Magnetic-field suppression of the photoplastic effect in gamma-irradiated NaCl crystals

E. V. Korovkin
Institute of Solid State Physics, Academy of Sciences of the USSR

(Submitted 29 April 1982)

Pis'ma Zh. Eksp. Teor. Fiz. **35**, No. 11, 481–483 (5 June 1982)

A magnetic field weakens the photoplastic effect. The weakening becomes more pronounced as the field is intensified or the temperature lowered.

PACS numbers: 75.80. + q, 61.80.Ed, 62.20.Fe

The photoplastic effect in γ-irradiated alkali halide crystals occurs because the light generates point defects ("photopins") which pin dislocations.[1,2] The photopins form from point defects which either are not pinning dislocations or are doing so only weakly when these defects capture electrons scattered from F centers or other color centers by the light.[4,5] The observation that the photoplastic effect (and the photoplastic aftereffect, one manifestation of the photoplastic effect[3]) occurs at low temperatures [down to 10 K (Ref. 6) down to 4.2 K (Ref. 7), and down to 1.65 K in the present experiments] and the substantial magnitude of these effects at low temperatures (comparable to that at room temperature) indicate that the formation of the photopins does not involve any significant diffusion or coalescence of point defects.

The photopin is thus one of the simple color centers. The most promising hypothesis is Nadeau's hypothesis that the F' center is the photopin.[8]

If the defect from which the photopin is formed has an unpaired electron, and if the probability for the formation of a triplet state is lower than that for the formation of a singlet state, then the capture of a photoelectron by the photopin may be suppressed by a magnetic field. The F-F' transformation in an alkali halide crystal is a process of this type.[9] It is thus clear that a study of how a magnetic field affects the photoplastic effect will be useful for identifying the color center responsible for the photoplastic effect. This was the motivation for the present experiments.

For the experiments we developed an attachment to an Instron apparatus which made it possible to deform crystals at $T = 1.65$ K in a magnetic field and to illuminate the crystals with F light from a DKSSh-200 lamp with an optical system consisting of a lens, an SS-8 filter, mirrors, and a quartz lightguide. Single-crystal NaCl samples with dimensions of 4 × 8 × 12 mm were synthesized by the standard method.[7] The magnetic field was directed along the compression axis.

To arrange prolonged plastic deformation at such a low temperature, we used the method of Ref. 7 to prepare the samples. A sample is first deformed to ~0.5% at room temperature; the load is removed, and the sample is cooled to 4.2 K; and then the sample is deformed again. By alternating deformations at different rates (5 and 50 μm/min) with relaxation intervals several times, it is possible to reduce the hardening coefficient and to increase the placticity of the sample. The load is then removed from the sample

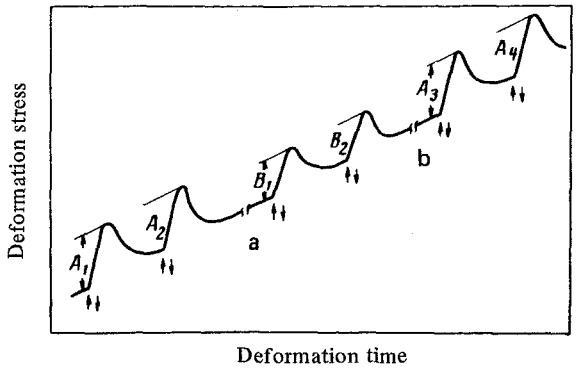

FIG. 1. Diagram illustrating the experimental procedure. Up and down arrows–Light pulse; a–magnetic field applied; b–magnetic field removed.

again, and the sample is cooled to 1.65 ± 0.05 K and again deformed at a rate of 10 μm/min. Illumination of the sample during the plastic flow led to the observation of a photoplastic effect or a photoplastic aftereffect, depending on the duration of the illumination. After the first three or four light pulses, the hardening coefficient stopped decreasing and assumed a steady level; the kinetics and magnitude of the photoplastic aftereffect also stabilized for a constant duration and intensity of the light pulses. At this point the preparation procedure was terminated, and the measurements were begun.

We measured the dependence of the aftereffect on the strength of the magnetic field with light pulses of constant intensity and constant duration (3-10 s). The following procedure was observed in the measurements (Fig. 1). The aftereffect was measured twice in the absence of a field (A_1 and A_2); then a field was applied, and the aftereffect was measured in its presence (B_1 and B_2). The field was then removed, and the aftereffect was measured again (A_3 and A_4). The ratio of $B=(B_1+B_2)/2$ to $A=(A_1+A_2+A_3+A_4)/4$ is a measure of the effect of the field on the photoplastic aftereffect. The scatter in the values of A_1-A_4 and B_1-B_2 determines the measurement error. The results are shown in Fig. 2. We see that the magnetic field suppresses the aftereffect and that the suppression becomes more pronounced as the field is strengthened or the temperature lowered. Changing the direction of the field does not affect the results.

At a constant duration and intensity of the light pulses, the magnitude of the photoplastic aftereffect depends on the rate at which the photopins are formed, i.e., on the probability for the capture of a photoelectron. If we assume that the numbers of unpaired electrons of both the source of the photoelectrons (the F centers) and their sink (the future photopins, possibly also F centers) are $n^{-}/n = 1/[1+\exp(-2\mu H/kT)]$ (these are the unpaired electrons which are oriented along the field H) and $n^{+}/n = [\exp(-2\mu H/kT)]/[1+\exp(-2\mu H/kT)]$ (oriented opposite the field), where μ is the Bohr magneton, and the probabilities for the formation of the triplet state and for the loss of the spin memory are zero, then we find

$$B/A = 4[\exp(-2\mu H/kT)]/[1+\exp(-2\mu H/kT)]^2 .$$

This expression is illustrated by the solid curve in Fig. 2 for $T = 1.65$ K. We see that

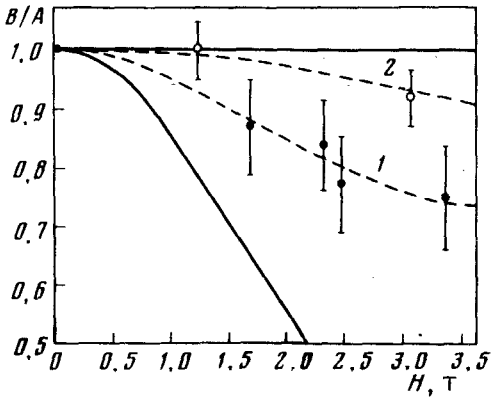

FIG. 2. Dependence of the photoplastic aftereffect on the magnetic field. Filled circles–$T = 1.65$ K; open circles–$T = 4.2$ K; solid curve–calculated for $T = 1.65$ K, $\epsilon = 0$, $\beta = 0$; dashed curves–calculated for $\alpha = 0.67$ and temperatures of 1.65 K (1) and 4.2 K (2).

the experimental results predict a field dependence weaker than that described by this curve.

The polarization of the electrons of the source is described by $p_F = \tanh(\mu H/kT)$. If we allow some loss of spin memory (characterized by the quantity ϵ), so that the polarization of the electrons that reach the capture centers is lower,[9] $p_e = (1 - \epsilon)p_F$, or if we allow some probability for the formation of a triplet state (characterized by β, the ratio of the probabilities for the formation of the triplet and singlet states), then we can write

$$B/A = \frac{4[\exp(-2\mu H/kT)] + \alpha[1 + \exp(-2\mu H/kT)]^2}{[1 + \exp(-2\mu H/kT)]^2},$$

where $\alpha = \epsilon + 2\beta/(1+\beta)$. With $\alpha = 0.67$ we find the field dependence of B/A shown in Fig. 2 by the dashed curves for $T = 1.65$ K (curve 1) and 4.2 K (curve 2). These results agree well with the experimental data.

It follows from these results that the defect from which the photopin forms has an unpaired electron. This conclusion is a further argument in favor of the hypothesis that the photopin is an F' center. For the F-F' transformation in NaCl, however, we would expect–by analogy with KCl–small values of ϵ and β($\epsilon \approx 0$, $\beta \approx 0$; Ref. 9). These parameters do have significant values in NaI and NaBr crystals,[10] but in these cases the F and F' centers have certain anomalous properties in comparison with other alkali halide crystals. In the case of interest in the present letter, only F centers lying near a dislocation play a role in the effect,[7] and the photoelectron is transferred not through the conduction band (or not exclusively through the conduction band) but through a dislocation level.[6,11] This circumstance may also be responsible for the large values of ϵ and β.

We should point out that the experimental data which have been obtained cannot tell us which of these mechanisms is operating: the loss of spin memory, a probability for the formation of a triplet state, or both, in some proportion. To resolve this question, it will apparently be necessary to use other procedures, perhaps to develop new procedures.

1. G. A. Ermakov, E. V. Korovkin, and Ya. M. Soĭfer, Fiz. Tverd. Tela (Leningrad) **16**, 697 (1974) [Sov. Phys. Solid State **16**, 457 (1974)].
2. G. A. Ermakov, E. V. Korovkin, and Ya. M. Soĭfer, Fiz. Tverd. Tela (Leningrad) **16**, 1756 (1974) [Sov. Phys. Solid State **16**, 1139 (1974)].
3. E. V. Korovkin, Fiz. Tverd. Tela (Leningrad) **21**, 1785 (1979) [Sov. Phys. Solid State **21**, 1021 (1979)].
4. G. A. Ermakov, E. V. Korovkin, and Ya. M. Soĭfer, Fiz. Tverd. Tela (Leningrad), **15**, 1911 (1973) [Sov. Phys. Solid State **15**, 1276 (1973)].
5. E. V. Korovkin, Fiz. Tverd. Tela (Leningrad) **23**, 2486 (1981) [Sov. Phys. Solid State **23**, 1458 (1981)].
6. G. A. Ermakov and É. M. Nadgornyĭ, Pis'ma Zh. Eksp. Teor. Fiz. **14**, 45 (1971) [JETP Lett. **14**, 29 (1971)].
7. E. V. Korovkin, Fiz. Tverd. Tela (Leningrad) **23**, 2545 (1981) [Sov. Phys. Solid State **23**, 1493 (1981)].
8. J. Nadeau, J. Appl. Phys. **35**, 669 (1964).
9. F. Porret and F. Lüty, Phys. Rev. Lett. **26**, 843 (1971).
10. G. Baldaccini, G. P. Gullerano. U. M. Grassano, and F. Lüty, in: Tezisov mezhdunarodnoĭkonferentsii "Defekty v diélektricheskikh kristallakh" (Proceedings of the International Conference on Defects in Dielectric Crystals), Riga, 1981, p. 142.
11. E. V. Korovkin, Fiz. Tverd. Tela (Leningrad) **24**, 524 (1982) [Sov. Phys. Solid State (to be published)].

Translated by Dave Parsons
Edited by S. J. Amoretty