RELAXATION OF $^{53}\text{Cr}$ SPIN ECHO SIGNALS IN Cd$_{0.985}$Ag$_{0.015}$Cr$_2$Se$_4$

G.N. ABELYASHEVA*, V.N. BERZHANSKYA, S.N. POLULYAKHA AND N.A. SEREDEV

*Department of Physics, Simferopol University
Yaltinskaja 4, 333007 Simferopol, Ukraine

bInstitute of Physics, University of Szczecin, Wielkopolska 15, 70-451 Szczecin, Poland

The frequency dependences of the relaxation times of NMR spin echo signals of quadrupole nuclei $^{53}\text{Cr}$ at $t_e = \tau$ and $t_e = 3\tau$ in ferromagnetic semiconductor Cd$_{0.985}$Ag$_{0.015}$Cr$_2$Se$_4$ were investigated at temperature 4.2 K. It was shown that there are two kinds of the quadrupole nuclei $^{53}\text{Cr}$, which have quite different relaxation times. The existence of two kinds of the nuclei $^{53}\text{Cr}$ was connected with doping of the cadmium selenochromite with Ag$^+$ ions.

PACS numbers: 76.20.+q, 76.60.—k, 76.60.Lz

1. Introduction

The pulse-NMR method is one of the powerful techniques for the study of the spin dynamics in magnetically ordered materials. In the case of the quadrupole nuclei with spin $I = 3/2$ (for example $^{52}\text{Cr}$ nuclei), when the quadrupole interactions of the nuclei do not equal zero, the two echo signals may be observed at $t_e = \tau$ and $t_e = 3\tau$ [1–3]. The first echo signal $V_\tau$ is the usual Hahn echo and the NMR spectrum $V_\tau(\nu)$ recorded with the aid of this echo reflects all NMR spectral lines of the quadrupole nuclei. However, the spectrum NMR $V_{3\tau}(\nu)$ recorded with the aid of the echo at $t_e = 3\tau$ consists of the NMR resonance frequencies, whose values are determined by the hyperfine magnetic interaction only [1–3]. The aim of this paper is to analyze the relaxation of the $V_\tau(\nu)$ and $V_{3\tau}(\nu)$ echo signals of the quadrupole nuclei $^{53}\text{Cr}$ in ferromagnetic semiconductors Cd$_{0.985}$Ag$_{0.015}$Cr$_2$Se$_4$.

*e-mail: roton@ccssu.crimea.ua
2. Experimental results and discussion

The NMR measurements were made on the polycrystalline multidomain sample Cd$_{0.985}$Ag$_{0.015}$Cr$_2$Se$_4$ at $T = 4.2$ K in zero static external magnetic field. The experimental results are shown in Fig. 1 and Fig. 2. The analysis of the obtained experimental results were provided assuming that the time fluctuations in the electron magnetization $M_e$ due to the fluctuations in the hyperfine magnetic and quadrupole interactions lead to the relaxation of the spin echo signals. Assuming the frequency $\tau_{ee}^{-1}$ of the time fluctuations of $M_e$ is smaller than NMR resonance frequencies $\nu_i$ and so remaining in the fluctuating hyperfine magnetic and electric quadrupole Hamiltonians the secular terms only we obtained the following expression for the relaxation rate of the echo signal $V_\tau(\nu)$:

$$T_2^{-1}(\tau, \nu_i) = A + B_i \sin^2(2\theta_0),$$

(1)

where $i = 1, 2, 3$; $\nu_1$ is the resonance frequency of the NMR transition $\pm 1/2 \leftrightarrow \mp 1/2$; $\nu_{2,3}$ are the resonance frequencies of the NMR transitions $\pm 3/2 \leftrightarrow \pm 1/2$. In Eq. (1) the angle $\theta_0$ is the angle between the local trigonal axis and a direction of the electron magnetization vector $M_e$. The NMR resonance frequencies $\nu_i$ are uniquely determined by the angle $\theta_0$. The solid lines shown in Fig. 1 represent the theoretical frequency dependences obtained from the best fit of Eq. (1) to the observed values of $T_2(\tau, \nu)$. As is seen, the theoretical curves agree well with the experimental results. In the secular approximation we obtained the following expression for the relaxation of the multiquantum echo signal $V_3(\nu_1)$:

$$T_2^{-1}(3\tau, \nu_1) = 3T_2^{-1}(\tau, \nu_1).$$

(2)

Fig. 1. Frequency dependence of the relaxation time $T_2(\tau, \nu)$ of the $^{53}$Cr nuclei in Cd$_{0.985}$Ag$_{0.015}$Cr$_2$Se$_4$ at $T = 4.2$ K. The solid lines are the theoretical curves obtained from the best fit of Eq. (1) to the measured values of $T_2(\tau, \nu)$. Curve 1 is the dependence $T_2(\tau, \nu_1)$; curves 2 and 3 are the dependences $T_2(\tau, \nu_2)$ and $T_2(\tau, \nu_3)$. Broken line 4 is the theoretical curve $T_2(\tau, \nu_1)$ obtained in the nonsecular approximation.
As is seen from Fig. 2 only two experimental points (the open circles) coincide with frequency dependence (2). In order to understand the source of this discrepancy we considered the relaxation of the echo signal at $t_e = 3\tau$ assuming that the time fluctuations of $M_e$ are not small ($\tau_{ce}^{-1} \gg \nu_1$) and retaining in the fluctuating Hamiltonians the nonsecular terms too. The obtained expression for the relaxation rate of spin echo $V_3\tau(\nu_1)$ has the form

$$T_2^{-1}(3\tau, \nu_1) = C + D \cos^2(2\theta_0).$$  (3)

As is seen from Fig. 2 the dependence (3) well describes the observed dependence of $T_2(3\tau, \nu_1)$.

The obtained results suggest that in Cd$_{0.985}$Ag$_{0.015}$Cr$_2$Se$_4$ there are two kinds of the $^{53}$Cr nuclei which have quite different relaxation channels ("secular" and "nonsecular"). The nuclei of the first kind $^{53}$Cr(I) give the main contribution to the echo signal $V_\tau(\nu)$. In the echo signal $V_3\tau(\nu)$ these nuclei are observed only at $\nu > 44.5$ MHz (the open circles in Fig. 2). The nuclei of the second kind $^{53}$Cr(II) have very short relaxation time $T_2(\tau, \nu)$ and so they do not give the contribution to the observed echo signal $V_\nu(\tau)$. We may observe these nuclei only with help of the echo $V_{3\tau}(\nu)$ (the black circles in Fig. 2). In order to understand why the nuclei $^{53}$Cr(II) do not give the contribution to the echo signal at $t_e = \tau$ we considered the nonsecular relaxation of the echo signal $V_\tau(\nu)$. The broken line in Fig. 1 represents the obtained theoretical curve. As is seen the relaxation of the echo signal $V_\tau(\nu)$ from the nuclei $^{53}$Cr(II) is indeed smaller one for the nuclei $^{53}$Cr(I). It is reasonable to assume that the existence of two kinds of the nuclei $^{53}$Cr in Cd$_{0.985}$Ag$_{0.015}$Cr$_2$Se$_4$ is connected with the doping of CdCr$_2$Se$_4$ with Ag$^{+}$ ions. The doping of the cadmium selenochromite with silver ions produces, as a result of electric charge compensation, the Cr$^{4+}$ impurities. The different relaxation channels for the nuclei...
$^{53}\text{Cr}(\text{I})$ and $^{53}\text{Cr}(\text{II})$ are probably connected with the dynamical nature of the Cr$^{4+}$ defects. We assume that electron exchange between the Cr$^{4+}$ and Cr$^{3+}$ ions sited inside of the defect region leads to the rapid fluctuations in the local electron magnetization $(\tau_{ce}^{-1} \gg \nu_i)$ so the nuclei $^{53}\text{Cr}(\text{II})$ located in these defect regions "feel" due to the hyperfine and quadrupole interactions the rapidly fluctuating electron magnetization. The rate of local fluctuations of $M_e$ for the nuclei $^{53}\text{Cr}(\text{I})$ which are sited far from defects is small, then $\nu_i$ and the relaxation of the echo signals from these nuclei is "secular".

References