NONLINEAR PROPERTIES OF A SUPERCONDUCTING LEAD FILM AT MICROWAVE FREQUENCIES

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Recent communications report the use of superconducting films for microwave conversion [1,2]. We observed frequency conversion in a superconducting lead film in the 3-cm band.

Lead films 200 - 400 Å thick were deposited in vacuum on one of the broad faces of a rectangular dielectric resonator (rutile single crystal measuring 4 x 4 x 1.5 mm), placed in a waveguide in such a manner that the magnetic field component was in the plane of the film. The fundamental mode of this resonator had a much lower frequency than those used in the experiment, so that one of the higher modes was employed. The coupling between the resonator and the waveguide was regulated by varying its depth of insertion in a section of waveguide operating beyond cutoff. The intrinsic Q of such a resonator in the 3-cm band was about 10^4 at liquid-helium temperature. All the experiments were made in a zero magnetic field at 4.2°K.

When two signals of close frequency were fed to the resonator, a combination frequency spectrum $[(m + 1)f_1 - mf_2]$, $m = 0, \pm 1, \pm 2, \ldots$ was obtained. Raising the power of

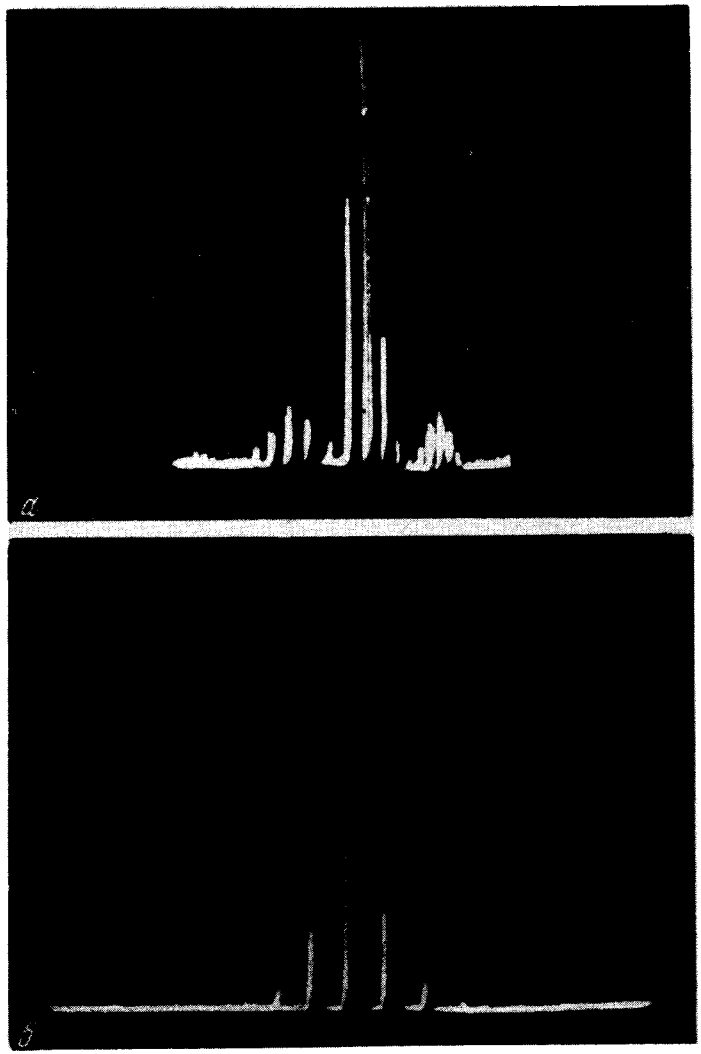

Fig. 1. a - combination spectrum of two microwave signals in the generation mode; b - the same in the presence of only the "illumination" signal (weak microwave signal turned off, frequency scale reduced).

any of the two signals to -34 dBm caused the spectrum to become more complicated, in that additional frequencies appeared and the ratio of the spectral-line amplitudes were altered (Fig. 1a). After the weaker signal was turned off, it was observed that the spectrum retained besides the frequency of the more powerful signal ("illumination") several additional frequencies, obviously generated by the superconducting film itself (Fig. 1b). The spectrum of these additional frequencies consists of a series of spectral lines symmetrically disposed on the two sides of the "illumination" frequency. The power level of the pair of lines closest to the "illumination" frequency is 15 ± 1 dB lower than the "illumination" level, and that of the next pair is lower by another 15 ± 2 dB. When the "illumination" power is increased above -34 dBm, the frequency difference between these lines and the "illumination" frequency increases gradually, but their amplitude remains practically unchanged. However, when the frequency deviation of the closest pair of lines becomes of the order of 2 - 3 MHz, the spectral intensity of these additional lines drops rapidly to zero.

At the instant of the onset of generation in the superconducting film, a "step" is produced on the envelope of the signal reflected from the resonator (Fig. 2). Further increase of the "illumination" power level leads to the appearance of several additional "steps" (up to five). An investigation of the dependence of the form of these "steps" on the duration of the microwave signal acting on the film has made it possible to establish that at least the last of them is already connected simply with the thermal action of the microwave power. This is apparently due to the inadequate cooling of the lead film. As to the remaining "intermediate" "steps," no such unequivocal influence of the thermal processes was observed here. On the other hand, no spectral changes connected with these "steps" were likewise observed. Further research is therefore necessary to explain their occurrence.

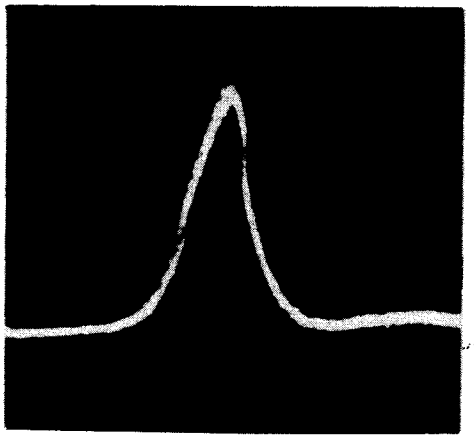

Fig. 2. "Step" on envelope of signal reflected from a resonator with superconducting lead film.

The appearance of "steps" on the signal reflected from the resonator with the superconducting film was observed also at certain definite frequencies located far outside the pass band of the resonator. Unlike earlier experiments, the magnetic field here was different from zero (≈10 - 20 Oe), and the "step" remained in fields up to about 100 Oe. Although no generation in the investigated frequency range was observed in these cases, it is quite possible that generation nevertheless did occur at those subharmonics of the "illumination" which coincided with certain lower modes of the resonator.

[1] A. S. Clorfeine, Proc. IRE 52, 844 (1964).
[2] R. V. D'Aiello and S. J. Freedman, Appl. Phys. Lett. 9, 323 (1966).