NONLINEAR EFFECTS IN THIN SUPERCONDUCTING TIN FILMS AT MICROWAVE FREQUENCIES

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Submitted 23 July 1967
ZhETF Pis'ma 6, No. 7, 752-755 (1 October 1967)

Much attention is being presently paid to investigations of the behavior of thin superconducting films of varying configuration at microwave frequencies [1-3].

We have investigated certain effects that occur in superconducting thin tin films (2000 Å thick) at frequencies on the order of 10 GHz. The film constituted a strip resonator placed in a rectangular waveguide parallel to the broad wall. The film was sputtered on a quartz substrate. To reduce its geometric dimensions but retain its electric length, the film was covered with a dielectric having a large value of ϵ, in our case sapphire ($\epsilon \approx 10$). The resultant film dimension was 2 x 6 mm.

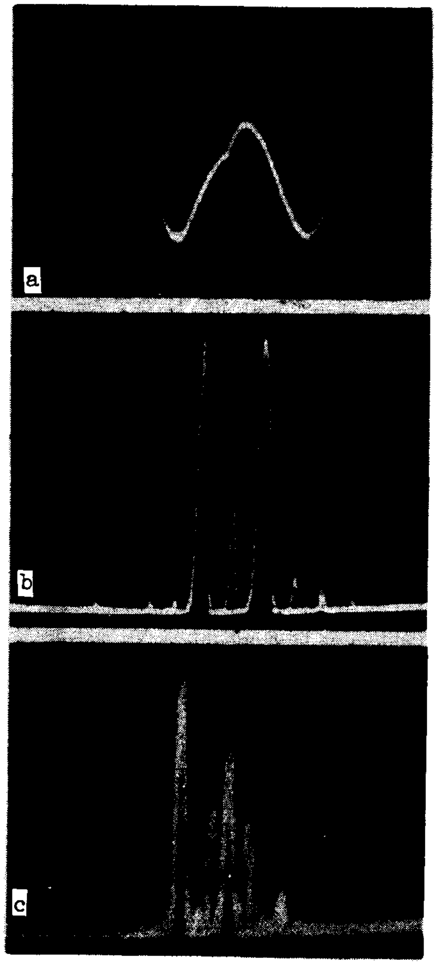

Fig. 1

Unlike in [1,3], there was no resonance in the dielectric at the working frequency used in our experiments, and the role of the resonator was assumed by the film itself, which was placed in an H_{10} antinode of the microwave field. A circulator was used to observe the reflected power. The use of a frequency-modulated signal made it possible to trace the resonance curve of the strip resonator. When the incident power was increased to 10^{-5} W, a step appeared abruptly on the top of the resonance curve (Fig. 1a), thus indicating a jumplike retuning of the strip resonator to another lower frequency. The produced step remains at the same power level, shifting with increasing incidence power along the resonance curve, while new steps appeared on its top. Up to 20 steps were observed when the incident power was increased from 10^{-5} to 10^{-2} W.

The appearance of steps can be attributed to the fact that when the microwave power is increased the intensity of the microwave magnetic field also increases and when the latter reaches the first critical value H_{c1} it penetrates into the superconductor, causing a change in the resonant frequency of the resonator. To check on this assumption, we obtained experimentally the temperature dependence of the microwave power at which the first step appears, and also calculated the temperature dependence of the power at which the intensity of the microwave magnetic field reaches the value H_{c1}. The calculation results and experimental points are shown in Fig. 2, where the abscissas represent the relative temperature $t = T/T_c$ and the ordinates the value of $H_{micr} \sim P^{1/2}$ normalized to its maximum value, where P is the incident microwave power. The temperature dependence of the critical field, $H_{c1}(t) = H_0(1 - t^2)$ [4], of the depth of penetration of the field in the superconductor $\lambda(t) = \lambda_0(1 - t^4)^{-1/2}$, and of the surface resistance $R_s(t) \sim [t^4(1 - t^2)]/[(1 - t^4)^2]$ [5] were all taken into account in the calculations. It is seen from Fig. 2 that the experimental points agree well with the calculated curve up to $t \approx 0.5$. The deviation for $t < 0.5$ can be attributed to the presence of residual resistance in the superconductor at microwave frequencies when $t = 0$ [5].

The presented temperature dependence and the presence of a large number of steps arising periodically with increasing incident power indicate that the appearance of the steps is due to the jumplike penetration of the magnetic field into the film, and possibly to the formation of a vortex structure in the film [6].

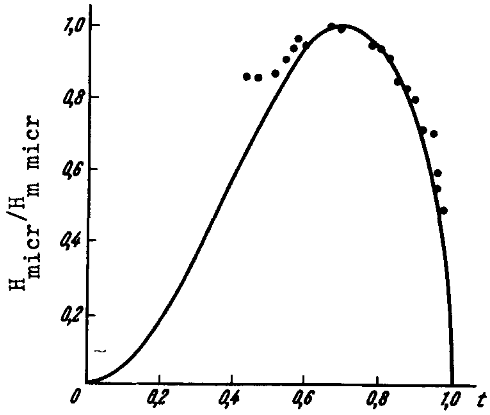

Fig. 2

The experiments show that when microwave power is fed to a superconducting strip resonator, a change takes place in the resonator parameters (resonant frequency), and consequently the resonator is a nonlinear element. We should therefore observe in it all the effects inherent in nonlinear parametric systems. Indeed, we have observed experimentally a frequency shift and the generation of a new frequency (Fig. 1).

To observe the frequency shift, we fed to the resonator two signals with different but close frequencies lying in the pass band of the resonator. Up to seven combination frequencies were observed in this case, thus indicating that the strip resonator is highly nonlinear.

When two signals of nearly equal power ($P \approx 10^{-5}$ W) were applied, generation of a new frequency, not a combination, was observed. If the signal frequencies were symmetrical about the resonant frequency of the resonator, the generation took place at the resonator frequency (Fig. 1b). On the other hand, if the frequency of one of the signals was equal to the resonant frequency, then two new frequencies were generated, symmetrically situated relative to the resonance (Fig. 1c). Generation appeared when the power of any one of the signals increased, and was observed in a narrow power interval. Further increase in power stopped the generation, leaving only the combination frequencies of the two signals. The signal at the generated frequency was very sensitive to an external constant magnetic field normal to the film surface.

Thus, a thin superconducting tin film 2000 Å thick exhibits strong nonlinear properties at microwave frequencies, leading not only to the appearance of already known effects, but to a highly unique interaction between two signals incident on such a film. The nature of this interaction may be connected with the development of certain types of instabilities when the microwave magnetic field penetrates into the film. The physical picture of the instabilities is still to be explained.

The authors are grateful to B. I. Verkhin for continuous interest in the work and to I. O. Kulik for a useful discussion of the results.

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LUMINESCENCE INDUCED BY ALPHA PARTICLES IN LIQUID XENON IN AN ELECTRIC FIELD

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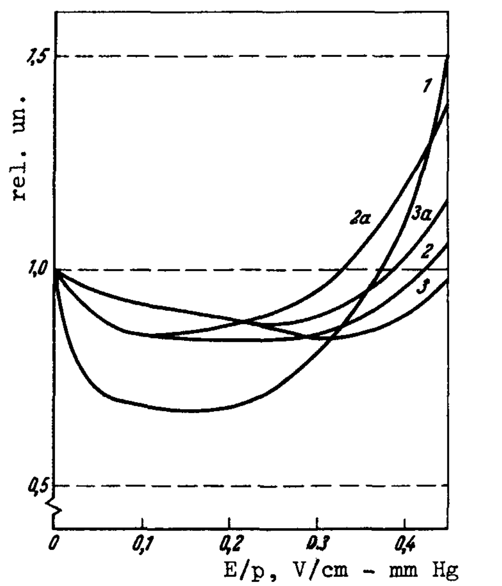
Submitted 25 July 1967
ZhETF Pis'ma 6, No. 7, 755-757 (1 October 1967)

Study of the luminescence induced by the passage of an ionizing particle through a liquefied noble gas in an electric field is of interest, first, to ascertain the behavior of the free electrons in the liquid, and second, to assess the possibility of registering the trajectories of ionizing particles in a liquiefied noble gas by the method used in technique of gas-filled spark track detectors.

The experimental setup has made it possible to register the luminescence of liquid xenon with the aid of a photomultiplier, in electric fields $E \leq 150$ kV/cm. The luminescence was initiated by 5.15-MeV alpha particles. The momenta from the photomultiplier were fed to a pulse-height analyzer.



Amplitude of luminescence in xenon at different E/p. 1 - gaseous xenon, density 0.5 g/cm^3, t = 20°C; 2 and 2a - liquid xenon, 1.74 g/cm^3, +10°C; 3 and 3a - liquid xenon, 2.07 g/cm^3, -5°C.

The figure shows the results of measurements of the luminescence in liquid and gaseous xenon at different values of E/p, where p is the pressure that would be possessed by xenon of given density were it to be an ideal gas at 300°K, and E is the intensity of the constant electric field.

The characteristic drop in luminescence amplitude (see curves 1, 2, and 3) observed for $E/p < 0.1$ is probably connected with the drawing-out of the electrons from the α-particle trach, which decreases the number of recombinations on the track. The attenuation of the luminescence amplitude was observed earlier in gaseous argon [1] and in liquid helium [2].

The increase in the luminescence amplitude at large E/p is due to the acceleration of an