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Magnetoacoustic emission of natural pyrrhotite

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Abstract

We consider data of study of the parameters of magnetoacoustic emission performed on pyrrhotite from magnetite and pyrite ores from the deposits of the Urals. It is shown that the difference in signals is mainly due to different types of domain structure which forms during the crystallization of pyrrhotite as pinacoids or prisms. Five types of pyrrhotite are recognized depending on the parameters of magnetoacoustic emission. This information can be used as typomorphic features of pyrrhotite of different geneses.

Keywords: magnetoacoustic emission; domain structure; movement of domain walls; pyrrhotite; magnetic field; ferrimagnetic material; antiferromagnetic material

Introduction

Natural pyrrhotite ($FeS_{(1+x)}$) is widespread in some types of sulfide deposits, in which it is, sometimes, the principal ore mineral, accompanied by some commercial ore minerals. It is usually endogenic (magmatic, hydrothermal, or contact-metasomatic). In rare cases, small amounts can form under exogenic conditions—during the diagenesis of sediments (Ramdohr, 1960).

The magnetic properties of pyrrhotite depend on the structural type: Troilite FeS and intermediate hexagonal pyrrhotite are antiferromagnetics, whereas monoclinic pyrrhotite is a ferrimagnetic material with a Curie temperature of 300–320 °C. It was established in (Brodskaya, 1980a) how the magnetic properties of pyrrhotite change depending on its temperature prehistory. The domain structure of pyrrhotite was studied by M.A. Grabovskii and O.N. Zherdenko (1964) under an optical microscope. The behavior of the domain structure is studied at the Institute of Geophysics, Uralian Branch of the Russian Academy of Sciences, with the use of magnetoacoustic emission (MAE)[1]. An advantage of this method is that it provides information abouth the rearrangement of the domain structure not only on the surface of the studied sample but also in the entire remagnetized mass.

When the effect of magnetoacoustic emission is used in nondestructive testing, samples are remagnetized with a frequency of 50 Hz. The most important parameter in nondestructive testing is the amplitude of the MAE signal. It is directly related to the grain size of the studied material, the presence of defects, and the temperatures of quenching and annealing (Gorkunov et al., 2002). The remagnetization of synthetic ferromagnetic materials with a frequency of 0.1 Hz causes a dramatic decrease in the signal amplitude and an increase in the time of measurements. However, the MAE signal is recorded well in natural ferrimagnetics with a remagnetization frequency of 0.1 Hz, and the signal/noise ratio reaches 30/1. Note that there is a complicated dependence between the signal and the value of the field of magnetization, which is characterized by different numbers of maxima with different amplitudes.

Previously, MAE within frequencies of 50–200 kHz was demonstrated in (Ivanchenko and Glukhikh, 2009; Ivanchenko et al., 2012) for magnetite and magnetite ores of different geneses. The effect of MAE within this frequency range is explained by a shift of domain boundaries with a change in the magnetic state of a sample (remagnetization by a low-frequency external magnetic field).

In (Glikhikh et al., 2007; Ivanchenko et al., 2007), MAE is considered in complex sulfide–magnetite ores, in which the presence of pyrrhotite is marked by an additional maximum

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[1] Magnetoacoustic emission caused by acoustic pulses during the remagnetization of a ferromagnetic sample with a magnetic field was discovered by C.W. Heaps in 1924 and has been studied in detail by A.E. Lord and others since 1974. Magnetoacoustic emission is widely used in the development of methods for nondestructive testing.

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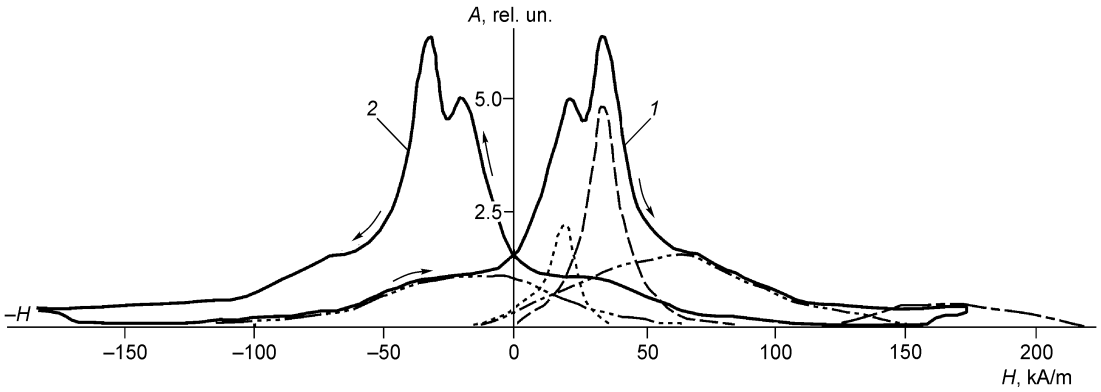

Fig. 1. Resolution of the curve of MAE into components. *A*, Amplitude of the signal. See description in the text.

on the curve showing the dependence of the amplitude of the MAE signal on the magnetization field. However, no attention was paid to pyrrhotite as a source of MAE. When averaged parameters of MAE for the types of ores were used, some observed effects (e.g., strong anisotropy of MAE in the samples) could not always be explained. Therefore, it became necessary to study the MAE of samples whose magnetic mineralization is represented predominantly by pyrrhotite.

Methods of measurements

Magnetoacoustic emission was measured for cubic samples 2.4 m^{-3} in size on special equipment by the technique described in (Ivanchenko and Glukhikh, 2009; Ivanchenko et al., 2012). Remagnetization was carried out with the use of a magnetic field with a frequency of 0.1 Hz and an amplitude of up to 180 kA/m. Acoustic signals were received by piezoceramic sensors.

The frequency range of the recording was 135 to 145 kHz. The following parameters of MAE were used: the value of the magnetization field of the maximum MAE signal, the range of manifestation of MAE, and the signal amplitude. The resulting dependence of MAE on the applied magnetic field is an additive sum of MAE from different sources, which are identified by the resolution of the total MAE curve into components with one maximum. A group of domain boundaries with a certain boundary energy and degree of mobility is such a single source of MAE with changing domain structure. Evidently, the type of domain structure is directly related to the genesis of a sample. Figure 1 shows an example of the recording of a MAE signal and the resolution of the total curve into components which might be related to different sources of MAE. A MAE signal in the case of remagnetization from $-H$ (–180 kA/m) to $+H$ (+180 kA/m) is shown in Fig. 1 (curve *1*), and that in the case of remagnetization from $+H$ (+180 kA/m) to $-H$ (–180 kA/m) is shown on curve *2*. To study the anisotropy of MAE, the measurements were taken with a magnetic field directed perpendicularly to three faces of a cubic sample.

Description of the samples

We selected pyrrhotite samples from the Cu–Zn ores of the Uzel'ga deposit (1P, 3P, 5P, 6P, 8P, and 12P) and samples with predominant pyrrhotite mineralization from the magnetite ores of the Estyunino (8420/1231.7) and Novaya Peschanka (Southern zone: samples SZ-10 and SZ-11; West Peschanka zone: samples WPZ-9 and WPZ-23) deposits.

The Estyunino deposit, which belongs to a subassociation of Ti-poor magnetite ores, is confined to the western exocontact of the Tagil syenite–diorite pluton (Smirnov and Dymkin, 1989). The Novoe Estyunino ore-bearing zone, which a sample for the study (Rudnitskii et al., 2000) was taken from, is localized in a thick series of felsic volcanics which underwent high-grade metamorphism. The deposit includes several types of ores differing in parageneses, texture and structure, and characteristics of magnetite (Fominykh, 1981). The most heterogeneous one is the group of massive ores, which might be a result of the recrystallization (crushing and superposition of a skarn process and sulfide mineralization) of the previously formed ores. Sample 8420/1231.7 was taken from the zone of occurrence of this type of ores. A mineralogical study showed that the disseminated ore in the sample is mostly pyrrhotite. The mineral has an allotriomorphic-granular texture, with rare idiomorphic grains. The average grain size is 1 mm. Besides, isometric (sometimes, idiomorphic) magnetite grains of different sizes with reticulate and tabular decomposition structures are observed.

The Novaya Peschanka deposit, which consists of a group of orebodies, is localized at the northwestern contact of the Auerbakh intrusive pluton, composed of diorites, gabbro-diorites, and gabbro (Smirnov and Dymkin, 1989). The deposit includes massive magnetite, sulfide–magnetite, and disseminated skarn–magnetite ores. The sulfide mineralization is superposed on magnetite mineralization. Samples of pyrrhotite ores from the West Peschanka and Southern zones were taken for the MAE study.

Sample WPZ-9 lacks magnetite, and its sulfide mineralization (total content 30%) includes pyrrhotite (10%), chalcopyrite (10%), pyrite (5%), and arsenopyrite (5%). Apparently, pyrrhotite occurs as an intermediate variety, because the initial