Nonlinear excitations in quasi-two-dimensional system of spins localized in a Bloch wall

V. S. Gornakov, L. M. Dedukh, and V. I. Nikitenko
Institute of Solid State Physics, Academy of Sciences of the USSR

(Submitted 13 December 1983)
Pis'ma Zh. Eksp. Teor. Fiz. **39**, No. 5, 199–202 (10 March 1984)

Solitary nonlinear soliton-type waves have been observed in a system of spins localized in a monopolar 180-degree Bloch wall of yttrium ferrogarnet. These waves arise under the influence of a sinusoidal magnetic field acting along the magnetization vectors in neighboring domains.

As is well known, magnetization and magnetization reversal of ferromagnets is determined particularly by nonlinear processes of rotation of magnetization by large angles. A rigorous theoretical analysis of these phenomena, yet to be performed, represents an important fundamental problem.

In recent years, however, considerable success has been achieved in developing methods for solving exactly the nonlinear Landau–Lifshitz equations of motion of magnetization in an idealized situation: for a ferromagnet in the absence of dissipation.[1,2] Analysis of these results shows that the nonlinear dynamics of a strongly excited system of spins can be described by taking into account the multimagnon processes, which lead to the formation of a bound state of a large number of magnons–magnon drops. In a one-dimensional ferromagnet, such a nonlinear excitation represents a solitary wave, which at high amplitude transforms into a bound state of two domain walls—two topological solitons, called a dynamic (self-localized) soliton or bion.

In the light of this situation, there is great interest in searching for proof of the existence of nonlinear soliton-type excitations in a real, magnetically ordered crystal, clarification of the conditions required for their appearance, and development of methods for obtaining information concerning their properties. In this work, we were able to realize an experimental situation in which it was possible to generate solitary nonlinear magnetization waves ($\mathbf{M}_s$) in a monopolar Bloch wall and to obtain complete information concerning their characteristics.

The investigations were performed for single-crystalline yttrium garnet plates 40–80 μm thick, bounded by $\{110\}$ or $\{112\}$ planes. They contained in the starting state 180-degree domain walls (DW), separated by Bloch lines into sections (subdomains) with opposite polarity (Fig. 1(a). When a constant magnetic field H_z, normal to the surface of the plate, and a sinusoidal field H_x, parallel to $\mathbf{M}_s$ in domains, were applied to the crystal (with the help of Helmholtz coils), the entire system of starting Bloch lines moved in a single direction[3] and the DW became monopolar. A uniform polarization of spins remains in it even after the external field is removed (Fig. 1b).

The spin system in the DW was excited by means of the field H_x. To eliminate

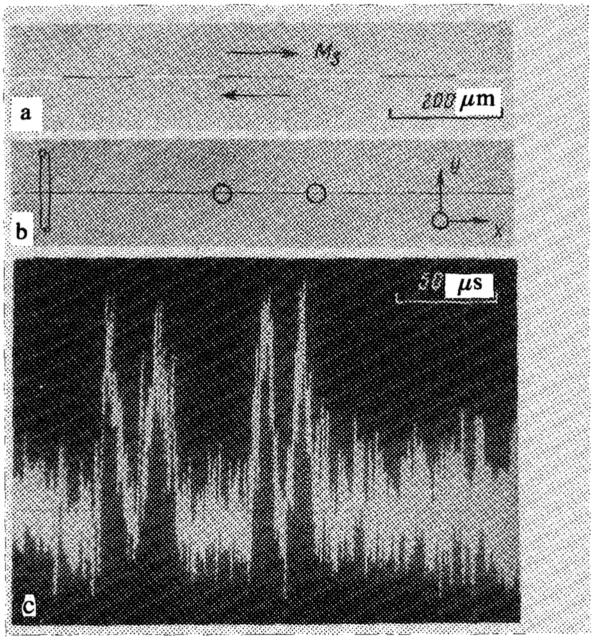

FIG. 1. a) 180-degree DW in the starting state (the nicols of the polarization microscope are uncrossed); b) same after application of a magnetic field H_x ($H_x^0 = 20$ mOe, frequency $\nu = 50$ kHz) to a crystal with $H_z = 8.5$ Oe. The positions of the conductor and light spots are indicated (the diameter of a spot is 20 μm, and the distance between spots is 160 μm); c) single-fold oscilloscope trace reflects the successive passage of two disturbances along DW through the light beams. These disturbances are produced by the continuous action of the fields H_x ($H_x^0 = 20$ mOe, $\nu = 0.4$ MHz) and $H_z = 11.5$ Oe and are characterized by essentially inverted spins. Each split peak corresponds to the motion of a single excitation through two beams.

the possibility of random nucleation of subdomains with inverted spin orientation, a constant field H_z of several oersted was maintained during the entire experiment.

To record dynamic changes of the structure of the DW, polarized LG-36 laser radiation was split by a birefringent plate into two beams, which were transmitted through the crystal at the location of a single DW (Fig. 1b) and were directed toward the photomultiplier (PM). The intensity of the light passing through slightly uncrossed nicol prisms of a microscope was determined by means of the Faraday effect. The PM signal due to it was recorded on the screen of a storage oscilloscope in the single scanning mode.

In the case of low amplitudes (H_x^0) of the field H_x at all frequencies of the field investigated (0.1–10 MHz), no changes in the structure in the "magnetized" DW were recorded by the PM. When H_x^0 was increased to several threshold values $H_{\rm cr}$, excitations of DW were observed. These excitations were recorded by the oscilloscope in the form of peaks shown in Fig. 1c. These intensity spikes were caused by nonlinear spin waves propagating along DW.

Figure 2 shows the frequency dependence of the amplitude of the field $H_{\rm cr}$ that initiates their excitation. At frequencies and amplitudes of the field H_x lying above

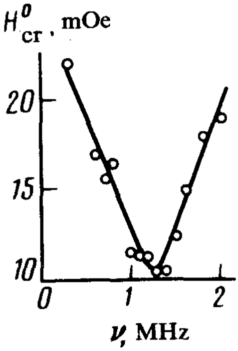

FIG. 2. Dependence of the critical amplitude (H^0_{cr}) of the field H_x on its frequency (ν). $H_z = 11.5$ Oe.

this curve, nonlinear magnetization waves were a necessary element of the structure of the DW, similar to the thermal magnon for a weakly excited system. Their repetition frequency increased with H^0_x and could be estimated from the oscilloscope trace, an example of which is shown in Fig. 1c. The starting "demagnetized" state of DW in the range of values of H^0_x used was not restored.

At $H^0_x < H^0_{cr}$, nonlinear excitations in DW did not appear. However, under these conditions it was possible to generate solitary nonlinear magnetization waves by a single magnetic field pulse, created by an electric current that was passed through a thin metal wire placed on top of the crystal (Fig. 1b), Figure 3a shows an example of the trace of the signal from such a wave. The solitary nonlinear wave passed through the sections in which photometric measurements were made 150 μs after the local action of the field pulse.

Knowing the distance between the beams and the average intensity of the signal,

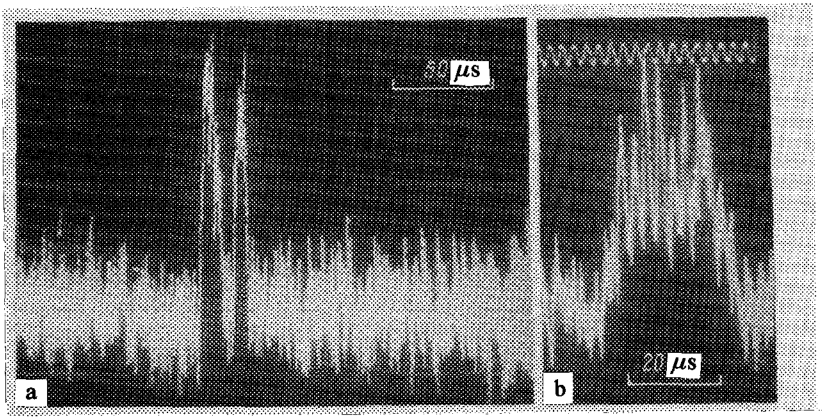

FIG. 3. Magneto-optical signals associated with successive passage of a single disturbance through two light spots (a) and light spot one (b). The moment of application of a 0.18-μs local field pulse coincides with the beginning of each oscilloscope trace: a-$H^0_x = 10$ mOe, $\nu = 0.4$ MHz, $H_z = 11.5$ Oe; b-$H^0_x = 12$ mOe, $\nu = 0.4$ MHz (upper sinusoid), $H_z = 10$ Oe.

corresponding to spin inversion in the wall, and measuring from the oscilloscope trace the time between the peaks, it is possible to calculate the velocity (v) of the nonlinear excitation, and its spatial characteristics and amplitude according to their shape and amplitude. For the case in Fig. 3a, $v \simeq 8$ m/s, and the size of the excited region in the direction of motion is $\sim 60\,\mu$m. Peaks were observed in the experiments both from very low background disturbances, but reliably identified above the noise, as well as from the corresponding completely inverted spins. Moving the crystal and changing the position of the regions for which photometric measurements were performed in the wall, it is possible to obtain information on the kinetics of formation of the nonlinear excitation.

When the time scale was increased, modulations of the signal with a frequency equal to the frequency of the field H_x were clearly observed (Fig. 3b). The modulation could be due to both a periodic change in the size of the excited region and precession of the spins situated in it.

The high-amplitude ($\sim 180^\circ$) solitary nonlinear magnetization wave described above is a bound state of two Bloch lines—topological solitons for the spin subsystem under study. It has the same properties as the dynamic solitons in theories developed to describe nonlinear dynamic magnetization in ferromagnets in the absence of dissipative processes.[2] Thus the results discussed here give a direct proof of the existence of dynamic solitons, which are localized in the DW of a real magnetic material, provided there is dissipation when energy is pumped into the system by means of an external magnetic field.

The authors are deeply grateful to A. V. Mikhaĭlov and É. I. Rashba for a discussion of the results.

[1] I. A. Akhiezer and A. E. Borovik, Zh. Eksp. Teor. Fiz. **52**, 1332 (1967) [Sov. Phys. JETP **25**, 885 (1967)].
[2] A. M. Kosevich, Fiz. Met. Metalloved. **53**, 420 (1982).
[3] L. M. Dedukh, V. S. Gornakov, and V. I. Nikitenko, Phys. Status Solidi A **75**, K117 (1983).

Translated by M. E. Alferieff
Edited by S. J. Amoretty