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OBSERVATION OF CONSTANT SHORT-CIRCUITED CURRENTS IN A METAL EXCITED BY A MICROWAVE FIELD

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Constant potential differences (on the order of several microvolts) induced in bismuth single crystals at helium temperatures by microwaves (power on the order of several milliwatts) in constant magnetic fields (on the order of several kOe) were investigated in [1]. It was established there that two emf's are excited in the bismuth: 1) the Nernst emf due to heating of the sample by the microwave current, and 2) an rf emf due to the action of the microwaves. The potential difference was measured between two points on the sample, to which the measurement leads were welded by an electric spark. The sample was a single-crystal disk of approximate diameter 18 mm and thickness 0.2 - 1 mm, and served as the bottom of a strip resonator, so that the sample was exposed to the microwave field on one side, while the measurement leads were welded to its other side.

The experiments have shown that the rf emf directed parallel to the microwave currents in the sample and perpendicular to the constant magnetic field (this vector orientation is optimal) is proportional to the microwave power and increases with decreasing sample thickness. It follows from these facts that the field of the emf inside the sample is inhomogeneous and a closed electric current due to the radio emf should flow in the sample and should be discernible by its magnetic field.

In the experiments described below we observed the existence of closed electric currents in metal single crystals exposed to microwaves and placed in a constant magnetic field at helium temperatures.

The investigated metal sample was placed in a strip resonator similar to that used in [1]. The arrangement of the main parts of the instrument is shown in Fig. 1. The microwave currents J flow in the strip St and in its image Im in the sample along a strip length equal to half the microwave wavelength ($\lambda \approx$ 1.4 cm). The rf emf also has the same direction. The receiving induction coil C (400 turns of PEL 0.05 wire, length 3 mm, cross section $\sim$30 mm^2) is located below the center of the sample, approximately 0.5 mm from its surface, and is contained in a thin conducting screen Scr, which prevents capacitive coupling between the coil and the sample. The coils terminals are connected to the input of an amplifier with a synchronous detector tuned to 15 kHz; the noise level of the circuit is $\sim$0.3 nV, corresponding to a magnetic-flux amplitude $\sim 10^{-9}$ G-cm^2 in the coil. The alternating magnetic flux received by the coil is produced by the closed current I (Fig. 1) excited in the sample by microwave radiation from a klystron meander-modulated at 15 kHz.

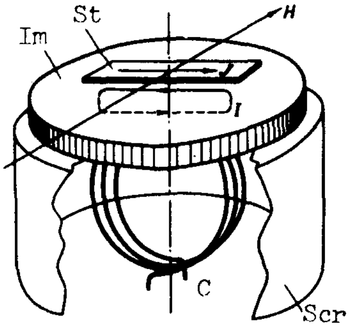

Fig. 1

Figure 2 shows the signal obtained in the experiment with single-crystal bismuth. The vertical Φ scale represents the amplitude of the flux received by the measuring coil; the I scale is the result of the following calibration: the sample

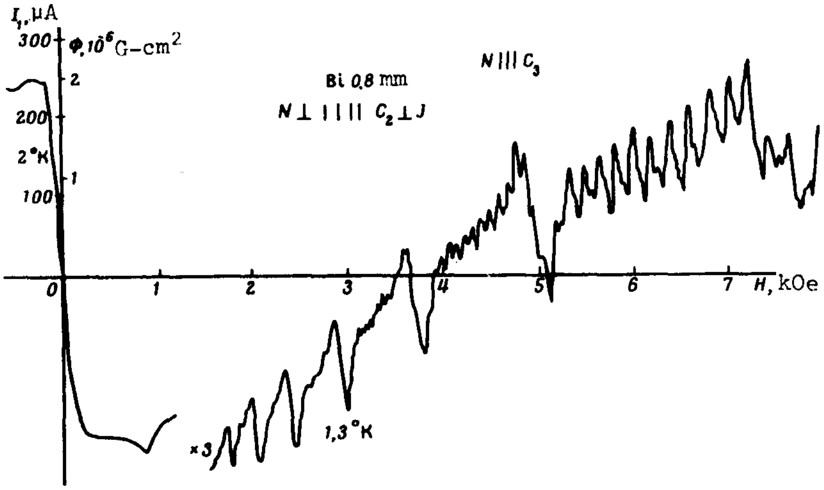

Fig. 2

was replaced by a coil simulating that part of the sample which is located under the strip and in which, by assumption, the current I flows. A known 15-kHz current i was made to flow through this coil and produced in the measuring coil the calibrated signal Φ. The current $I_1 = ni$ is the single-turn equivalent of n turns of the simulating coil. The I_1 scale therefore makes it possible to estimate the closed current I flowing in the sample.

The observed signal Φ is proportional to the microwave current. A rise in temperature leads to a decrease of the amplitude Φ and to a resolution of the peaks of the quantum oscillations and of the magnetoplasma resonances. The signal is maximal at $H \perp J$ and decreases to zero at $H \parallel J$; the anisotropy of the bismuth crystal in the basal plane has little effect here. The time needed for Φ to assume its steady-state value does not exceed 10 μsec.

The observed excitation of constant closed currents in metals by microwave fields is obviously directly connected with the excitation of constant emf's, several possible mechanisms for which were discussed in [1]. Recent papers [2, 3] analyze certain cases in which closed currents should appear in metals. The numerical estimates, however, are not in satisfactory agreement with experiment. The observed phenomenon therefore still needs explaining.

We emphasize the appreciable methodological advantages of investigating the magnetic fields of currents in a sample as compared with measuring potential differences. The elimination of the galvanic contacts with the sample prevents damage to the single crystal, eliminates noise due to contact potential differences and potential emf's (which cannot cause eddy currents in the sample), and facilitates the study of the anisotropy of the effect. On the other hand, if the emf induced in the metal operates in the short-circuit regime, there are no potential differences across the sample and the currents flowing in the sample can be revealed only by the magnetic field they produce.

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EXPERIMENTAL OBSERVATION OF OSCILLATIONS ON THE ELECTRON DISTRIBUTION FUNCTION FOLLOWING PLASMA-BEAM INTERACTION

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It follows from the recently developed nonlinear theory of plasma-beam interaction [1 - 3], in which account is taken of the bunching of the beam electrons (formation of "macroparticles") and of capture of the beam electrons by the field of the wave, that the beam velocity distribution function should have a complicated multiple-peak form that varies during the course of the electron-beam relaxation. In many experiments, however, the observed distribution function was smooth and tends in the limit to the plateau predicted by the quasilinear theory.

It was shown earlier experimentally that even under conditions of stationary injection of the beam into the plasma the interaction has a nonstationary character manifested by rapid variations of the amplitude, of the frequency spectrum, and of the structure of the excited oscillations, and due, in particular, to the excitation of different modes of low-frequency oscillations [4, 5]. One should expect the distribution-function oscillations predicted by the nonlinear theory likewise to reveal in the experiments a nonstationary character, since their character is determined by the amplitude and by the frequency spectrum of the field. Such a nonstationary behavior should lead at a large measurement time constant to averaging of the experimentally-observed distribution function.

Even if the beam interacts with a monochromatic wave of given amplitude, the time averaging, as shown by our calculation[1)], leads to a smoothing of the oscillations on the distribution function and ultimately, with a sufficiently long averaging interval, to formation of a plateau.

It should be noted that in the experiments performed to date the time measurement of the distribution function was always larger than the characteristic period of the nonstationarity, and this inevitably led to averaging of the measured quantity and to smoothing of the observed distribution function.

To ensure experimental observation of the fine structure of the distribution function, it is thus necessary to make the measurement times short compared with the nonstationarity period. We present below the results of such an experiment.

The experiment was performed with a plasma-beam discharge in hydrogen in a longitudinal magnetic field of 0.2 Tl with initial electron-beam energy 1 keV at a current of 20 - 40 mA [6]. The electrons were velocity-analyzed with a grid analyzer in coaxial form, which make it possible to record the delay-current curve within a time on the order of several dozen nanoseconds. The decelerating voltage was a sawtooth pulse of 1.5 kV amplitude with a growth rate of 6×10^9 V/sec. The upper limit of the bandwidth of the measuring circuits was not lower than 200 MHz. The measurement system operated in a single-triggering regime with stationary beam injection.

[1)] This calculation will be published in a detailed article.