OPTICAL RESPONSE OF HIGHLY GRANULAR YBACUO FILMS PREPARED BY NON-VACUUM
AEROSOL DEPOSITION

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Highly granular YBaCuO films on $SrTiO_3$ substrates with $T_{c,0} \sim 90K$ and $J_c > 10^4$
A/cm^2 were prepared by non-vacuum aerosol deposition. The optical response
for these films was investigated on a 10×10 μm^2 microbridge. Besides a
bolometric response around the transition temperature, a sharp response
peak was observed at low temperature and high bias current using a He-Ne
laser (0.63μm wavelength) illumination. This response was caused by a
junction behaviour due to the presence of many boundary-type weak links in
our microbridge.

1. INTRODUCTION

   One of the most promising applications of superconducting thin films is the
optical detector because of its broad detective range (visible and infrared),
high sensitivity and very short response time in the order of 10^{-10} seconds.
This attractive research started with the pioneer work on granular BaPbBiO
films[1]. Hence, since the discovery of a new class of high T_c superconductors,
research on the optical detection, especially for vacuum-deposited films, has
been carried out by a number of groups[2-9]. However, so far the investigation
is still in the initial stage. Conclusions about the occurrence of non-equi-
librium[3-5] (non-bolometric) or bolometric effects[7,8] are, in our opinion,
closely related to the presence of internal junctions (or weak links) of the
films.

   Recently a junction behaviour (an abrupt voltage jump) in the I-V curve has
been observed in granular YBaCuO films prepared by non-vacuum aerosol deposi-
tion[10]. One of the advantages of the aerosol process is that it is possible to
fabricate granular films with fine stoichiometric grains, having dimensions in
the order of 200 nm, which are separated by their boundaries, whereby an ideal
grain-boundary-grain structure can be obtained. This junction behaviour is not
only observed in the I-V curve but can also be found in the optical response.
A sharp response peak due to the above-mentioned junction behaviour will be
reported in this paper.

   In principle, there are two kinds of response modes. One of which is the
non-equilibrium mode. When light (energy $\hbar\omega$) is absorbed by a superconducting

film, the Cooper pairs are broken up and excess quasiparticles are excited.
The increase in quasiparticles induces a non-equilibrium state in the super-
conductor and results in a decrease in the energy gap Δ^1. A voltage change due
to a drop in the critical current can then be detected[11]. The other is a bolo-
metric mode, by which the optical illumination only acts as a normal heater
increasing the temperature in the detective area. When the film temperature is
in the vicinity of the transition temperature, the resistance will change with
the light illumination. In the bolometric mode the induced voltage change ΔV
(response) is proportional to dR/dT. Because the thermal diffusion time is
much longer than the recombination time of the non-equilibrium effect, it is
impossible to develop a high-speed detector by use of the bolometric mode.

Taking into account the grain-boundary-grain structure in our case, it is
very difficult to discriminate between both modes. The reason is that the
boundary barrier acting as a normal metal (boundary-type weak link) will
present a dynamic resistance during transition. This dynamic resistance ΔR,
which is different from the normal resistance R_N, varies with bias currents
and temperatures, and directly influences the dR/dT and dV/dI curves.
Therefore, the agreement of the optical response curve with the dR/dT or dV/dI
curves cannot be uniquely used as a criterion for determining which response
mode it is. In the following the term "bolometric response" means the optical
response in the vicinity of the transition temperature which is measured at
low bias current, while the response from the junction effect is refered to as
the junction-related response.

2. EXPERIMENTAL PROCEDURES

YBaCuO thin films with a c-axis orientation were prepared by non-vacuum
aerosol deposition using the metal β-diketonates of Y, Ba and Cu as precur-
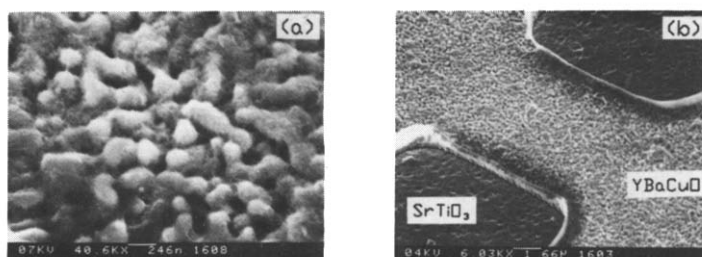

Fig.1 SEM photographs of highly granular YBaCuO films on SrTiO$_3$ substrates.
(a) granular morphology, (b) a $10 \times 10 \ \mu m^2$ microbridge made by ion-beam
milling and used for optical response measurements. The region of (a) is
selected inside the microbridge.

sors. Previous work on Si substrates has been published[12]. A good quality film, with thickness h=250 nm, could be obtained on $SrTiO_3$ (100) substrates, where $T_{c,0}$ is up to 90K and J_c is larger than 10^4 A/cm^2 at 77K. After deposition an 850 °C post-annealing in oxygen is performed to produce stoichiometric $YBa_2Cu_3O_{7-x}$ films. The properties of films on $SrTiO_3$ (100) substrates will be published elsewhere. The film growth in this process is rather different from vacuum deposition enabling a highly granular morphology to be obtained. Fig.1(a) shows SEM photographs of granular YBaCuO films. The grain size is approximately 200 nm. Photolithographic technology and Ar ion-beam milling have been used to structure our films. Afterward plasma etching is performed to remove the photoresist. Using this process a 10 × 10 μm^2 microbridge can be made as shown in Fig.1(b). The zero-resistance transition temperature ($T_{c,0}$) on $SrTiO_3$ after structuring shows a slight decrease (1-2K).

Fig.2 shows the experimental set-up and schematic structure of an YBaCuO film used for optical detection. A 0.63μm He-Ne laser is used as illumination source. The laser can be chopped at frequencies up to 4 kHz. Four-point pin contacts (or silver pads) are used for the resistance and optical response measurements. It can be estimated that the temperature increase of our He-Ne laser (0.63μ) illumination is about 0.025K/mW, which is determined by the I-V
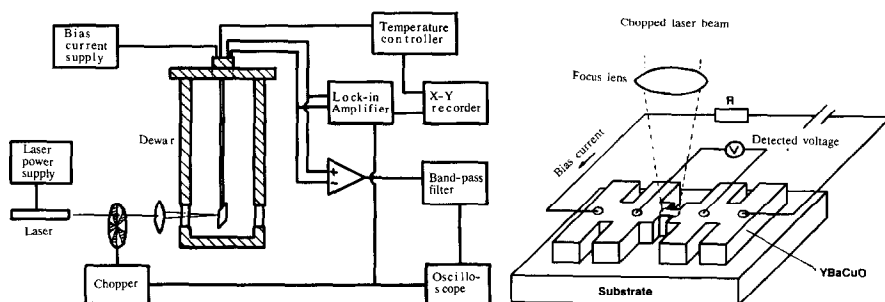

Fig.2 Experimental set-up and schematic structure of a YBacuO film used as a light detector.

Table 1 Typical parameters of the specimens in this work.

Sample No.	Substr.	Resistivity (Ω cm,300K)	h (nm)	Bridge (μm^2)	$T_{c,on}$ (K)	$T_{c,0}$ (K)	J_c(77K) (A/cm^2)	Grain (nm)
#596	$SrTiO_3$	$7.0*10^{-3}$	250	10×10	93	~90	$3.0*10^4$	~200
#598	$SrTiO_3$	$1.2*10^{-2}$	250	10×10	93	~90	$2.0*10^4$	~200

curve shift. Typical parameters of the specimens in this work are presented in Table 1.

3. RESULTS

3.1. Temperature dependence

Fig.3 shows the temperature dependence of the resistance, dR/dT and optical response for different bias currents 0.5mA, 1mA, 5mA and 7.5mA. In order to see the results clearly, we classify them in two parts. It is shown that at a low bias current (<1mA), with an increase of current the resistance versus temperature curves (R-T curves) are almost the same with only a slight decrease in $T_{c,0}$. While at a high bias current (>2mA), the R-T curves significiently shift to the low temperature direction as shown in Figs.3(a) and (d). In the meantime a junction behaviour takes place, which shows an abrupt voltage jump in the I-V curve[10]. The dR/dT curves in Fig.3 are calculated from the R-T curves, and the optical responses are measured at an 820 Hz chopping frequency with a 1mW light power.
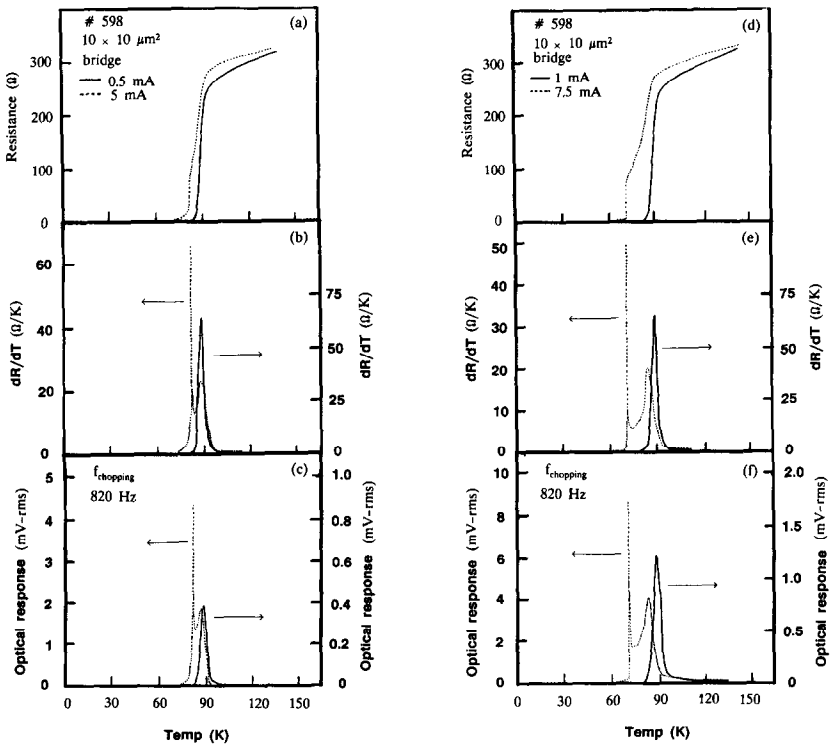

Fig.3. (a), (b) and (c) indicate the resistance, dR/dT and optical response as a function of temperature, respectively, for 0.5mA and 5mA bias currents; (d), (e) and (f) indicate the same ones for 1mA and 7.5mA bias currents.

The optical response reveals a typical bolometric effect at low bias
current: a single peak appears in the vicinity of the transition temperature.
However, with high bias current a very sharp response peak can be found during
temperatures below 80K, as shown in Figs.3(c) and (f). During this period the
optical response presents double peaks. The sharp peak is caused by an abrupt
voltage jump, which is due to the presence of boundary-type weak links in our
bridge. Actually, the magnitude of these junction-related responses is higher
than that shown in the figures. In order to display the bolometric peaks, we
reduce the height of the sharp ones. The response images, obtained by oscillo-
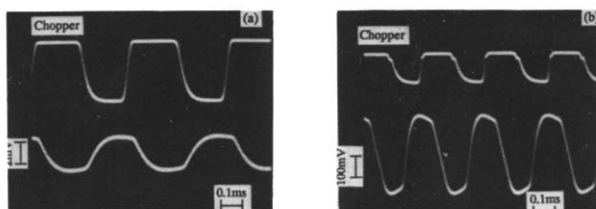scope, for both bolometric and junction-related responses are shown in Fig.4.

Fig.4. Images of optical response on $SrTiO_3$, (a) bolometric response, T=89K,
I_{bias}=1mA, P=2mW and $f_{chopping}$=2270H$_z$. The vertical scale of the response is
2mV/div and the horizontal is 0.1ms/div; (b) junction-related response, T=77K,
I_{bias}=7.5mA, P=5mW and $f_{chopping}$=3700Hz. The vertical scale is 100mV/div and
the horizontal is 0.1ms/div.

   In Figs.4(a) and (b) the top curves show the chopper frequency as a
reference. Due to the fact that it is difficult to retain the point at which
the junction-related response is maximum, we observe a response at a point as
close as possible to the optimum in Fig.4(b). The height of the junction-
related response is much larger than that of the bolometric response in
Fig.4(a) in our case.

   3.2. Light-power dependence

   The responsivity of the detector is one of the most important parameters.
Fig.5 illustrates the incident power dependence of the optical response for
the bolometric mode in 10 μA and 100 μA bias currents. The experimetal results
show that at low bias current the response is directly proportional to the
light power. The responsivity is about 1 V/W for the bolometric mode which
is consistent with some reports on vacuum-deposited films[2,8]. However the data
from the junction-related response is much higher than this value. Due to the
fact that the responsivity of the junction-related response is strongly
dependent on the parameters of the operating point, such as temperature and
bias current. Under certain conditions, a responsivity as high as 10^3 V/W
can be found.

3.3. Bias-current dependence

Fig.6(a) shows the optical respones vs. bias current for the bolometric mode. The optical response of this mode is proportional to the value of the bias current I_{bias} multiplied by dR/dT. As the temperature is fixed, assuming the dR/dT is constant, the optical response will be a linear function of the bias current. These properties can be found at low bias current. While, at a high bias current, the dR/dT is shifted to the low temperature direction as shown in Figs.3(b) and (e), so that the optical response decreases at 91K.
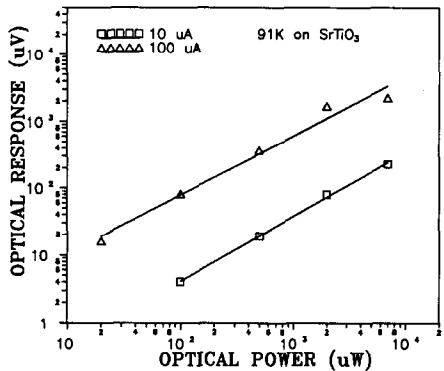
Fig.5. Incident power dependence of bolometric optical response for 10μA and 100μA bias currents at low chopping frequency.
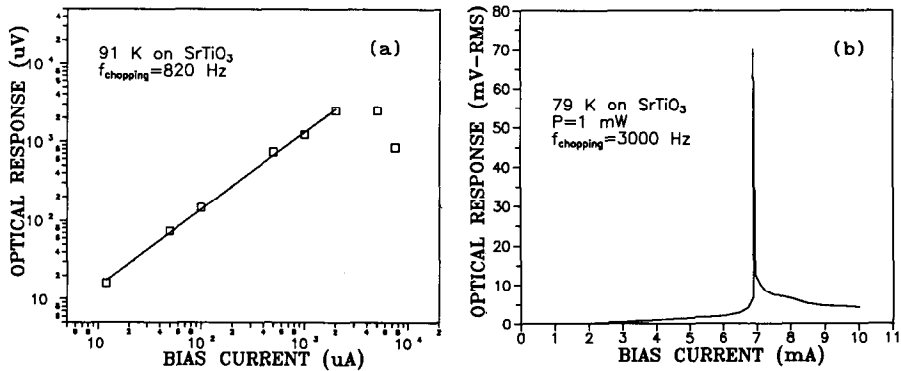
Fig.6. Bias-current dependence of the optical response (a) for the bolometric response, (b) for the junction-related response.

With respect to the junction-related effect the bias-current dependences are quite different from those for the bolometric effect. Fig.6(b) illustrates the one obtained at 79K. It shows that at low bias current, the optical

response slightly increases with a nonlinear behaviour, a sharp peak will appear at a critical value, which corresponds to the voltage jump in the I-V characteristic. The bias current dependence of the junction-related response is in good agreement with that of the dV/dI curve.

3.4. Chopping frequency properties

Fig.7 shows the optical responses against the chopping frequency for both junction-related and bolometric responses. It can be seen that the bolometric response at 91K decreases with frequency more significantly than the junction-related response at 77K. The difference between both curves is an indication that both responses are not caused by the same principle.
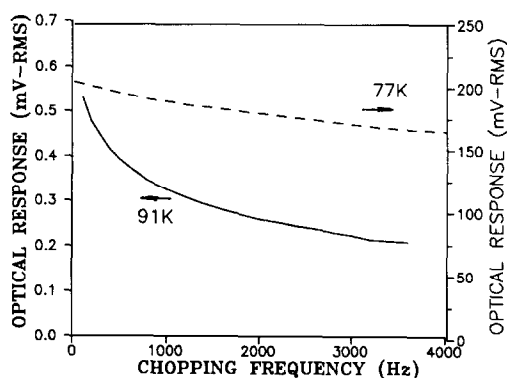

Fig.7. Optical response as a function of the chopping frequency. The solid line indicates the bolometric response obtained at T=91K, I=0.5mA and P=1mW. The dashed line presents the junction-related response obtained at T=77K, I=7.5mA and P=5mW.

4. DISCUSSION AND CONCLUSIONS

So far the origin of this sharp optical response related to the junction behaviour is not clear. Based on our experimental results, it cannot completely be caused by an equilibrium Joule heating. There are two reasons for this. First, we mount our sample with a good thermal contact on a copper block which has a RhFe thermometer and a heating element. Normally this block is cooled by 1 atm ^{4}He exchange gas, but in this case we immerse the block directly in liquid nitrogen. In both cases, at T=77K no difference in the I-V characteristics (including the voltage jump) could be detected. Second, the chopper-frequency dependence does not show a significant decrease in the junction-related response, but on the contrary it always occurs in the bolometric response at a temperature around T_c (90K) as shown in Fig.7. Further evidence for the non-equilibrium character of the observed junction

effect will be given in Ref.13.

On the other hand, as a high (in the order of mA) bias current flows through the bridge, which is being exposed to laser illumination, the bolometric component is inevitably involved in the junction-related optical response. Probably this response is attributed to a combination of the non-equilibrium and bolometric effects. We believe that the best way to distinguish the non-equilibrium from the bolometric mode is to use an extremely short pulse laser to investigate the performance of the junction-related response. This work is in progress.

In conclusion: (1) A sharp optical response peak related to the junction behaviour has been experimentally found in the highly granular film prepared by non-vacuum aerosol deposition. (2) The temperature dependence of both the bolometric and junction-related response agree with that of the dR/dT curve, for the latter the bias-current dependence is also consistent with that of the dV/dI curve. (3) The responsivity of our $10 \times 10 \ \mu m^2$ microbridge is in the order of 1 V/W for the bolometric mode, while it will be 2-3 orders higher for the junction-related response.

ACKNOWLEDGMENTS

REFERENCES

1) Y. Enomoto, T. Murakami, J. Appl. Phys., 59 (1986) 3807.
2) Y. Enomoto, T. Murakami, and M. Suzuki, Physica C 153-155 (1988) 1592.
3) M. Leung, P. R. Broussard, J. H. Claasen, M. Osofsky, S. A. Wolf, and U. Strom, Appl Phys. Lett., 51 (1987) 2046.
4) H. S. Kwok, J. P. Zheng, and Q. Y. Ying, Appl. Phys. Lett., 54 (1989) 2473.
5) E Zeldov, N. M. Amer, G. Koren, and A. Gupta, Phys. Rev. B 39 (1989) 9712.
6) D. P. Osterman, R. Drake, R. Patt, E. K. Track, M. Radparvar, and S. M. Faris, IEEE Trans. Magn., 25 (1989) 1323.
7) M. G. Forrester, M. Gottlieb, J. R. Gavaler, and A. I. Braginski, IEEE Trans. Magn., 25 (1989) 1327.
8) W. S. Brocklesby, Don Monroe, A. F. J. Levi, M. Hong, S. H. Liou, J. Kwo, C. E. Rice, P. M. Mankiewich, and R. E. Howard, Appl. Phys. Lett., 54 (1989) 1175.
9) A. Frenkel, M. A. Saifi, T. Venkatesan, P. England, X. D. Wu, and A. Inam, J. Appl. Phys., 67 (1990) 3054.
10) Q. Tang, A. Driessen, P. Hoekstra, and Th. J. A. Popma, to be published.
11) J. Talvacchio, M. G. Forrester, and A. I. Braginski, Photodetection with high-T_c superconducting films, in: Science and Technology of Thin Film Superconductors, eds. R. D. McConnell and S. A. Wolf (Plenum Press, New York, 1989) pp. 449-458.
12) Q. Tang, A. Driessen, L. T. H. Hilderink, and Th. J. A. Popma, YBaCuO thin films prepared by organometallic aerosol deposition, in: Physics and Materials Science of High Temperature Superconductors, NATO ASI Series E181, eds. R. Kossowsky, S. Methfessel and D. Wohlleben (Kluwer, Dordrecht 1990) pp. 401-408.
13) A. Driessen, Q. Tang, P. Hoekstra, and Th. J. A. Popma, to be published.