[5] V.M. Golyanov, A.P. Demidov, M.N. Mikheeva, and A.A. Teplov, Zh. Eksp. Teor. Fiz. 58, 528 (1970) [Sov. Phys.-JETP 31, 283 (1970)].

THERMOGRAPHIC RECORDING ON A MANGANESE-PERMALLOY FILM WITH EXCHANGE ANISOTROPY

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Submitted 9 February 1972
ZhETF Pis. Red. 15, No. 7, 368 - 370 (5 April 1972)

1. Much attention is being paid of late to research on thermomagnetic information recording. This method consists of heating a local section of a ferromagnet in a magnetic field for a short time. This reverses the magnetization of the heated section, which is subsequently the only depository of the information. The thermomagnetic method of recording and the magnetic materials on which such recording is possible are promising objects for the construction of permanent memories for electronic computers.

Several modifications of thermomagnetic recording are known at present, viz., recording by heating to the Curie point, recording on a material having a sharp temperature drop of the coercivity, recording on gadolinium iron garnet at the condensation point, the thermostriction method, and recording on films with stripe domains [1].

We propose here the use of a new physical phenomenon for thermomagnetic recording, using a two-layer manganese-permalloy film as an example. The phenomenon in question is exchange (or unidirectional) anisotropy due to exchange interaction between the ferro- and antiferromagnetic regions.

2. Manganese-permalloy films with exchange anisotropy [2] are made up of ferromagnetic and antiferromagnetic layers. Owing to the exchange interaction between the layers, such films have a hysteresis loop that is shifted along the field axis. It was shown in [3, 4] that even the minute details of the domain structure can be made permanent by the exchange interaction with the antiferromagnet. This phenomenon can be used for thermomagnetic recording.

Let us examine the recording mechanism by using the scheme of Fig. 1. Figure 1a shows a film with exchange anisotropy in the initial state. The upper layer is ferromagnetic and the lower antiferromagnetic. Thermomagnetic recording is effected by applying to the film a magnetic field that magnetizes in a direction opposite to that of the easy magnetization. A small section of the film is then heated above the Neel point of the antiferromagnetic layer. This state is illustrated in Fig. 1b. The entire ferromagnetic layer is magnetized in the direction of the external field. Within the limits of the heated section (bounded by dashed lines), the magnetization of the ferromagnetic layer is decreased somewhat, but is still high (since the Curie point is higher than the Neel point). In the antiferromagnetic layer, on the other hand, this section has become paramagnetic.

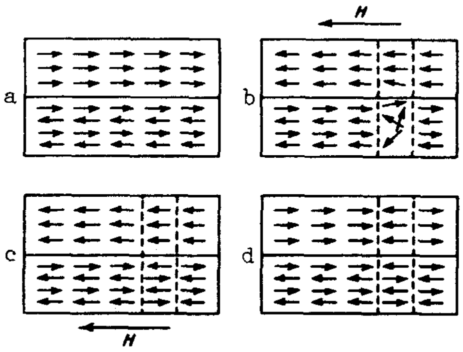

Fig. 1. Diagram explaining the mechanism of thermomagnetic recording on a film with exchange anisotropy.

During the time of cooling in the magnetic field, the heated section of the lower layer becomes antiferromagnetic. This transition is influenced by the exchange interaction with the ferromagnetic layer above it. As a result, the spin system of the

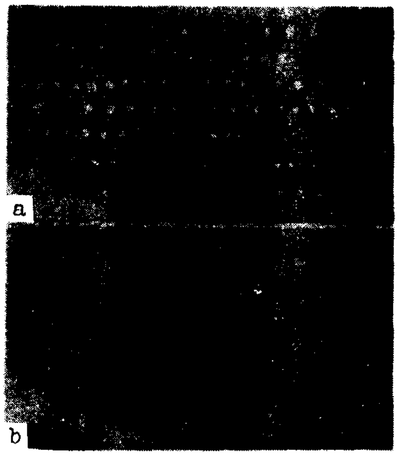

Fig. 2. Example of thermomagnetic recording: a) film with recorded information, b) film in 15-Oe field. Film diameter 10 mm.

antiferromagnet in the heated section assumes a new direction (Fig. 1c). After the external magnetic field is turned off, the magnetization in the entire film returns to the initial state, except in the heated section, where the exchange interaction with the reoriented antiferromagnetic section leaves the magnetization in the same direction as before (Fig. 1d). Thus, as a result of the described procedure, the local section of the ferromagnetic layer reverses magnetization. It can be used as a bit of information and can be observed, for example, with the aid of the Kerr effect.

3. The thermomagnetic recording described above was realized with a manganese-permalloy film obtained by successively sputtering, in a vacuum of 5×10^{-5} mm Hg, layers of manganese and of the alloy 82% Ni - 18% Fe. Layers of 1000 Å thickness were deposited in a magnetic field of 70 Oe on a glass substrate heated to 200°C. The film was coated from above with a layer of SiO to keep it from oxidizing during the thermal recording. After sputtering, the film was annealed at 350°C for two hours and cooled in a magnetic field. The antiferromagnet produced thereby had a Neel point on the order of 300°C [5].

The recording was produced by touching the film, in a magnetic field of 20 Oe oriented against the easy-magnetization direction, with a pointed nichrome wire raised to red heat. Figure 2a shows a photograph of the film, with the recorded points revealed with the aid of the longitudinal Kerr effect. The smallest points have a dimension on the order of 100 μ. Smaller spots can probably be produced by a better heating method, say with a laser beam.

A field on the order of 15 Oe saturates the film to magnetization and makes the recording invisible (Fig. 2b). The information is not lost, however, since the reorientation of the antiferromagnetic region is not destroyed thereby. After turning on the field, the recorded picture is fully restored. Application of fields of 40 kOe to the film did not destroy the magnetic structure of the antiferromagnetic regions, i.e., did not lead to loss of information. To erase a recorded point it is necessary to reheat the given section locally to the Neel temperature in the presence of a field opposite that used for recording.

4. We note some advantages of manganese-permalloy films with exchange anisotropy, as media for thermomagnetic recording of information, over the customarily used materials. First, the recorded information cannot be irreversibly destroyed by external magnetic fields of even hundreds of kOe, owing to the high threshold fields of the antiferromagnets. In many cases this circumstance can be very useful and ensures high reliability of information storage. Second, application of an alternating magnetic field of several dozen Oersteds in the plane of the film makes it possible to modulate the entire recorded picture without destroying it. This can be used for dynamic reading methods.

Thus, thermomagnetic recording on films with exchange anisotropy, by heating the films in a field up to the Neel point, should be regarded as a fully independent method of such recording, alongside with the known methods mentioned above.

[1] L.M. Klyukin, B.M. Stepanov, V.A. Fabrikov, and A.V. Khromov, Fotografirovanie na magnitnye plenki (Photography on Magnetic Films), Atomizdat, 1971, p. 7).
[2] A.A. Glazer, A.P. Potapov, R.I. Tagirov, and Ya.S. Shur, Fiz. Tverd. Tela 8, 3022 (1966) [Sov. Phys.-Solid State 8, 2413 (1967)].
[3] A.A. Glazer, A.P. Potapov, and R.I. Tagirov, Izv. AN SSSR, ser. fiz. 30, 1059 (1966).
[4] A.A. Glazer, R.I. Tagirov, A.P. Potapov, and Ya.S. Shur, Fiz. Met. Metallov. 26, 289 (1968).
[5] A.A. Glazer, A.P. Potapov, R.I. Tagirov, L.D. Uryasheva, and Ya.S. Shur, Izv. AN SSSR, ser. fiz. 31, 735 (1967).

OBSERVATION OF MICROWAVE RADIATION ABSORPTION BY ELECTRON-HOLE DROPS IN Ge AND Si

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Submitted 14 February 1972
ZhETF Pis. Red. 15, No. 7, 371 - 374 (5 April 1972)

At low temperatures, the non-equilibrium electrons and holes in semiconductors are bound into excitons, and the fraction of the excitons increases with increasing pair concentration and with decreasing temperature. At a certain exciton density $n_{cr}(T)$ and at sufficiently low temperatures, the excitons can coalesce into drops and become metallized [1, 2].

The creation of metallic drops from excitons should be accompanied by a number of effects due to the formation of high-conductivity regions in the sample.

To study the formation of electron-hole drops in semiconductors, we have investigated the absorption of microwave radiation in the 8-mm band in Ge and Si samples[1]. Samples 20 - 100 mm thick were placed in a waveguide perpendicular to its broad wall, at the maximum of the electric field of the wave, and exposed to a laser pulse of 5×10^{-8} sec duration through an opening in the narrow wall. The measurements were performed in a wide temperature interval, 2.2 - 300°K. The resistance of the Ge and Si samples at 300°K was 40 and 100 ohm-cm, respectively. We registered the changes of the amplitudes of the transmitted and reflected microwave signals, due to the action of the laser light on the crystal.

Figure 1 shows oscillograms of the transmitted microwave signal for Ge samples at 2.2°K. At low pump levels, the attenuation pulse duplicates the shape of the exciting-light pulse. In this case the free carriers exist only during the time of action of the light pulse, after which they are rapidly bound into excitons, and there is no absorption of the microwave radiation.

At a laser light intensity exceeding $\sim 10^{22}$ kV/cm^{2}sec, a number of irregular sharp spikes of attenuation is produced after the termination of the light pulse. The number, durations, and amplitudes of these pulses fluctuate greatly.

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[1] Direct-current investigations of the photoconductivity do not make it possible to trace the drop-formation process, since the conductivity is then registered only after the drops have already filled the entire samples, at which instant the jump of photocurrent is observed [3, 4]. The study of IR absorption ($\hbar\omega > E_x$, where E_x is the energy of binding into an exciton) does not make it possible to distinguish between electron-hole pairs and excitons, since the IR absorption cross sections are the same in the two cases [5].