COMMENTS AND ADDENDA

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Stability of supercurrents in cylindrical films of tin. II. Single-crystal substrates*

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The previous measurements of Phillips and Meissner (which used Pyrex substrates) have been repeated using single-crystal quartz tubes as substrates. Differences in the results are rather minor, indicating that the observed phonomena are indicative of the superconductor rather than the substrate.

I. INTRODUCTION

This paper is a continuation of a paper by Phillips and Meissner,[1] hereafter referred to as PM. The investigation is concerned with the stability of supercurrents in cylindrical films of tin. While one would expect that in a cylindrical arrangement supercurrents are stable up to the Ginzburg-Landau[2] limit, this is not the case.

Using current pulses rising in less than 0.5 nsec, and with a duration of 250 nsec, it is found that the voltage V depends on time t as $V(t)=af(t/t')$ if the amplitude of the current density J exceeds a value $J_1(T)$ (T is the temperature). In PM it was suggested that the instability is a "flute instability" as invisioned by Fink and Presson[3] for currents in a superconducting surface sheath. Since then a theory of the stability of flux flow in superconducting films has been developed by Thompson and Hu.[4] This theory is in qualitative agreement with earlier experimental results by Tholfsen and Meissner.[5,6] Although the theory of Thompson and Hu assumes and depends on the presence of flux tubes, the data of Tholfsen and Meissner, in the limit of $H\rightarrow 0$ join (near T_c) the results obtained for the cylindrical films. In both cases, the expected final result is that the film breaks up into alternating normal and superconducting stripes oriented perpendicular to the current. Theoretical investigations of the stability of the supercurrent may lead to results which are qualitatively similar to those of Thompson and Hu. It is also possible that the residual magnetic fields (~1 mG) which still give ~10^4 flux tubes/cm^2 play a role in the initiation of the instability with the cylindrical films.

While for the start of the instability energy storage does not enter the problem, after the start of the instability entropy production and energy storage become important. As explained in PM, one would expect that this leads to extremely complicated processes. Instead, a universal time function $f(t/t')$ has been found in PM with the time constants t' ranging from 0.5 to 200 nsec, for temperatures from $0.95T_c$ to $0.5T_c$.

The purpose of this investigation is to see whether a single-crystal quartz tube as a substrate will provide a better heat sink than a Pyrex tube and give significantly different results.

As will be shown below differences are astonishingly small and can be explained by variations from sample to sample and slightly different emphasis during data taking.

II. EXPERIMENTAL ARRANGEMENT

The experimental arrangement is identical to that used in PM with only minor modifications. The pulses were produced by charging a rigid 50-Ω

TABLE I. Properties of samples.

Sample	T_c (°K)	$R_{4°K}$(total) (Ω)	$R_{4°K}$(sample) (Ω)	$R_{300°K}$ (Ω)	Film thickness (Å)	$H_c(0)$ (G)
*M*2	3.890	0.347	0.226	4.613	1115	1025
*M*3	3.878	0.909	0.859	7.534	615	2580
*M*4	3.833	0.432	0.412	4.579	917	1290

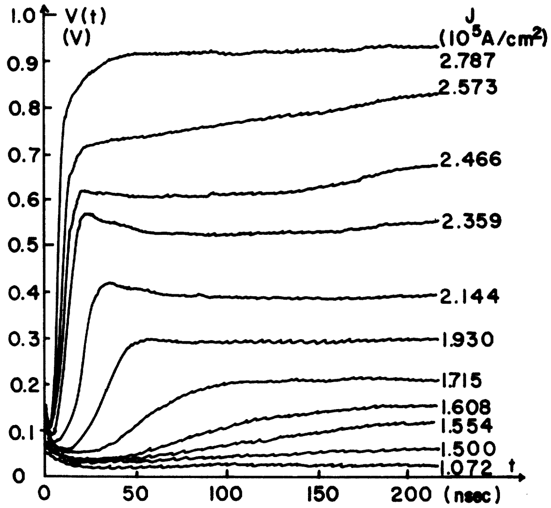

FIG. 1. Sample voltage as a function of time, sample $M4$, $T = 0.972T_c$; compare PM Fig. 2. The inductive spike at $t = 0$ is not caused by the kinetic inductance of the superconductor but by the sample mount.

coaxial line and discharging it through a concentrically mounted mercury relay. The sample is in a dual coaxial mount, forming the common conductor between two coaxial systems. The response with a normal film has been discussed in Ref. 7.

III. SAMPLES

The single-crystal quartz tubes (from Insaco Inc., Quakertown, Pa.) used for the substrates had an outer diameter of 3.17 mm, an inner diameter of 1.32 mm, and were 51 mm long. Their ends were fired with "Bright Platinum" and suitable brass end pieces were soldered on with soft solder. They were then installed in the rotating mount of a

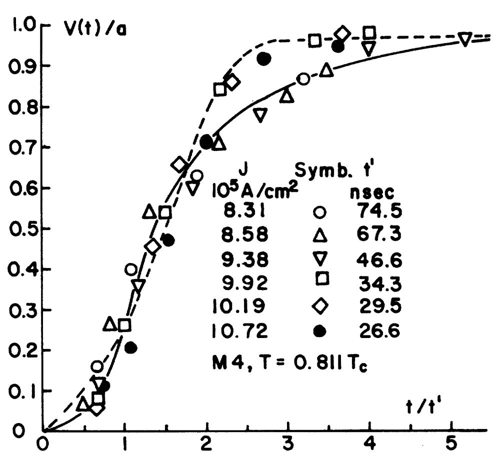

FIG. 2. Normalized voltage as a function of normalized time, sample $M4$, $T = 0.972T_c$; compare PM, Fig. 2.

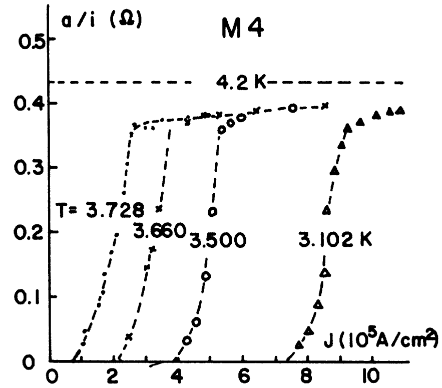

FIG. 3. Normalized amplitude a/i as a function of current density, compare PM, Figs. 3 and 4.

vacuum system. The tin was vapor deposited as described in PM. The ends were reinforced with an extra layer of tin. The sample mount, current return, etc., were quite similar to the one described in PM, with all impedances $Z_0 = 50\ \Omega$.

Table I shows the important properties of the samples which were determined as in PM.

Note that for sample $M2$ the extra layer of tin on the ends was too thin, leading to a rather large resistance of the ends [that is a large value of

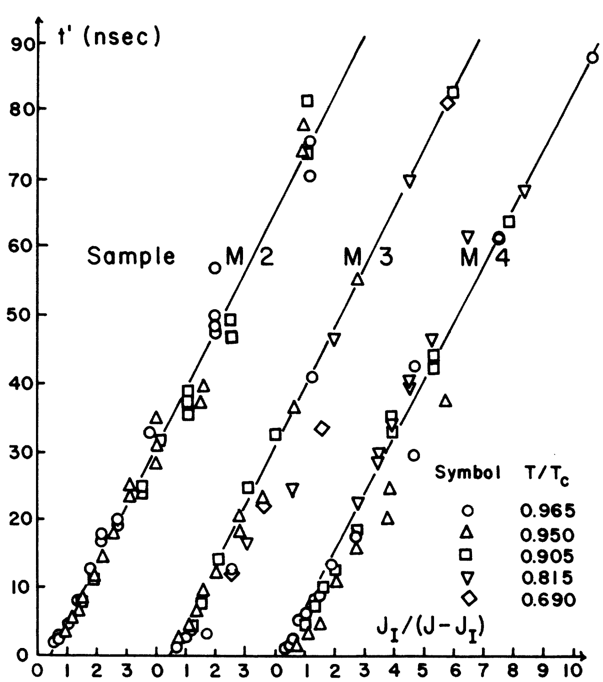

FIG. 4. Dependence of the time constant t' on $J_I/(J - J_I)$. The data for different samples have been shifted against each other by $J_I/(J - J_I) = 4$; compare PM, Fig. 5.

TABLE II. Density of instability current.

Sample	T/T_c	J_I (10^5 A cm^{-2})	$J_I(0)$ (10^5 A cm^{-2})
$M2$	0.959	2.383	15.45
	0.942	3.339	15.70
	0.902	5.425	16.05
		$\langle J_I(0)\rangle$[a]	15.76
$M3$	0.961	1.524	10.36
	0.946	2.242	11.26
	0.903	4.127	12.31
	0.803	7.452	12.76
	0.690	9.609	12.42
		$\langle J_I(0)\rangle$	12.14
$M4$	0.972	1.417	13.19
	0.955	2.557	15.20
	0.913	4.280	14.02
	0.811	7.902	13.92
		$\langle J_I(0)\rangle$	14.09

[a]Weighted average, assuming uncertainty in T_c of 0.015 K.

R_4(total) $-R_4$(sample)] and, at the higher temperatures, to a finite resistance even at low currents.

It should be mentioned that, in general, the construction of the ends was not as satisfactory as it was in PM. The irregularities in the platinum film gave rise to disturbances of the axial symmetry of the current distribution. This had little effect on the determination of the amplitudes or time constants of the $V(t/t')$ curves.

IV. EXPERIMENTAL RESULTS

Figure 1 shows a plot of sample voltage vs time typical for a time scale of 50 nsec/division, T close to T_c, and amplitudes ranging from rather small to rather large values. On this plot three types of behavior are visible: For small amplitudes the $V(t)$ curves have the universal shape used in PM. At somewhat higher amplitudes a small overshoot appears, most likely an inductive signal arising from the redistribution of the current around the circumference of the sample.

At still higher amplitudes one sees a slow gradual rise over most of the 250 nsec. At the highest amplitudes one sees a response with a perfectly flat top.

In the data taking in PM, time scale and amplitude were usually adjusted such that the pulse leveled off at the end of the interval (see Ref. 1, Fig. 2). Here, in most of the graphs somewhat longer intervals were chosen.

A double check of the original data of PM turned up one case of the gradual rise and a few cases of the "flat top." Here the gradual rise was found for all samples and all temperatures if the time constant t' was less than ~40 nsec. At this point the amplitude was always less than that corresponding to the normal state. This is not in contradiction to PM.

Figure 2 shows a representative plot showing how the function $f(t/t')$ changes from the shape used in PM to one with a "flat top" for the shorter time constants. One can see that the change is slight and may escape detection if shorter time intervals are used.

Figure 3 shows a representative plot of the normalized amplitude factor a/i as a function of current density J.

Figure 4 shows a plot of the time constant t' as a function of $J_I/(J-J_I)$, where J_I has been chosen such that the data points fall most nearly on a straight line of slope $\tau_0 = 8.6$ nsec, which is smaller than that of PM (14 nsec).

Table II lists the values of J_I and the values of $J_I(0) = J_I[1-(T/T_c)^4]^{-1}$ as obtained from the t' plots. Comparison with Table III of PM shows that there is no significant difference in the data.

V. CONCLUSIONS

The data with single-crystal substrates are remarkably similar to those with Pyrex substrates. Apparently the thermal resistance between film and substrates is large enough that at all temperatures for the short times used here the film is rather independent of the substrate.

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