as emission begins (it begins in the central part of the ruby), the distribution of the refractive index in the cross section changes as a result of the change in the population, and the point of convergence of the rays emerging from the ruby moves farther away. This is equivalent to increasing the radius of curvature of the mirror, and consequently to a changeover to a low-loss resonator configuration, which is indeed the cause of the generation of the giant pulse. It is important to emphasize here that these effects are particularly strongly pronounced in resonator configurations in which the field becomes highly concentrated in the active sample.

Analogous phenomena were observed also in resonators made up of spherical and flat reflectors, or of convex and concave spherical mirrors. These effects were weaker for the latter configuration.

In conclusion we note that the described principle of generating giant pulses does not depend on the radiation wavelength and can apparently be employed in neodymium glass and other active media that generate in the infrared region.

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NONLINEAR MICROWAVE PROPERTIES OF THIN SUPERCONDUCTING FILMS

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1. Nonlinear effects in microwave resonators containing thin superconducting films have been described and discussed in a number of papers [1-2]. However, no satisfactory model capable of explaining, for example, the low values of the microwave power at which these effects arise has been proposed as yet.

The purspose of the present paper is to show that these nonlinear phenomena are connected with the structure produced in the films by vortices whose symmetry axes are normal to the plane of the film [3,4]. Such a structure differs strongly from the usual mixed state of bulky superconductors of the second kind, and this is indeed the reason why very small values of the fields suffice for this occurrence.

2. Let us consider a model of an experiment of the Clorfeine type [1], in which a rectangular dielectric resonator ($\epsilon \gg 1$) is produced with dimensions $a_x \times a_y \times a_z$, with $a_z \ll a_{x,y}$ 1). For such a resonator, the principal oscillation modes are H_{mno} and E_{mno} [5], for which the vectors $\vec{H}$ and $\vec{E}$ are respectively perpendicular to the larger faces of the resonator. We consider only the oscillation modes H_{mno}, which are noticeably coupled to the incident microwave.

Assume now that a superconducting film is now coated on the larger face of the resonator. Then the field of the oscillations in the resonator, having a vector component $\vec{H}$ normal to the film, excites Meissner currents in the film. Solving the boundary value problem by the method of the potential of a simple layer, for a film of small thickness ($d_0 \ll \delta, \xi_0$),

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1) An analysis of experiments of other types [2] yields practically analogous results.

when the conditions $\delta_\perp \ll \lambda/\sqrt{\epsilon} \ll a_z$ are satisfied, we can obtain for the currents in the linear case (for details see [6])

$$\nabla_2 j = (c\sqrt{\epsilon}/\lambda d_0)\vec{H}_0 \cos k_x x \cos k_y y. \qquad (1)$$

Here $\vec{H}_0 \cos k_x x \cos k_y y$ is the field in the resonator without the film, λ is the wavelength in vacuum, $\delta_\perp = 2\delta^2/d_0$ is the characteristic depth of penetration of the perpendicular field into the film [3], and $(k_x^2 + k_y^2)^{1/2} = 2\pi\sqrt{\epsilon}/\lambda$.

Assume now that a single Pearl vortex [3] enters into the film, carrying one quantum of magnetic flux (vortices of larger multiplicity are unstable in thin films [4]). This entry will be favored from the energy point of view if the Lorentz energy of the interaction between the vortex and the resonator field $\mathcal{E}_f$ is larger than its self-energy $\mathcal{E}_0$. The energy of the interaction is maximal at the nodes of the current (their number in the film is $m \times n$), and under the assumptions made above it is equal to

$$(\mathcal{E}_f)_{\max} = \varphi_0 H_0 \lambda / 4\pi^2\sqrt{\epsilon}, \qquad (2)$$

and the self-energy is

$$\mathcal{E}_0 = (\varphi_0/4\pi)^2 \delta_\perp^{-1} \ln(\delta_\perp/\xi) \qquad (3)$$

everywhere except in a narrow strip of width $\delta_\perp$ along the edge of the film.

Thus, if at a given instant of time H_0 is larger than the critical value H_{c1}, which in this case is equal to

$$H_{c1} = \frac{\sqrt{\epsilon}}{2}\,\frac{\phi_p}{\lambda\delta_\perp}\ln(\delta_\perp/\xi) \sim f(t) = (1-t^4)[1-\ln(1-t^4)/C_1], \qquad (4)$$

$$(t = T/T_c, \quad C_1 = \ln(\lambda/\xi_{t=0})),$$

then the entrance of one vortex in each of the nodes of the current on the film is facilitated, and owing to the different orientations of the field $\vec{H}$ the neighboring vortices should be antiparallel, making their interaction, which was not taken into account above, negligible. This interaction, however, is important for closely-lying vortices and makes it possible for more than one vortex to enter in each node of the current when $H_0 \gtrsim H_{c1}$.

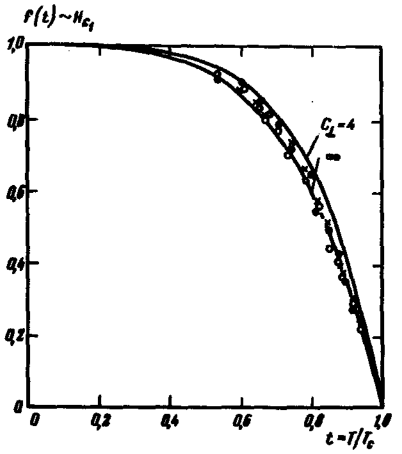

Fig. 1. Temperature dependence of H_{c1}: × - f = 39.14 GHz, ● - 38.76 GHz, o - 37.03 GHz; d_0 = 350 Å.

The entry of the vortices into the film is hindered by a sufficiently high edge barrier, the action of which, however, is reduced to nothing, as can be shown, by even very small irregularities of the film. One can therefore expect the vortices to enter and leave the current nodes each half cycle of the oscillations when the amplitude of the oscillations in the resonator exceeds only slightly the value of

H_{cl}. This should be accompanied by an appreciable dissipation and by an increase of the absorption of the microwave energy by the resonator, and also by a certain shift of the resonant frequency. Such effects were indeed observed in the experiments [1-2] in the form of pairs of steps on the resonance curve. The succeeding pairs of steps (with increasing microwave power) can be attributed to the entry of the succeeding vortices into the current nodes.

It is seen from (4) that the value of H_{cl} is quite small ($\sim 10^{-1} - 10^{-3}$ Oe). Therefore the nonlinear effects connected with the entry of the vortices should become manifest already at small powers ($\sim 10^{-4} - 10^{-8}$ W), and should be very sensitive to the normal component of the constant magnetic field, as was indeed observed in the experiment [1].

3. The model under consideration was verified by special experiments on the behavior of rutile resonators whose larger faces were sputtered thin films ($d_0 = 150 - 400$ Å) of tin, in response to microwave signals in the frequency ranges 9 - 10 and 35 - 39 GHz. Particular attention was paid to a thorough shielding against the normal components of the earth's magnetic field.

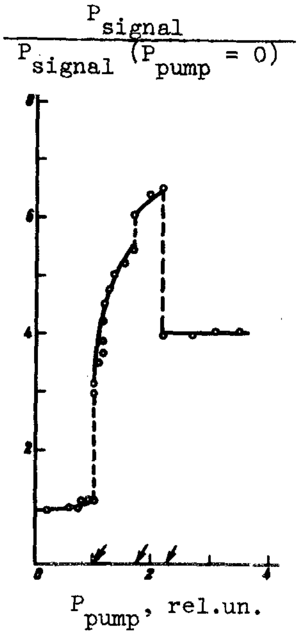

Fig. 2

The points in Fig. 1 show the experimental temperature dependence of H_{cl}. The solid lines show the theoretical dependence (4). Good agreement of these relations is observed.

The model considered above makes it also possible to determine correctly the absolute value of the field H_{cl}. Thus, for the experimental values of the parameters, $a_{xy} = 0.20$ cm, $a_z = 0.08$ cm, $t = 0.54$, $\lambda = 0.81$ cm, $d_0 = 350$ Å, $\delta_{t=0} = 2.4 \times 10^{-5}$ cm, and $C_1 = 4$, the value $H_{cl} = (1.0 \pm 0.3) \times 10^{-2}$ Oe obtained from (4) agrees with the experimental value $H_{cl} = (1.2 \pm 0.2) \times 10^{-2}$ Oe.

4. It follws from the model under consideration that the nonlinear effects in similar experiments are connected only with the motion of the vortices, and not with the manifestation of a nonlinearity of the Ginzburg-Landau type. Indeed, it follows from (1) and (4) that the deviation of the square of the parameter from the linear value at the instant of the entry of the first group of vortices is of the order of $\epsilon(\xi/\lambda)^2$ and does not exceed 10^{-5} for real values of the parameters. Therefore all the nonlinear effects (formation of combination frequencies, parametric amplification, etc.) should not become manifest before the total field intensity of the oscillations in the resonator reaches the value H_{cl}. Figure 2 shows a typical dependence of the reflected weak signal on the pump signal power, and the arrows mark the values at which pairs of steps appear on the resonance curve. We see that there is no amplification at fields weaker than H_{cl}.

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SEMICONDUCTOR - "QUASIMETAL" - SEMICONDUCTOR TRANSITION IN $Bi_{1-x}Sb_x$ ALLOYS UNDER THE INFLUENCE OF PRESSURE

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1. We investigated the influence of the pressure p ($0 \leq p \leq 20$ kbar) on the energy spectrum of $Bi_{1-x}Sb_x$ alloys with $0 < x \leq 0.15$ by measuring the galvanomagnetic characteristics in both extremely weak magnetic fields and in strong magnetic fields H in the temperature interval 1.5 - 300°K.

2. In the $Bi_{1-x}Sb_x$ alloys (at $x > 0.05$) we observed a transition under the influence of the pressure p (at $H = 0$) from the superconducting state into a new state (called "quasimetallic") characterized by anomalously small values of the energy gap ϵ_g and of the effective carrier masses. The transition is the result of the coming together, under the influence of the pressure, of the terms L_a and L_s (the notation is from [1]), which determine at $p = 1$ bar and $x > 0.05$ the bottom of the conduction band and the top of the valence band at the point L of the reduced Brillouin zone, respectively.

3. The change of the structure of the energy spectrum of the $Bi_{1-x}Sb_x$ alloys with increasing x under atmospheric pressure occurs in the following manner (Fig. 1a). The top of the valence band in T (the term T_{45} [1]) drops relative to the term L_s (of the bottom of

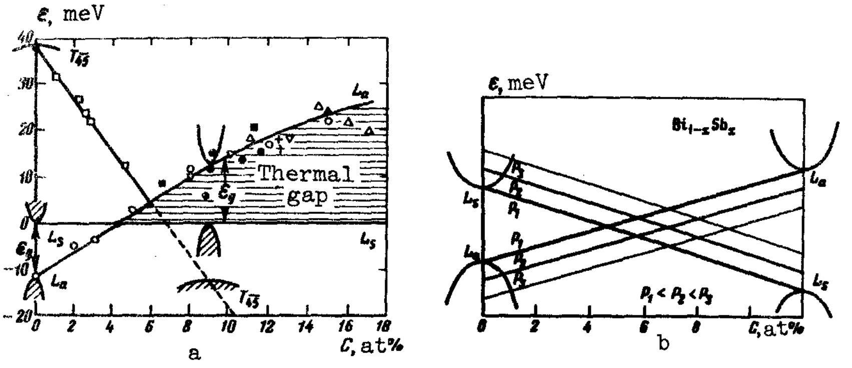

Fig. 1. a) Structure of energy spectrum of $B_{1-x}Sb_x$ alloys vs. the antimony concentration x at atmospheric pressure: o - [2], ● - [8], ▲ - [4], △ - [5], ▽ - [6], + - [7], □ and ■ - present data. b) Qualitative plot of energy ϵ of the terms L_s and L_a vs. pressure p in $Bi_{1-x}Sb_x$ alloys with different x.