(which in this case is approximately 0.2 mW), remains practically constant in time.

The foregoing data lead to the conclusion that elimination of the spatial inhomogeneity of the field in the laser generator makes it possible to intensify the coupling between the oscillation modes even in the case of a non-uniformly broadened line, and to obtain sufficiently powerful generation with 1 - 2 longitudinal modes.

[1] Tang, Statz, de Mars, and Wilson, Phys. Rev. 136, AI (1964).

CONNECTION BETWEEN REAL AND IMAGINARY PARTS OF SURFACE IMPEDANCE IN THE SIZE EFFECT

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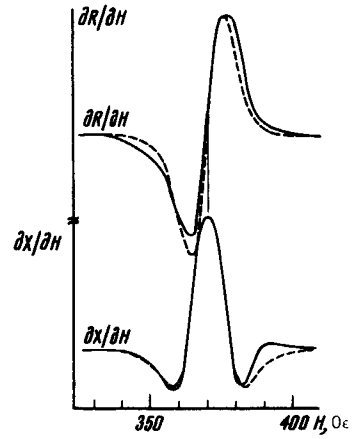
In the measurements of the radio-frequency surface impedance $Z = R + iX$ of thin metallic plates placed in a magnetic field H, a discontinuity ΔZ is observed on the Z(H) curve at that value of the magnetic field for which the diameter of the extremal trajectory of the electron is equal to the thickness of the sample. This type of size effect was observed by Gantmakher in tin [1] and proposed by him as a tool for the study of the Fermi surfaces of pure metals. Subsequently a different type of radio-frequency size effect was investigated, due to the electrons of the turning point [2]. It was noted in [1], where the imaginary part of the impedance was measured, that the resultant size-effect lines are quite varied in shape, and the latter does not depend on the frequency of the external electromagnetic field, or the thickness of the sample, and does not change after the surface of the metal is etched. For further study of the factors influencing the line shape, we have called attention in experiments with indium on the relationship between the changes of the imaginary and real parts of the surface impedance in the size effect.

The experiments were carried out at a temperature $T = 1.3°K$, using single-crystal samples grown from high-purity indium ($\sim 10^{-4}\%$ of impurities) in a dismountable polished quartz mold [3]. The samples constituted discs 18 mm in diameter and 0.3 - 0.4 mm thick. At a temperature $T = 1.3°K$, the mean free path of the electrons, estimated from the experimental data [4], was 0.5 mm. The sample was placed in the core of a radio-frequency oscillator tank circuit. The oscillation frequency was $f \sim 3$ Mcs, the oscillation amplitude $U \sim 0.1$ V. A modulation procedure was used to investigate the Z(H) dependence. The frequency of modulation of the magnetic field was 20 cps. By means of frequency [1] or amplitude detection of the oscillator carrier we registered a signal proportional respectively to $\partial f/\partial H \sim -\partial X/\partial H$ and $\partial U/\partial H \sim -\partial R/\partial H$. The circuits were not calibrated for absolute sensitivity.

The experiments have shown that on passing through a size-effect line the changes in the imaginary and real parts of the impedance are not proportional to each other. A qualitative comparison of the experimental $\partial R/\partial H$ and $\partial X/\partial H$ curves shows that for all the size-effect lines observed for indium, among which curves of a rather complicated form were encountered, the extrema of one function occur in places where the other function experiences the most abrupt change (each function is determined accurate to a multiplier and an arbitrary constant). The same is observed for lines of the size effect on turning points. In order to increase the group of phenomena considered, it would be interesting to modify the geometry of the experiment, for example, to employ a procedure similar to that used in [5], where a signal passing through a metallic plate was registered, or else to set up an experiment with our apparatus in the presence of a skin layer on only one surface of a plate made of the investigated metal (this can be done by depositing on the other surface of the sample a metallic film of sufficient thickness). However, even the observations already made make it possible to raise the question of the existence of the connection between the variation of ΔR and ΔX in the presence of size effects, due to some general properties of the equations of motion of the electrons in the metal.

As is well known, for resonance effect, for example nuclear resonance, where the susceptibility is a function of the frequency, the connection between the absorption and the dispersion is determined by the Kramers-Kronig relations [6]. In the case of size effects, we deal with an entirely different type of phenomenon, inasmuch as neither the position nor the shape of the line depends in practice on the frequency f of the electromagnetic field. We have attempted, however, to verify in the case of the size-effect line of simplest symmetrical form the existence of integral relations between ΔR and ΔX, which can be obtained from the Kramers-Kronig relations by formally replacing the variable f with the value of the magnetic field H. To this end we compared the $\partial R(H)/\partial H$ and $\partial X(H)/\partial H$ curves for a specially chosen size-effect line with the functions given in [6], connected with the Kramers-Kronig relations (see the figure, where the dashed curves are the derivative of the Gaussian curve and the function obtained from it [6] with the aid of the indicated relations).



Size-effect line recorded for an indium sample 0.3 mm thick. The normal to the surface of the sample is parallel to [001], and the high-frequency electric field on the surface of the sample is directed along [100]. The angle between H and the [010] axis is 37°. The ordinate scale is arbitrary, and is not the same for the upper and lower curves.

The sufficiently good agreement between the curves in the figure speaks in favor of the existence of the assumed integral relations between ΔR and ΔX. We emphasize that we are dealing only with changes in impedance under the size effect, and that the region of integration includes the width of the line, but does not extend over all values of the magnetic field.

It must be noted in this connection that the described relations between ΔR and ΔX are not valid for phenomena where, unlike the size effects, the quantization of the energy levels of the electron in the magnetic field is essential. Indeed, in the case of another frequency-independent effect, namely quantum oscillations of the surface impedance, the nonmonotonic variation of $\Delta R(H)$ and $\Delta X(H)$ are proportional. This follows from the theoretical analysis [7] and was verified by us experimentally. Oscillations of the impedance of indium single crystals, periodic in the reciprocal field, were observed at H = 8 - 10 kOe, and the oscillograms of R and X had no noticeable phase shift.

There are no theoretical calculations as yet for the size-effect line shape, since these calculations entail noticeable difficulties. It is possible, however, that the observed connection between ΔR and ΔX in the size effect can be explained by starting directly from the properties of the equations for current distribution in metal, without calculating the line shapes for different concrete cases.

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[1] V. F. Gantmakher, JETP 44, 811 (1963), Soviet Phys. JETP 17, 549 (1963).
[2] V. F. Gantmakher and E. A. Kaner, JETP 45, 1430 (1963), Soviet Phys. JETP 18, 988 (1964).
[3] Yu. V. Sharvin and V. F. Gantmakher, PTE, No. 6, 165 (1963).
[4] V. F. Gantmakher and I. P. Krylov, JETP 47, 2111 (1964), Soviet Phys. JETP 20, 1418 (1965).
[5] W. M. Walsh and C. C. Grimes, Phys. Rev. Lett. 13 (17), 523 (1964).
[6] G. E. Pake and E. M. Purcell, Phys. Rev. 74, 1184 (1948).
[7] M. Ya. Azbel', JETP 34, 1158 (1958), Soviet Phys. JETP 7, 801 (1958).

GENERATION IN GaAs UNDER TWO-PHOTON OPTICAL EXCITATION OF NEODYMIUM-GLASS LASER EMISSION

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To produce a population inversion in a medium using a three-level scheme, the pump photon energy should be larger than the energy difference between the working levels. Operating in an analogous scheme is a semiconductor laser with optical pumping [1], in which the energy of the exciting photon exceeds the energy width of the forbidden band.

We have succeeded in exciting with GaAs emission a neodymium-glass laser (with modulated Q) when the energy of the pump photon, equal to 1.17 eV (λ = 1.06μ), was considerably smaller than the energy width of the forbidden band in GaAs, which amounts to 1.51 eV (λ = 8200 Å) at T = 77°K. In other words, the energy of one exciting photon was not enough to transfer the electron from the valence band of GaAs to the conduction band. However, at large light-flux densities incident on the sample, excitation is possible as a result of nonlinear optical