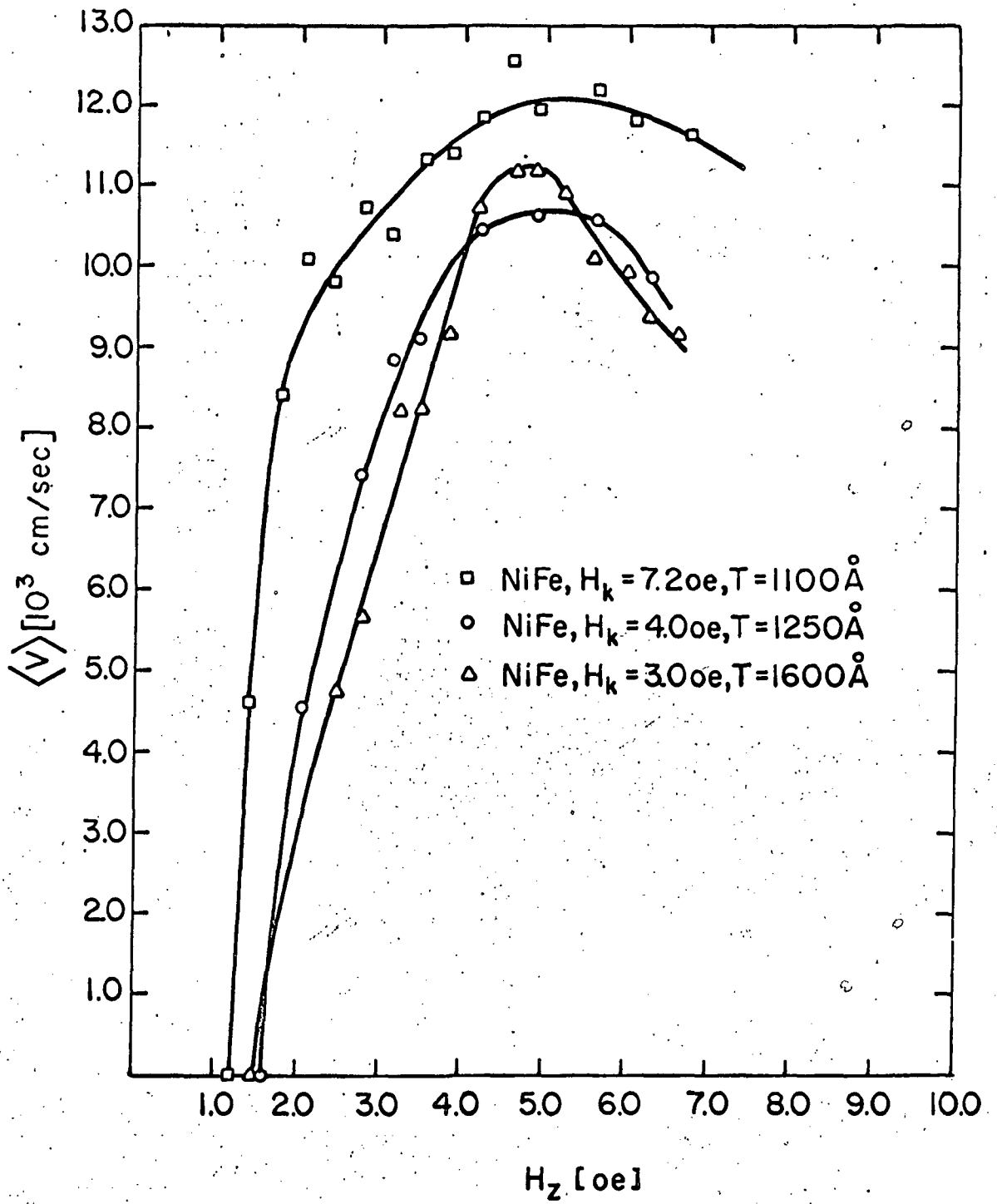


FIG 2  
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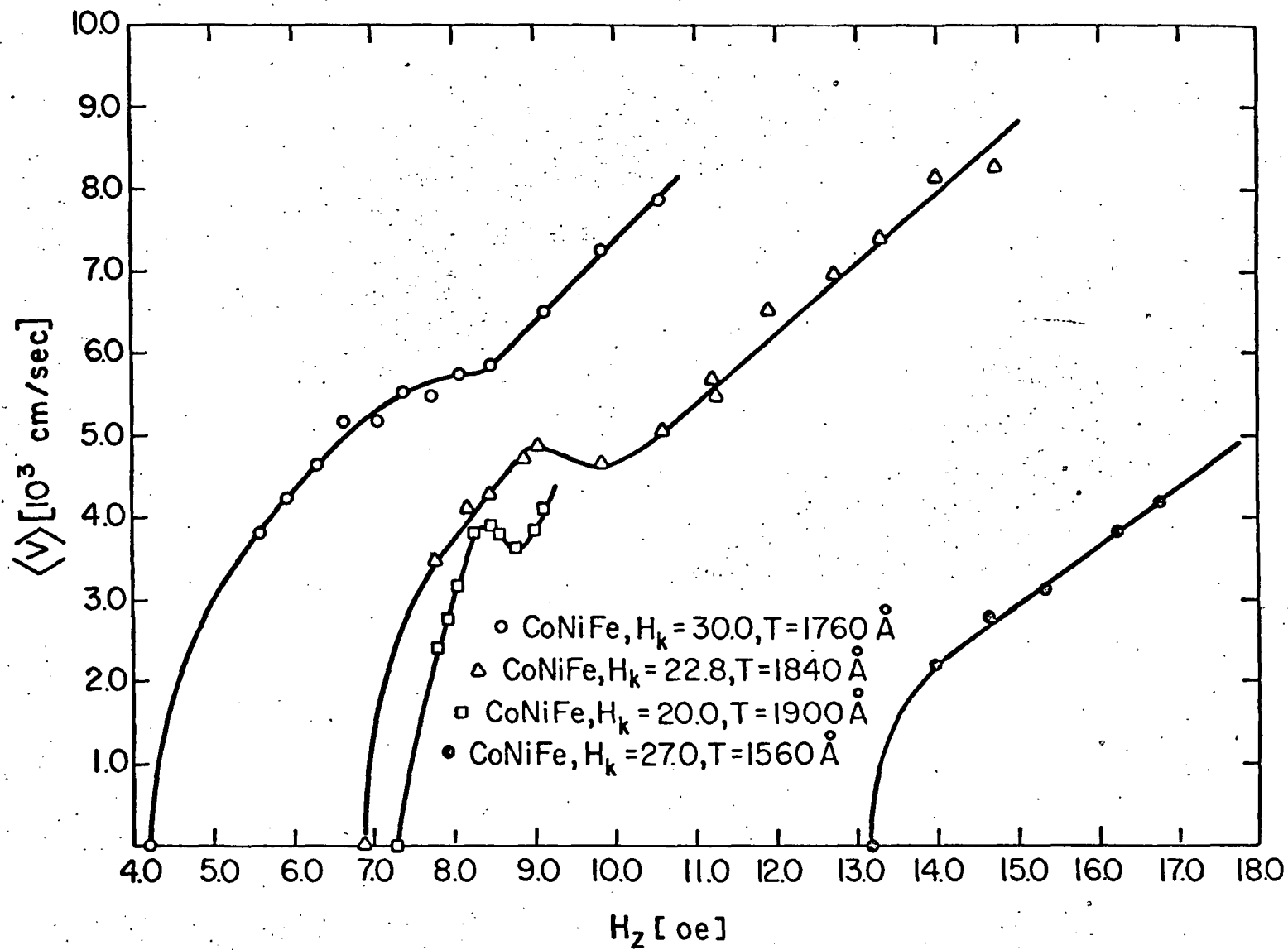


FIG 3.  
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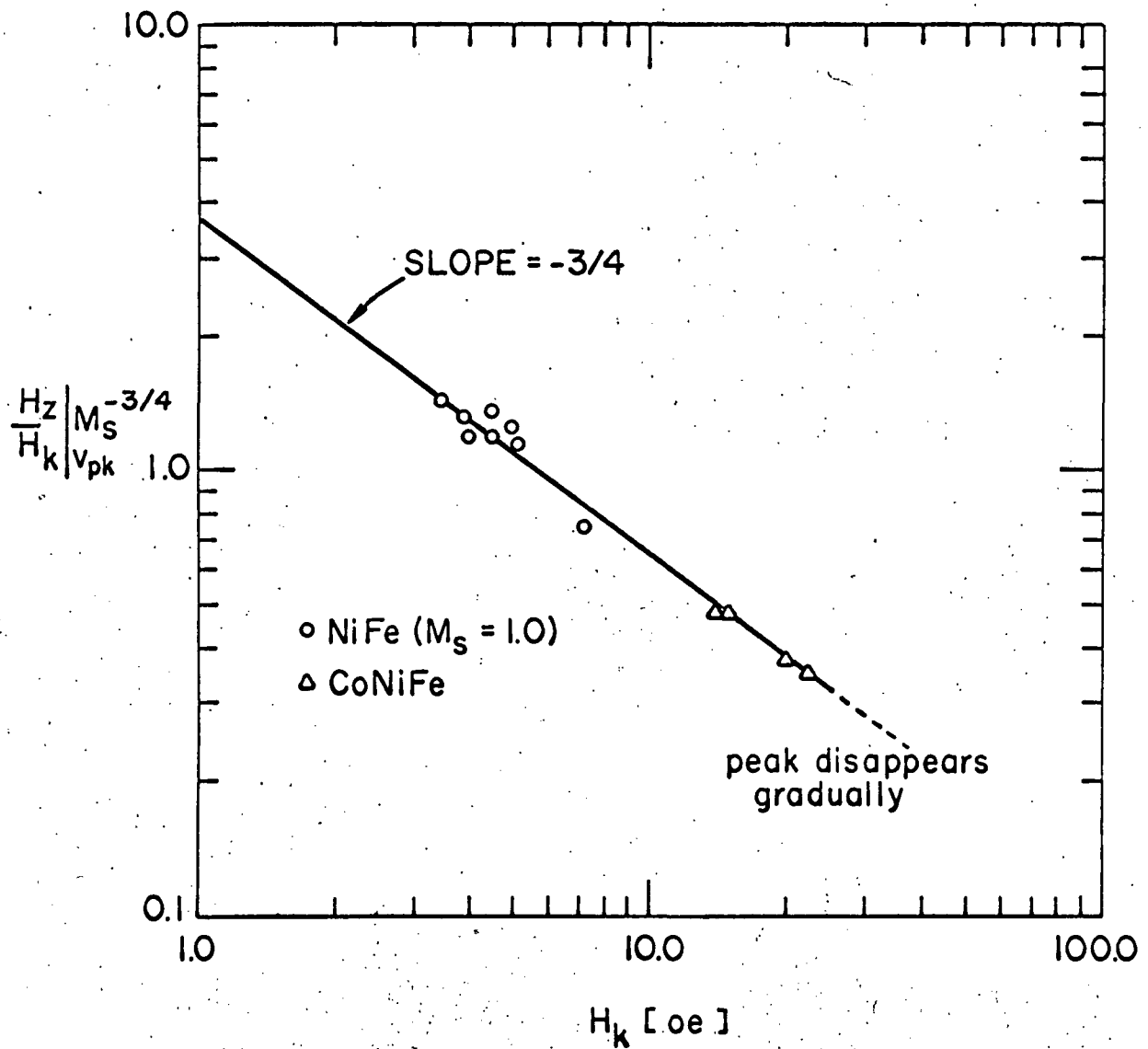


FIG 4  
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