DETECTION OF LIGHT USING HIGH TEMPERATURE SUPERCONDUCTING MICROSTRIP LINES

J. C. Culbertson, H. S. Newman, U. Strom, J. M. Pond,
D. B. Chrisey, J. S. Horwitz, and S. A. Wolf
Naval Research Laboratory
Washington, D. C. 20375

Abstract

We report the results of measurements of the effects of external light on the transmission of microwaves through superconducting $YBa_2Cu_3O_{7-\delta}$ microstrip lines. The microstrip geometries used include an asymmetric ring and a meander path. Measurements were made as a function of the microwave frequency (up to 12 GHz), as a function of temperature (above to below the superconducting transition temperature), and as a function of microwave power. We observed a position dependent photoresponse due to local variations in the T_c of the superconductor - caused by locally varying microwave current densities (standing wave component); At low microwave powers this technique can be used to optically probe the local character of the superconducting film without having to move contacts over the film. The asymmetric ring microstrip interferometer was observed to show light induced shifts in the null frequencies due to the kinetic inductance effect.

Introduction

In recent years the photoresponse of superconductors has been most frequently studied using audio frequency techniques[1-5]. In this work we have studied the photoresponse of high temperature superconductors using microwave transmission as a probe.

Our basic experiment involves routing microwaves through a microstrip, shining light on a part of that microstrip, and measuring the photoresponse by measuring the change in microwave transmission. The microwave frequencies used varied from 2 GHz to 12 GHz. The light modulation frequency was varied from steady state to 4 kHz using a mechanical chopper; due to these long time scales the light detection mechanisms observed were bolometric in character - due to resistive and kinetic inductance effects that are largest near the superconducting critical temperature T_c. The light source used was a 1 mW He-Ne laser (wavelength 6328 Å). The laser spot size on the microstrip was typically on the order of 1 mm.

The $YBa_2Cu_3O_{7-\delta}$ films were grown on 0.508 mm thick MgO substrates using a pulsed laser deposition technique. Critical temperatures were typically 88 K to 91 K with transition widths on the order of 0.5 K; the meander path discussed below has a lower critical temperature. Critical currents are typically greater than 10^6 A/cm^2 at 77 K and greater than 10^7 A/cm^2 at 4.2 K. The ground planes were copper.

The meander path occupied an area of 1.27 cm on a side; it consisted of eight straight strips about 1.27 cm long, 0.15 mm wide, and 5000 Å thick which were joined by semicircles to form the meander.

The ring interferometer was 0.75 cm in diameter; the ring path was 0.21 mm wide and 3000 Å thick. The microstrip lines connecting the ring to the outside world were 0.485 mm wide, this dimension being chosen to optimize the coupling into and out of the ring. The input and output microstrip transmission lines were positioned 120° apart to make the lengths of the two legs of the interferometer differ by a factor of two.

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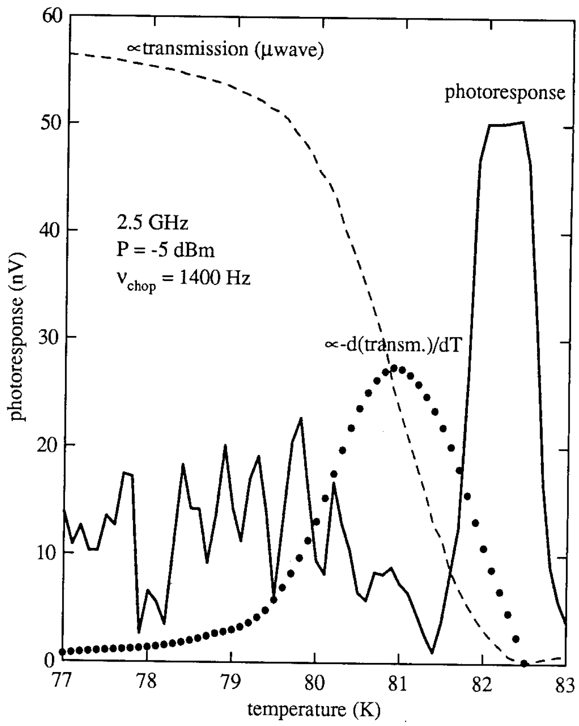

Figure 1. Photoresponse measured as a function of temperature (solid line); microwave transmission (dashed line); and the negative derivative of the microwave transmission with respect to temperature (dotted curve). Meander path.

Experiment: Meander Path

The measured microwave transmission through the meander paths showed a loss of up to 5 dB for microwave frequencies lower than 8 GHz. Figure 1 shows the results of photoresponse and microwave transmission measurements made as a function of temperature using a microwave frequency of 2.5 GHz; near 2.5 GHz the microwave transmission changes slowly with microwave frequency. The dashed curve in Fig. 1 is proportional to the measured microwave transmission. The solid curve in Fig. 1 is the photoresponse measured using a lockin referenced to the frequency (1400 Hz) at which the light was chopped. The dotted curve in Fig. 1 is proportional to the derivative of the microwave transmission (dashed curve).

The first question to be considered is: What is the source of this photoresponse? It is natural to suspect that the photoresponse is bolometric (i.e. thermal) in nature, given that light is being absorbed, the microstrip is heating up, and in this temperature range the microwave transmission varies with temperature. The bolometric change in microwave transmission, δF, caused by a light induced change in temperature, δT, is given by

$$\delta F = (\partial F/\partial T)\, \delta T. \tag{1}$$

Given the temperature rise caused by the absorption of light is relatively insensitive to the starting temperature of the microstrip, Eq. 1 indicates that a bolometric photoresponse is expected to peak at the temperature where $\partial F/\partial T$ peaks. This corresponds to the steepest part of the microwave transmission curve. In Fig. 1 the photoresponse (solid line) and $-\partial F/\partial T$ (dotted line) are peaked at distinctly different temperatures. Either the photoresponse is not completely bolometric or something has been neglected in the above analysis.

We examined this photoresponse further. When the chopping frequency was varied, the photoresponse was found to decrease with increasing chopping frequency in a step-like structure; this is expected for a bolometric photoresponse. When different microwave frequencies were used, the photoresponse was observed to shift downward in temperature as the microwave frequency was increased; the temperature widths of both the photoresponse peak and the microwave transmission change increased with increasing microwave frequency. All of this behavior is consistent with a bolometric photoresponse.

The photoresponse amplitude and the temperature where it peaked were found to vary when the laser spot was moved from one segment of the microstrip to another. Figure 2 shows a plot of the photoresponse measured for seven different spots on the meander path. There is a strong correlation between the amplitude of the photoresponse and the temperature where it peaks: the larger the amplitude, the lower the temperature where it peaks.

This behavior can be modeled in the following simple way: Consider a microstrip having a microwave transmission F as consisting of a combination of shorter microstrip lines connected in series; where the i'th constituent microstrip line has a microwave transmission equal to F_i. If the microstrip is divided up into n segments, then the total transmission F is given by

$$F = F_1 F_2 \ldots F_i \ldots F_n. \quad (2)$$

If light is incident on the i'th segment of the microstrip, then the change in the total transmission is

$$\delta F = F_1 F_2 \ldots F_{i-1} (\partial F_i/\partial T)\delta T\, F_{i+1} \ldots F_n. \quad (3)$$

This can be rewritten as

$$\delta F = (F/F_i)\,(\partial F_i/\partial T)\,\delta T. \quad (3)$$

If the i'th segment is not dominating the transmission loss then $F/F_i \approx F$ and Eq. 3 becomes

$$\delta F \approx F\,(\partial F_i/\partial T)\,\delta T. \quad (3)$$

This result, when used to explain the photoresponse data in Fig. 2, implies that the local microwave transmission of the microstrip varies from one place to another; T_c varies over a range of more than 0.5 K. The correlation between the amplitude of the photoresponse and its position is explained by the presence of the microwave transmission F as a factor in Eq. 3. The dashed line in Fig. 2 is the calculated shape of the photoresponse in the limit the illuminated part approaches being the weakest link in the microstrip (i.e. Eq. 3 with F substituted for F_i). No positions on the microstrip were found where the photoresponse peaked at a lower temperature than this limiting peak.

The data is consistent with the photoresponse being bolometric given the existence of local variations in the T_c of the film. There are several possible explanations for T_c varying with position: there could be spatial inhomogeneities in the film, or there could be something external to the film that is causing this apparent variation in T_c. One possible external effect on T_c is the existence of microwave currents. If there is a component of the microwaves in the meander path in the form of standing waves, then there will be spatially varying microwave currents. Regions having higher microwave current densities would correspond to regions having lower T_c. Figure 3 shows measurements of photoresponse as a function of temperature for a single spot on the microstrip; measurements were made for microwave power levels differing by a factor of five. A reproducible temperature shift downward of 0.1 K was observed for the higher power relative to the lower power.

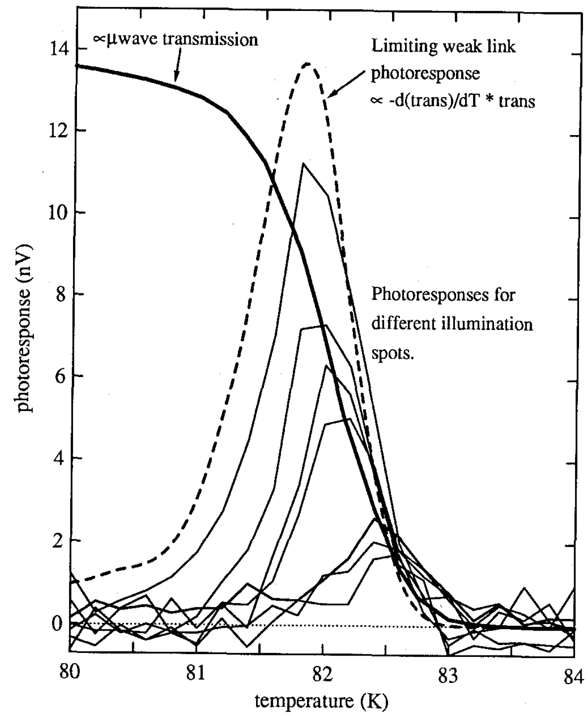

Figure 2. Photoresponse measured as a function of temperature for seven different illumination positions (thinner solid curves); microwave transmission (thick solid curve); limiting photoresponse peak position indicated by dashed curve. Meander path.

At the microwave power levels used to perform these experiments, the microwave currents are thus demonstrated to be sufficiently large to give rise to at least some of the local T_c variation. Measurements made in the limit of low power levels (*i.e. power levels where the photoresponse measured for a single spot on the microstrip is not observed to shift to lower temperatures when the microwave power is increased slightly*) can be used to measure variations in T_c due to structural inhomogeneities in the film.

Experiment: Asymmetric Ring Interferometer

The input transmission lines to the ring interferometer were oriented 120° apart so that the lengths of the two sides of the ring differ by a factor of two. If the microwave frequency is chosen so that the shorter leg is one half of a microstrip wavelength, then the long leg will be one full wavelength long and the waves will superimpose destructively at the output line to provide a minimum (null) in the transmission out of the interferometer. Other frequencies exist that result in destructive interference.

Figure 4 shows a measurement of the microwave transmission through the interferometer as a function of microwave frequency. A simple model calculation for the 55 K temperature of the measure-

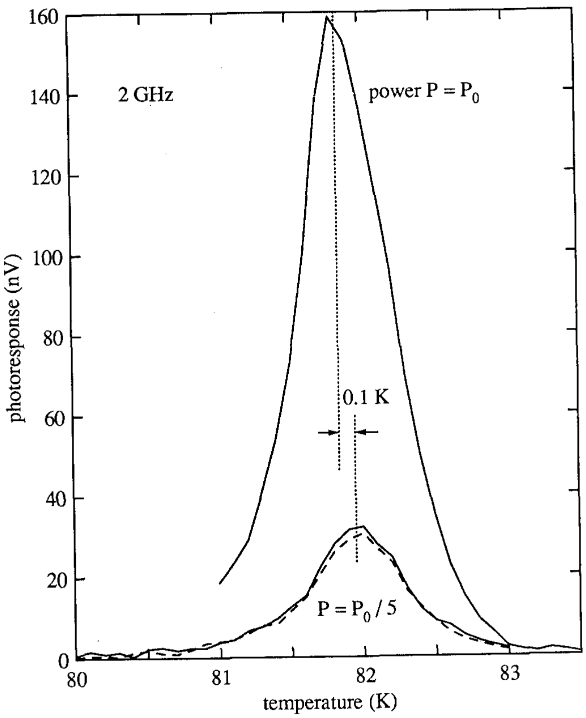

Figure 3. Photoresponse measured for two microwave powers differing by a factor of five. The higher microwave power shifts the peak temperature of the photoresponse downward 0.1 K. Meander path.

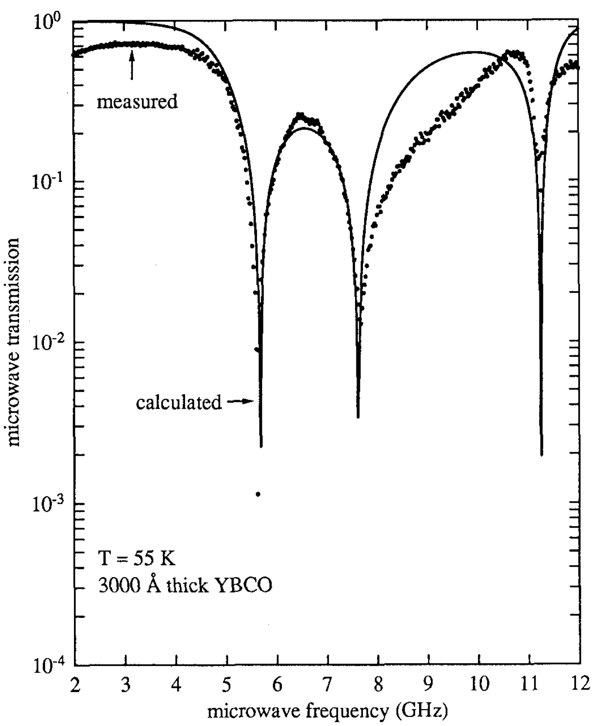

Figure 4. Microwave transmission coefficient measured as a function of microwave frequency for the asymmetric ring interferometer at a temperature of 30 K (dots) and a simple model calculation (solid line). Asymmetric ring interferometer.

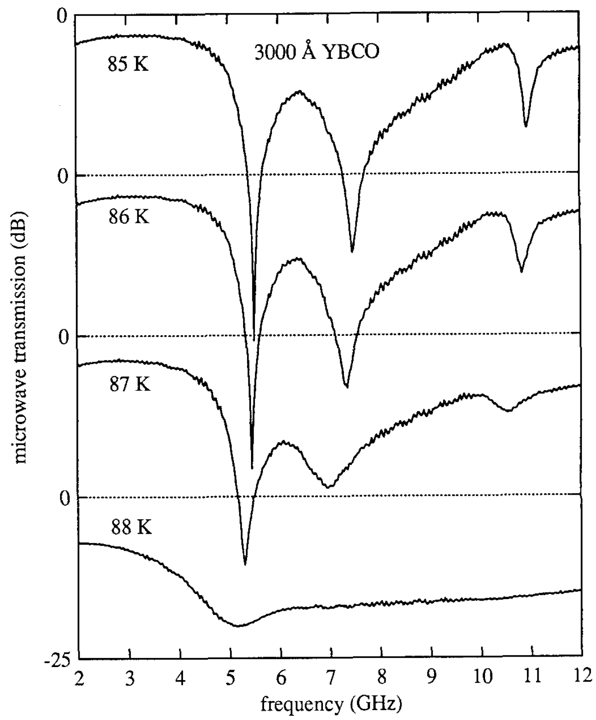

Figure 5. Microwave transmission coefficient measured as a function of microwave frequency for the asymmetric ring interferometer for the temperatures of 85 K, 86 K, 87 K, and 88 K. the horizontal lines are separated by 25 dB. Asymmetric ring interferometer.

ment is included on the figure. The critical temperature of the film is on the order of 89 K.

Figure 5 shows a sequence of measurements of the microwave transmission coefficient vs microwave frequency made just below T_c for four different temperatures. As the temperature increases toward T_c the null frequencies shift toward lower frequencies due to kinetic inductance effects.

As the temperature increases the depth of the nulls decreases. For the achievement of complete destructive interference, not only must the phases of the recombining waves be appropriate, the amplitudes must match as well. As the temperature approaches T_c the attenuation of the microwaves along the microstrip becomes significant; because one leg is twice the length of the other, the destructive interference becomes less complete.

Figure 6 shows the light induced change in the microwave transmission coefficient measured as a function of microwave frequency for four temperatures near T_c. At 86 K the lowest frequency null shifts to lower frequencies at a rate of about 100 MHz/K due to kinetic inductance effects. Thinner films will yield larger rates of shift. Under the conditions of these measurements the photoresponse is bolometric.

Conclusions

We have demonstrated that the microwave detection of a bolometric photoresponse can provide information about the local microwave current density in microstrip lines. In the limit of low microwave power this technique can be used to measure the variation of T_c as a function of position.

The asymmetric ring interferometer has been demonstrated to provide sharp frequency nulls, which in the kinetic inductance limit

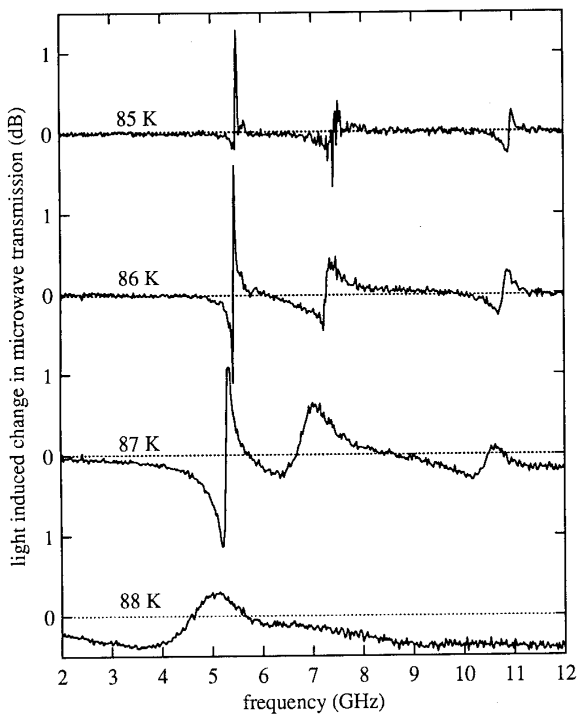

Figure 6. The light induced change in microwave transmission coefficient measured as a function of microwave frequency for the asymmetric ring interferometer for the temperatures of 85 K, 86 K, 87 K, and 88 K. Asymmetric ring interferometer.

shift bolometrically at a rate that can chosen by choosing the thickness of the film and how far the operating temperature is from T_c.

References

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