Role of magnetic interaction in oscillations of the magnetostriction of tin

V. M. Pudalov

Institute of Physics Problems, USSR Academy of Sciences
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Under conditions of magnetic interaction, $4\pi|\partial M/\partial H|\sim 1$, an analysis of the waveform of the quantum oscillations of magnetostriction makes it possible to find the amplitude of the oscillations of the magnetic moment and all the parameters that determine this amplitude. Such a simultaneous measurement of U_{ik} and M on one sample and during the course of one experiment has made it possible to determine, from the result of an experiment performed on tin at $T=0.37$ °K, the dependences of the areas of the sections δ_1^1 and δ_1^2 of the Fermi surface and the breakdown field on the lattice deformation.

It is known that to obtain quantitative data on the compressibility of the extremal section $\partial \ln S/\partial \sigma_{ik}$ of the Fermi surface (FS) from measurements of the oscillations of the magnetostriction U_{ik}, it is necessary to measure simultaneously with U_{ik} the oscillating part of the magnetic moment M.

We have previously reported[1] observation of oscillations of U_{ik} in tin at $T=1.4$ °K. These oscillations were connected with two extremal sections δ_1^1 and δ_1^2 of the hole part of the FS of tin in zone III.[2] At lower temperatures and in samples of better quality, it is possible to realize the condition $4\pi|\partial M/\partial H|\sim 1$, when the contribution of M to the induction B responsible for the formation of the Landau levels becomes appreciable.[3] The nonlinearity of this phenomenon complicates the spectrum of the observed oscillations in such a way that the ratio of the spectral components itself is determined by the magnetic moment. An analysis of the waveform of the oscillations of U_{ik} makes it possible to find not only the value of M, but also the unknown parameters that determine it, namely the curvature $\partial^2 S/\partial k_z^2$ of the extremal section of the FS, the g-factor averaged over the extremal section and the Dingle temperature T_D.

Under these conditions U_{ik} can be expanded in a series in the functions of the restructured oscillation spectrum

$$U_{ik} = \sum_j \tilde U_{ik}^{(j)} \quad (1), \qquad \tilde U_{ik}^{(j)} = -\frac{\partial \tilde\omega_j}{\tilde\omega_j \partial \sigma_{ik}} H \tilde M_j \,. \qquad (1')$$

Here $\tilde\omega_j$ is the jth combination of the frequencies of the "bare" Lifshitz-Kosevich spectrum,[4] and M_j is obtained by solving a nonlinear equation.[3]

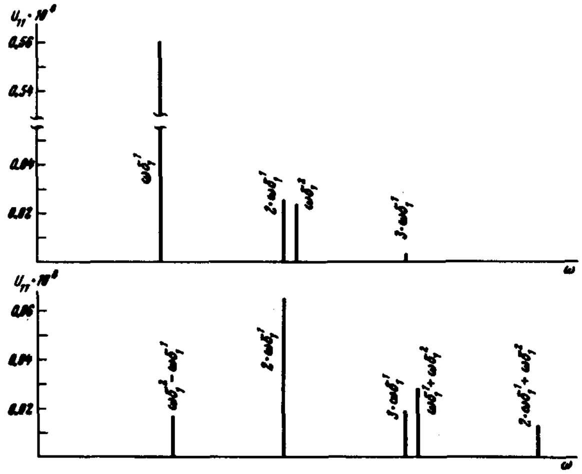
The analysis of the U_{ik} oscillations that are connected with the extremal section δ_1^1 of the hole FS of tin in zone III is made complicated by magentic breakdown, which connects this section with the hole part of the FS in zone IV.[2] An expression for the oscillations of the thermodynamic potential Φ was derived in[5]. The lattice deformation in the basal plane lifts the twofold degeneracy of the energy at the point X of the Brillouin zone,[6] so that in the differentiation

$$U_{ik} = -\left(\frac{\partial \Phi}{\partial \sigma_{ik}}\right) \qquad (2)$$

it is necessary to take into account also the change of the energy gap $\epsilon_g(\sigma_{ik})$ between the bands. Thus, the series (1) contains, besides terms of the type (1′), also terms describing oscillations in phase with Φ:

$$\tilde U_{ik}^{(j')} = \frac{\partial \ln H_0}{\partial \sigma_{ik}} \frac{H_0}{H} \frac{\exp(-H_0/H)}{[1-\exp(-H_0/H)]} \tilde\Phi^{(j')} \,. \qquad (3)$$

Here H_0 is the characteristic breakdown field.



Spectrum of the oscillations of $U_{\parallel}$ in a 6-kOe field at $T=0.37$ °K. Upper part of the figure – "bare spectrum",[4] lower part – new spectral components that appear as a result of the magnetic interaction.

EXPERIMENT

The measurements were performed in analogy with[1], in fields ranging from 4 to 9 kOe. At a magnetic-field direction $H\parallel[001]$ we measured the oscillations of two extremal FS sections δ_1^1 and δ_1^2.[2] A total of 2550 experimental values of $U_{\parallel}(H;\ T=0.37$ °K) and 1530 of $U_{\parallel}(H;\ T=1.4$ °K) were fed from a punched tape to a BESM-6 computer. A least-squares approximation was then carried out with functions of the restructured spectrum (1), (1′), and (3) with eight unknown parameters

$$g(\delta_1^1);\ g(\delta_1^2);\ \frac{\partial \ln S(\delta_1^1)}{\partial \sigma_{\parallel}};\ \frac{\partial \ln S(\delta_1^2)}{\partial \sigma_{\parallel}};\ T_D;\ H_0;\ \frac{\partial \ln H_0}{\partial \sigma_{\parallel}};\ \frac{\partial^2 S(\delta_1^1)}{\partial k_z^2}$$

and under the following initial conditions: 1) a single value of T_D was introduced for the two sections, 2) the effective masses $\mu(\delta_1^1)=0.10$ and $\mu(\delta_1^2)=0.16$ measured in[7] were introduced, 3) the curvature of the section δ_1^2

(1) Extermal section	$\frac{\partial \ln S}{\partial \sigma_{\parallel}} \cdot 10^{12}$ cm^2/dyn	$\frac{\partial^2 S}{\partial k_z^2}$	$g\mu$*	H_0 kOe	$\frac{\partial \ln H_0}{\partial \sigma_{\parallel}} \cdot 10^{12}$ cm^2/dyn	T_D, °K
δ_1^1	-8.8 ± 0.3	0.12 ± 0.01	1.62 ± 0.01 2.38 ± 0.01	7.3	$(1.5 \pm 0.3) \cdot 10^4$	0.28
δ_1^2	-1.0 ± 0.3	-1.96 ± 0.10	1.53 ± 0.02 2.47 ± 0.03	–	–	0.28

*The two possible values of the g-factor correspond to the principal values of the argument $(\pi g\mu/2)$. [4]

was obtained independently from the data of[2], viz., $(\partial^2 S/\partial k_z^2)_{[001]} = -1.96 \pm 0.1$.

The calculated values of the parameters are listed in the table. The difference between the results of the independent data reductions at $T = 0.37$°K and $T = 1.4$°K has made it possible to estimate the errors of the parameters in the table. The figure shows the spectrum of the oscillations of $U_{\parallel}$ under conditions when $4\pi|\partial M/\partial H| \approx 0.26$. Since the symmetry group of the undeformed tin lattice[6] contains three sets of mirror planes, all the first derivatives of S and H_0 with respect to U_{ik} with $i \neq k$ vanish. In addition, the deformation U_{33} does not lift the degeneracy at the point X, and consequently $\partial \ln H_0/\partial U_{33} \ll \partial \ln H_0/\partial U_{\parallel}$. Therefore our results (in the table) together with the results of direct measurements of the dependence of S on σ_{33}[8] and the values of the elastic-tensor components[9] make it possible to change over from derivatives with respect to σ_{ik} to derivatives with respect to the lattice deformation U_{ik}:

$$\frac{\partial \ln S(\delta_1^1)}{\partial U_{33}} = +17.2, \quad \frac{\partial \ln S(\delta_1^1)}{\partial U_{\parallel}} = -4.7.$$

The signs and the magnitudes of the derivatives

$$\frac{\partial \ln S(\delta_1^2)}{\partial U_{33}} = +3.4, \quad \frac{\partial \ln S(\delta_1^2)}{\partial U_{\parallel}} = -0.04,$$

$$\left(\frac{\partial \ln H_0}{\partial U_{\parallel}}\right) = +1.8 \cdot 10^4 \tag{4}$$

$\partial \ln S/U_{ik}(\delta_1^1)$ agree with the representations of the model of almost free electrons. The last of the parameters in (4) exceeds by one order of magnitude the value obtained from the rough estimate.

$$\frac{\partial \ln H_0}{\partial U_{\parallel}} \sim 2\frac{\partial \epsilon_g}{\epsilon_g \partial U_{\parallel}} \sim 2\frac{\epsilon_F}{\epsilon_g}.$$

It follows therefore also that in the case of a uniaxial compression with $\sigma_{\parallel} \sim 10^2$ atm the hole surfaces of zones III and IV should coalesce along the XL line of the Brillouin zone. [2]

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