Final Report

P 49

Title:	Optical and Electrical Properties of Thin Superconducting Films
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Starting Date:	June 1,1990
Ending Date:	December 31,1990
NASA Grant Number:	NAG 5 1347

(NASA-CR-188666) OPTICAL AND ELECTRICAL PROPERTIES OF THIN SUPERCONDUCTING FILMS Final Report, 1 Jun. - 31 Dec. 1990 (Sam Houston State Univ.) 49 p CSCL 20F

N91-27956

Unclas

G3/74 0030075

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ABSTRACT

Infrared spectroscopic techniques can provide a vital probe of the superconducting energy gap which is one of the most fundamental physical properties of superconductors. Currently, the central questions regarding the optical properties of superconductors are how the energy gap can be measured by infrared techniques and at which frequency the gap exists. An effective infrared spectroscopic method to investigate the superconducting energy gap, E_g, was developed by using the Bomem DA 3.01 Fourier Transform Spectrophotometer. We measured the reflectivity of a superconducting thin film of YBaCuO deposited on $SrTiO_3$. A shoulder was observed in the superconducting state reflectance R_s at 480 cm^{-1}. This gives a value of $E_g/kT_c = 7.83$, where k is the Boltzmann constant and T_c the superconducting transition temperature, from which, we suggest that YBaCuO is a very strong-coupling superconductor.

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CHAPTER 1

INTRODUCTION

In the past several years, there has been a dramatic intensification of activity in the research of superconductors. Until recently, the record for the highest superconducting transition temperature, T_c, was 23.2K achieved in 1973 for a niobium-germanium thin film near the stoichiometric composition Nb_3Ge. In mid-1986, Bednorz and Muller [1] reported a transition temperature in the 30K range for metallic, oxygen-deficient compounds of barium, lanthanum, and copper oxide. The search for a room-temperature superconductor began in earnest. By the end of 1986 and the beginning of 1987, other lanthanum compounds were fabricated which went superconducting close to 40K [2][3][4][5], and shortly thereafter the yttrium barium system was found to go superconducting at 85-95K [6][7]. Early in 1988, superconductivity reached the 120K range with the discovery of the BiSrCaCuO [8][9][10] and TlBaCaCuO [11][12][13] system.

The enormous potential of superconducting materials for practical application has been of great interest. A number of devices [14][15] have already been fabricated, which make it clear that high-T_c superconductors could have a substantial economic impact. They are also intrinsically capable of supporting large critical currents, and if high current devices can be successfully developed, these new materials should have a diversity of applications. Nature, however, has been reluctant in revealing her secrets. A large number of scientists, engineers, and technicians are being thrust into the field of high-T_c superconductors and a large variety of experimental techniques are being employed to investigate the properties of these materials.

The superconducting energy gap can be measured by many methods, such as inelastic neutron scattering, microwave surface impedance, susceptibility, and ultrasonics, but by far the most common way is by infrared spectroscopy. This is a technique that has been used with success in the classic superconductors.

Currently, the central questions regarding the infrared properties of high-T_c superconductors are whether or not the superconductor has an energy gap, if it does, how to detect it by infrared measurement, and at which frequency the gap exists. To address the above questions, it is necessary to develop an infrared technique to measure the high-T_c superconducting energy gap.

In the research reported here, we used Fourier transform infrared reflection spectroscopy to measure the energy gap of YBaCuO deposited on $SrTiO_3$. The specra were taken with a Bomem DA 3.01 Fourier Transform Spectrophotometer in the frequency range 50 and 5000 cm^{-1} and at 77K and 310K. An enhancement was observed in the superconducting state reflectance R_s at 480 cm^{-1}, this gives a value of $E_g/kT_c = 7.83$. From which, we suggest that YBaCuO is a very strong-coupling superconductor.

CHAPTER 2

SUPERCONDUCTING ENERGY GAP

1. BCS Theory and Energy Gap

In testing theories for mechanisms of high temperature superconductors, it becomes necessary to distinguish between strong and weak coupling of charge carriers. Measurement of E_g is essential in this regard, as is the dependence on temperature of E_g. Unless stated otherwise, when referring to the energy gap, we always have in mind the value E_g for $T < T_c$, that is , where its value is not significantly different from $E_g(0)$.

In 1957, Bardeen, Cooper and Schrieffer (BCS) developed a successful theory [16] which provided a useful tool to analyze the conventional superconductors. This theory also explains well the properties of most high-temperature superconductors. The BCS theory is based upon the existence of a net attractive interaction potential, V, between the electrons in a narrow energy range near the Fermi surface. This produces a ground state separated from the upper excited states by a gap in energy. The attractive interaction forms two-electron, single bound states in momentum space, called Cooper pairs. The BCS theory presupposes the formation of

Cooper pairs via an electron-electron attractive potential V. The simplest approximation is to assume that V equals a constant for electron energies within the range ($E_F + E_D$) or ($E_F - E_D$) of the Fermi energy and E_F and $V = 0$ beyond this range. Here E_D is a limiting energy which, in the case of a phonon mechanism, is equal to the Debye energy $k\theta_D$, characteristic of the lattice vibrations, where θ_D is the Debye temperature. A transcendental integral equation is solved to give the following expression for the energy gap E_g and the transition temperature T_c,

$$T_c = 1.134\theta_D \mathrm{EXP}[-1/VN(E_F)]$$

$$E_g = 4E_D \mathrm{EXP}[-1/VN(E_F)]$$

where $N(E_F)$ is the density of states at the Fermi level and V is an interaction potential between the electrons. Dividing the above second equation by the first provides the dimensionless ratio:

$$E_g/kT_c = 3.528$$

Even when dealing with conventional superconductors, it is common to see variations on the order of 30% from the value of E_g/kT_c, but the determination of this ratio is nevertheless a valuable tool for testing whether a particular superconductor has BCS-like behavior. A value near 3.5 indicates weak coupling, while values substantially above this level are evidence of strong coupling between electrons.

For instance, if weak coupling is involved for a 90K superconductor like YBaCuO, one would expect an energy gap, E_g, of $3.53k \times 90K$ or $E_g \sim 3.53 \times 8.625 \times 10^{-5} \times 90 \sim 27$ mev $\sim 217.5\ cm^{-1}$

2. **Measurement Techniques for Superconducting Energy Gap**

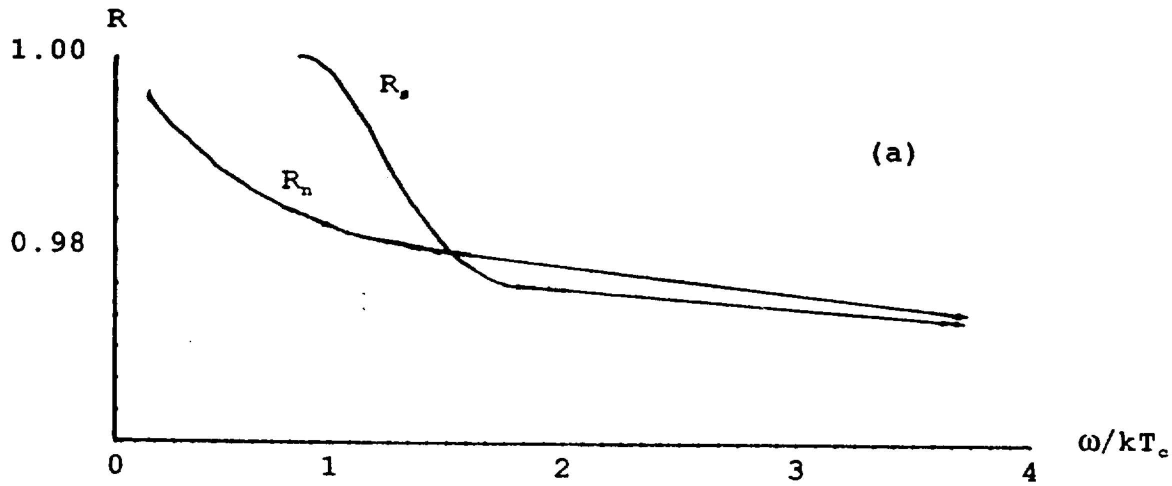
Usually there are three ways to measure the energy gap, the tunneling method, Andreev reflection measurement and infrared spectroscopy. The tunneling approach essentially involves measurement of the voltage required for initiation of quasiparticle flow across a superconductor-normal(SN) or a superconductor-insulator-superconductor(SIN) junction. Tunneling measurements, while very simple in principle, tend to give values of E_g/kT_c that are too low. This problem is related to the extremely short coherence lengths in the high-temperature superconductors. The short coherence lengths lead to anomalous behavior at surfaces and interfaces, such as those in superconductor-normal interfaces used in tunneling experiments. For this reason, tunneling measurements are not considered as trustworthy as other techniques in determining the energy gap in superconductors.

The second technique for energy gap measurement is Andreev reflection, which is made with a rather small point contact on the sample [17]. An electron with and energy less than E_g will not enter the superconductor as a quasiparticle because there are no states below the gap value. Instead, the electron tends to condense with a second electron (in the point contact) to form a Cooper pair. The resultant hole in the normal region of the point contact will move in the direction where the original electron originated. This "reflection" results in a lower contact resistance when the injected electron energy is below E_g.

Occupying the frequency range between about 5 and 15,000 cm^{-1}, infrared spectroscopy encompasses the region in which the characteristic energy scales of correlated systems tend to lie (e.g. superconducting and charge density wave energy gaps, etc.). In the superconducting state, there is little or no absorption of the electromagnetic waves until the photon energy is high enough to break the Cooper pairs. As such, infrared measurements provide a vital probe of the dynamics of these systems. The use of infrared techniques to measure the superconducting gap began with the work of Glover and Tinkham [18][19] in 1957. Their infrared work on Pb films provided the first spectroscopic measurement of a superconducting gap, and slightly preceded the advent of the BCS theory. More recently, Sievers and co-workers [20][21] have pioneered the use of infrared measurement to study the dynamics of highly correlated systems such as $CePd_3$ and UPt_3. These measurements provide historical examples of the utility of infrared spectroscopy and serve as a guideline to the potential ways infrared spectroscopic measurements can be used to study superconducting materials.

Measurements of superconducting samples can be performed using either transmission or reflection techniques. To perform transmission measurements requires a homogeneous film, no thicker than the electric field penetration depth. The penetration depth for the electric field parallel to the plane is about 1500 Å for YBaCuO material. The film must be grown on a substrate that is transparent over the frequency range of interest. At the present time, these conditions are rather difficult to satisfy. This study will concentrate on reflectivity measurements, which are performed on a thin film (1200 Å) of YBaCuO deposited on a $SrTiO_3$ substrate.

The energy gap can be measured by studying the infrared reflectivity both in the normal and superconducting state as a function of the energy of the incident photon. Figure 2.1 shows how the infrared reflectivity from a conventional superconductor should look in the normal and superconducting state. In the normal state, loss processes associated with the scattering of electrons cause absorption of the incident radiation at any finite frequency. In the superconducting state there are no electronic loss processes for photon energy less than the superconducting energy gap, therefore, when the frequency is less than E_g, there is no absorption and the reflectivity should be 100% as illu2strated in Figure 2.1a. As a small amount of impurity can cause a lot of absorption below the gap, it is very difficult to obtain the absolute reflectivity (to better than about 0.5%). It is much more usual to measure the gap by investigating the ratio of the reflectivity in the superconducting state to that of the normal state R_s/R_n. The gap appears as a peak at $\omega = E_g$ as shown in Figure 2.1b.



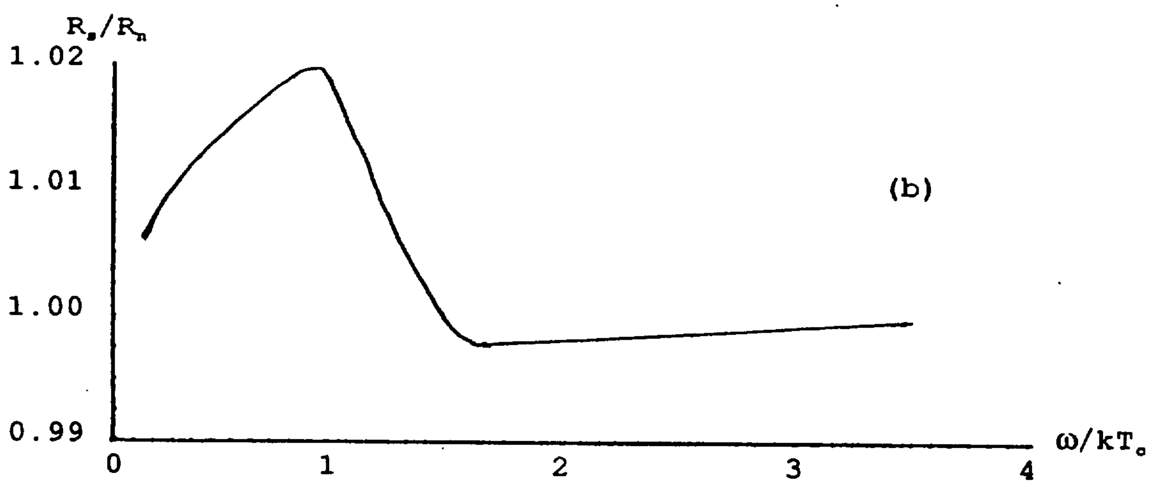


Figure 2. **(a)** Reflectivity in the normal and superconducting states of the conventional superconductors. **(b)** Reflectivity in the superconductivity state, R_s, divided by the reflectivity in the normal state, R_n. The peak in R_s/R_n occurs at $\omega=E_g$.

Currently, two infrared reflection spectral features have been assigned to the superconducting energy gap for the YBaCuO system. One [22] is an absorption onset at about 140 cm^{-1}, below which the superconducting state reflectance R_s is 100%. This frequency corresponds to $(3.1-3.2)kT_c$. The second [23] is a shoulder in the superconducting state reflectance at 440 cm^{-1} in YBaCuO. The ratio of superconducting to normal state reflectance, R_s/R_n, for this shoulder becomes maximum at 460-480 cm^{-1}, which is $7.3kT_c$ when T_c = 92k. A third group [24] suggests that neither of the above two frequencies should be assigned to the superconducting gap.

CHAPTER 3

FOURIER TRANSFORM INFRARED SPECTROSCOPY

The 'heart' of a Fourier Transform Spectrophotometer is an optical system called a Michelson interferometer. See Figure 3.1. It includes a beam splitter which splits the incoming IR radiation into two beams of approximately equal intensity and then allows them to recombine before going to the detector. There is a fixed mirror to reflect one beam and a moving mirror to reflect the other beam. Based on the principle of interference, the interferogram is generated by recombining the two beams due to a path difference produced by changing the position of the moving mirror. A signal maximum resulting from constructive interference of all the source frequencies will occur when the optical paths in the two arms of the interferometer are equal. This is called zero path difference or ZPD point. A signal minimum resulting from destructive interference is also produced. At any other point, a combination of constructive and destructive interference will exist. Obviously, by moving the mirror at constant speed, v, the Michelson interferometer is cable of 'modulating' the IR signal. It produces a new signal of frequency, f_m, which carries the same information as the original IR signal. If a

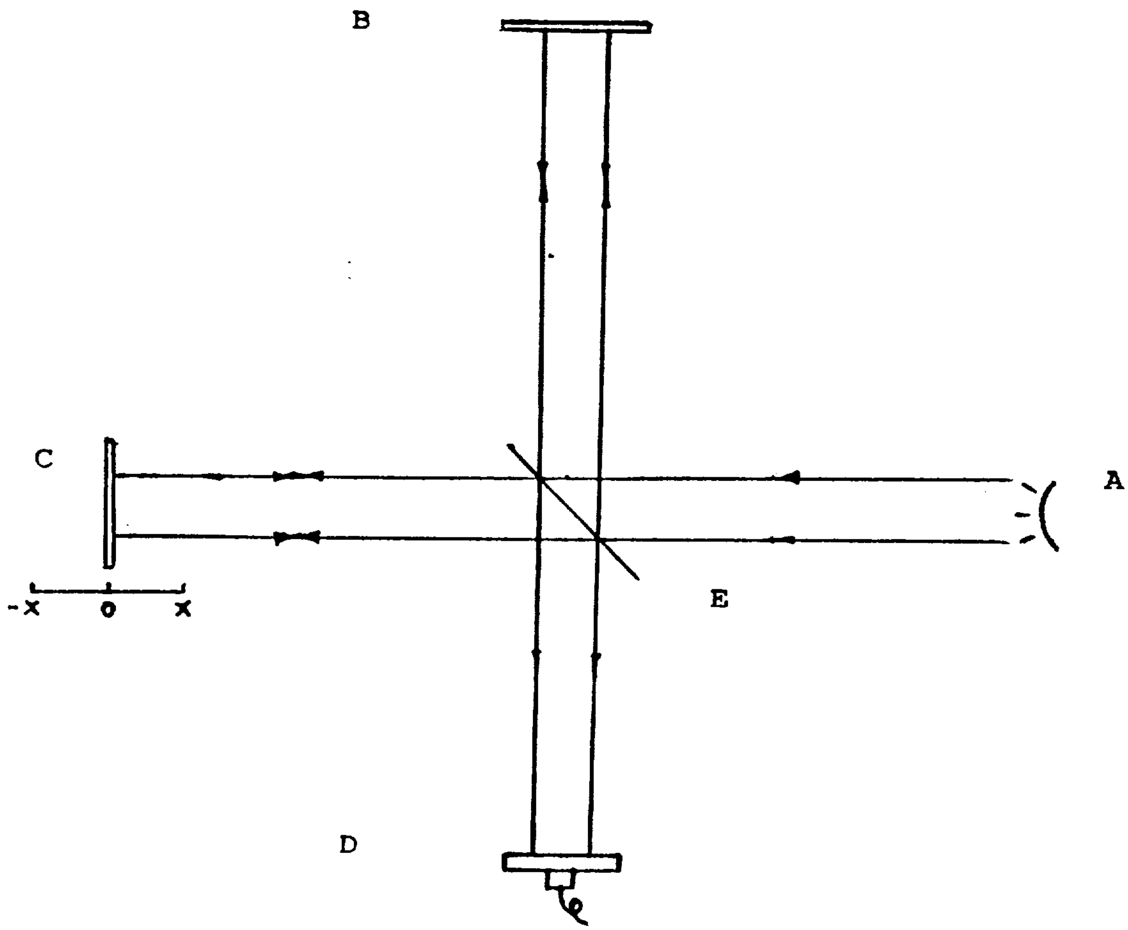


Figure 3.1 Michelson Interferometer

A: Source

B: Fixed Mirror

C: Moving Mrrior

D: Detector

E: Beamspliter

monochromatic IR wave of frequency, f, enters the Michelson interferometer, then the output will be of much lower frequency, $f_m = 2v\gamma$ HZ, where v is the moving speed of the mirror. In this way, the IR frequency ($\sim 10^{14}$ HZ) is changed to the audio frequency ($\sim 10^{2}$ HZ) region. Theoretically, the intensity of the interferogram arriving at the detector can be expressed as:

$$I(\delta) = I_o(\gamma)(1 + \cos 2\pi\gamma\delta)$$

where, δ is the path difference and $I_o(\gamma)$ is the source intensity.

If the incident beam has various different frequencies, the intensity of the interferogram between γ and $\gamma+d\gamma$ could be expressed as, $I(\gamma)d\gamma$. The total signal intensity over all frequencies can be expressed as:

$$I(\delta) = \int_{-\infty}^{\infty} I_o(\gamma)d\gamma + \int_{-\infty}^{\infty} I_o(\gamma)\cos 2\pi\gamma\delta d\gamma$$

$I_o(\gamma)$ is not a function of δ, so we can neglect the first term of above equation when we evaluate $I(\delta)$, thus we can write:

$$I(\delta) \propto \int_{-\infty}^{\infty} I_o(\gamma)\cos 2\pi\gamma\delta d\gamma$$

Prior to the availability of relatively cheap computers, it was rather difficult to evaluate the multicolored inferferogram $I(\delta)$ directly. Fortunately, we can use the Fourier transform technique to transform the interferogram $I(\delta)$ to spectrum $I(\gamma)$. $I(\gamma)$ can be expressed as :

$$I(\gamma) = \int_{-\infty}^{\infty} I(\delta)\cos 2\pi\gamma\delta d\delta$$

$$= 2\int_{0}^{\infty} I(\delta)\cos 2\pi\gamma\delta d\delta$$

If the signal travels through a sample before entering the detector, the intensity at some frequencies in the spectrum could be absorbed. The infrared properties then could be investigated by studying the spectrum which carries all the information concerning the optical characteristics of the sample.

To obtain a real spectrum of the sample, a reference spectrum of the background, $I_o(\gamma)$, has to be first acquired and stored before taking the absorption spectrum of the sample, $I(\gamma)$. In order to take out the influence of the background, the real absorbance spectrum of sample is calculated by:

$$A(\gamma) = -\ln[I(\gamma)/I_o(\gamma)].$$

CHAPTER 4

EXPERIMENT

1. INSTRUMENT

The infrared measurements were performed by using a Fourier Transform Infrared Spectrophotometer (FTIR) Bomem model DA3.01, which, using a conventional Michelson interferometer as the essential element, consists of

i a spectrophotometer.

ii a high speed vector processor system.

iii a host computer.

The main components are described in Figure 4.1.

The different frequency range measurements were carried out by applying different kinds of sources, beamsplitters, detectors and windows, which are listed in Table 4.1.

Table 4.1 Sources, Beamsplitters, Detectors, and Windows

regions (cm^{-1})	10-500	400-5000
sources	glober	glober
beamsplitters	mylar	KBr
detectors	DTGS	MCT
windows	Polyethylene	KBr

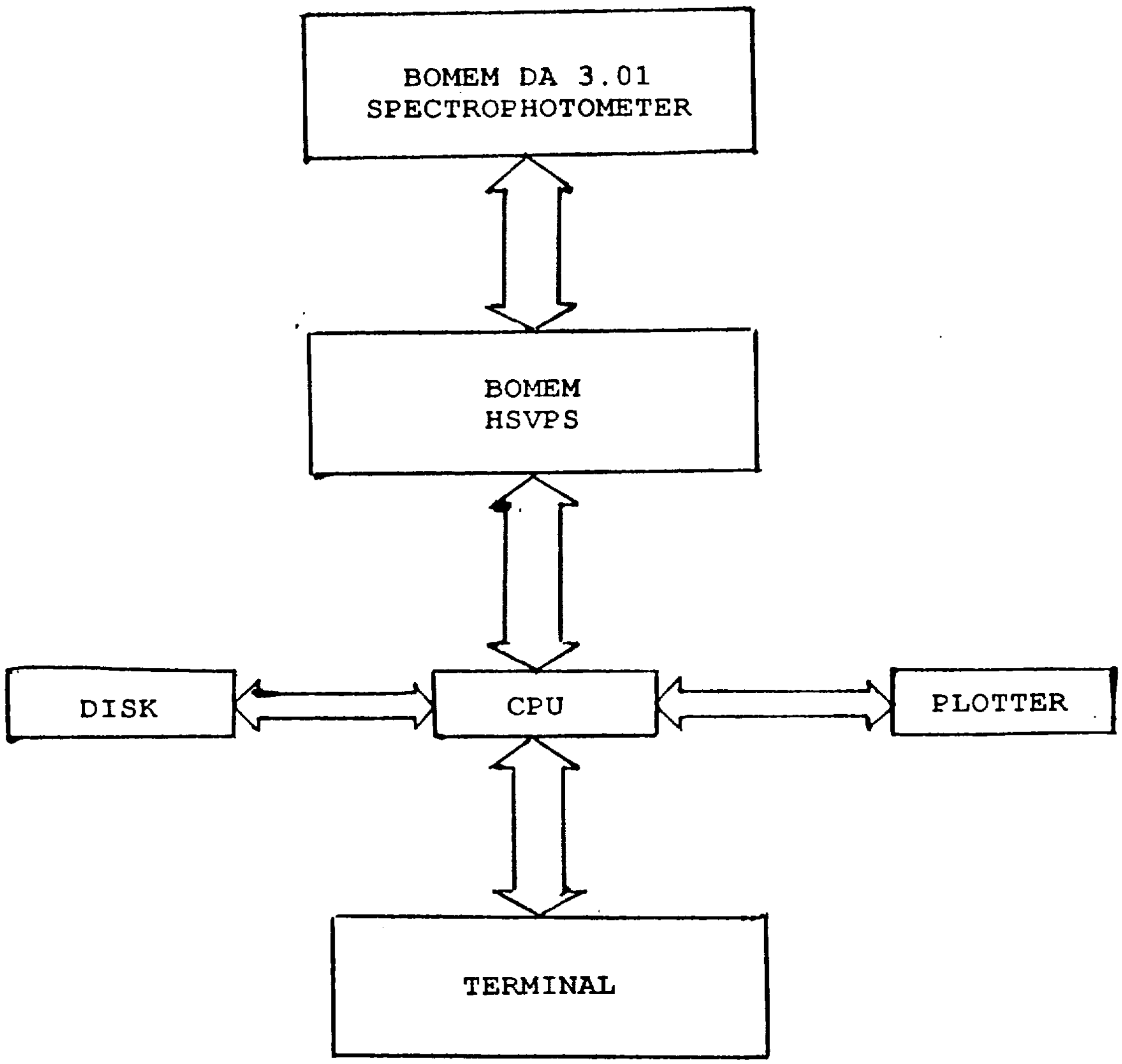


Figure 4.1 Schematic Block Diagram of Major Components in the BOMEM DA 3.01 Interferometric spectrophotometer system

2 EXPERIMENTAL PROCEDURE

Since this was the first time for a high-T_c superconducting, thin film to be examined in our Bomem DA 3.01, considerable difficulty in preparing the measuring equipment had to be overcome before the results were obtained.

The YBaCuO superconducting thin film on $SrTiO_3$ sample was fabricated by a laser ablation technique at the NASA Lewis Research Center. Fabrication techniques are reported in detail elsewhere [25][26]. AC susceptibility measurements showed the superconducting transition at 88.3K, Figure 4.2.

Because transmission spectroscopy can observe a direct interaction with the elementary excitation which plays an important role in the superconducting state, the most direct method to measure the superconducting energy gap is a transmission measurement. As mentioned previously, to perform a transmission measurement requires a homogeneous film, with a thickness less than 1500 Å, and grown on a substrate which is transparent over the frequency range of interest. With the incident electric field in the a-b plane of our film, we did take the transmission spectrum of YBaCuO deposited on $SrTiO_3$ in the range from 100 to 5000 cm^{-1} at room temperature. Due to the influence of the substrate we could not derive any useful information.

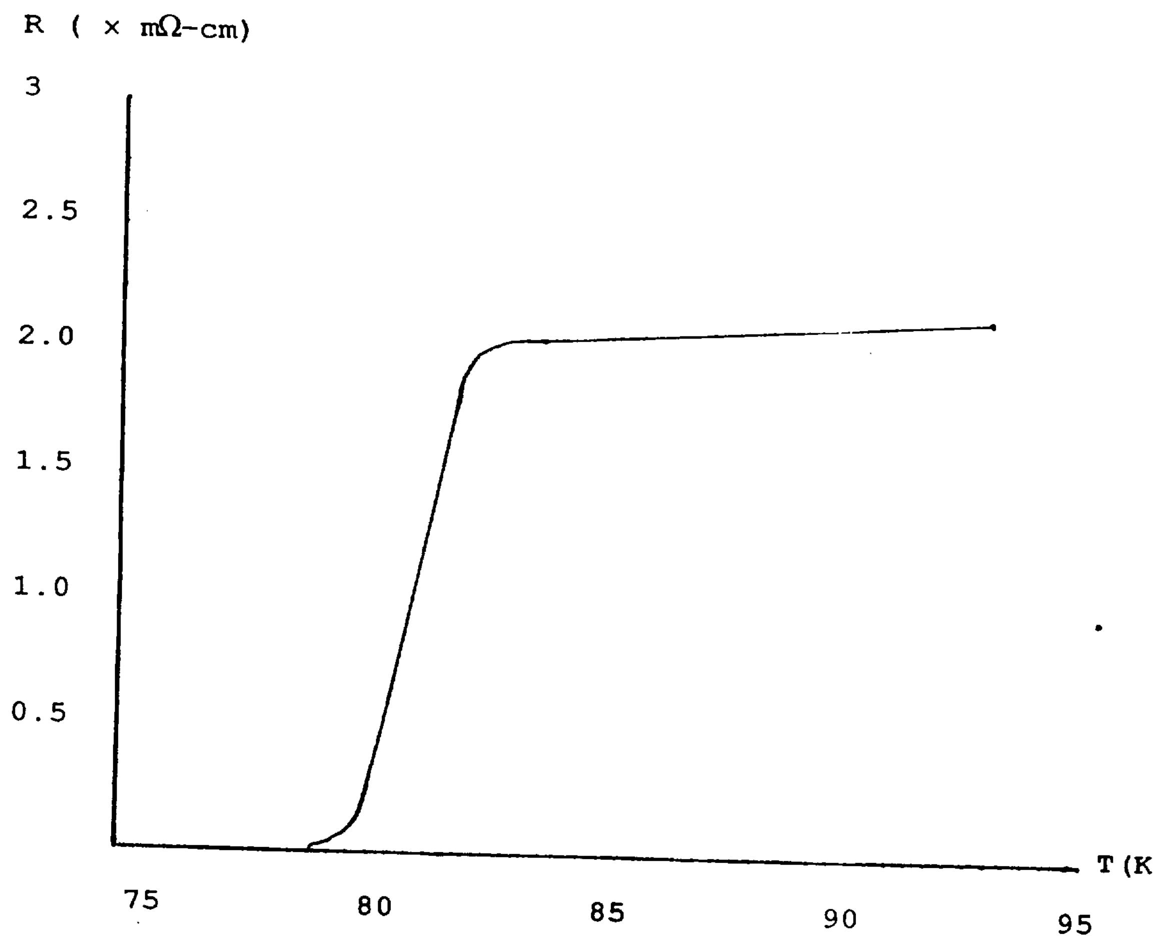


Figure 4.2 Resistivity (× 100 mΩ-cm) vs. temperature for the sample of YBaCuO superconductor. (source: NASA Lewis Research Center.)

Reflectivity measurements are crucial to the investigation of the optical properties of YBaCuO. Using the Bomem DA3.01, we performed the reflection measurements in the frequency range from 10 to 5000 cm^{-1} and at 77K and 310K. Different beamsplitters, detectors and windows, corresponding to different frequency ranges, were used. The infrared radiation was incident at near normal incidence to the sample's a-b plane. After taking the phase and reference spectra with a high quality reference mirror which has the same size as the sample, we replaced the reference mirror with the sample at exactly the same position.

The sample was mounted on the cold finger of a Janis cryostat with copper impregnated grease, which is to improve thermal conductivity and reduce mechanical strain on the sample during thermal contraction. The sample compartment of the cryostat was under a pressure of about 10^{-6} Torr. This prevented the conduction of heat from the surroundings to the sample. This pressure was realized using a CVE301 Vacuum Station.

Without changing any environmental conditions, we coadded hundreds of scans to get the reflection spectrum of the sample. The spectrum of the superconducting state was taken by using liquid nitrogen to cool the sample to 77K. This was done immediately after the normal state spectra were taken. Since a small distortion of the light beam could lead to large energy loss, the reflection energy should be adjusted to be as large as possible before the spectrum is taken, therefore, both the sample and reference mirror should be positioned exactly at the center of the infrared beam.

CHAPTER 5

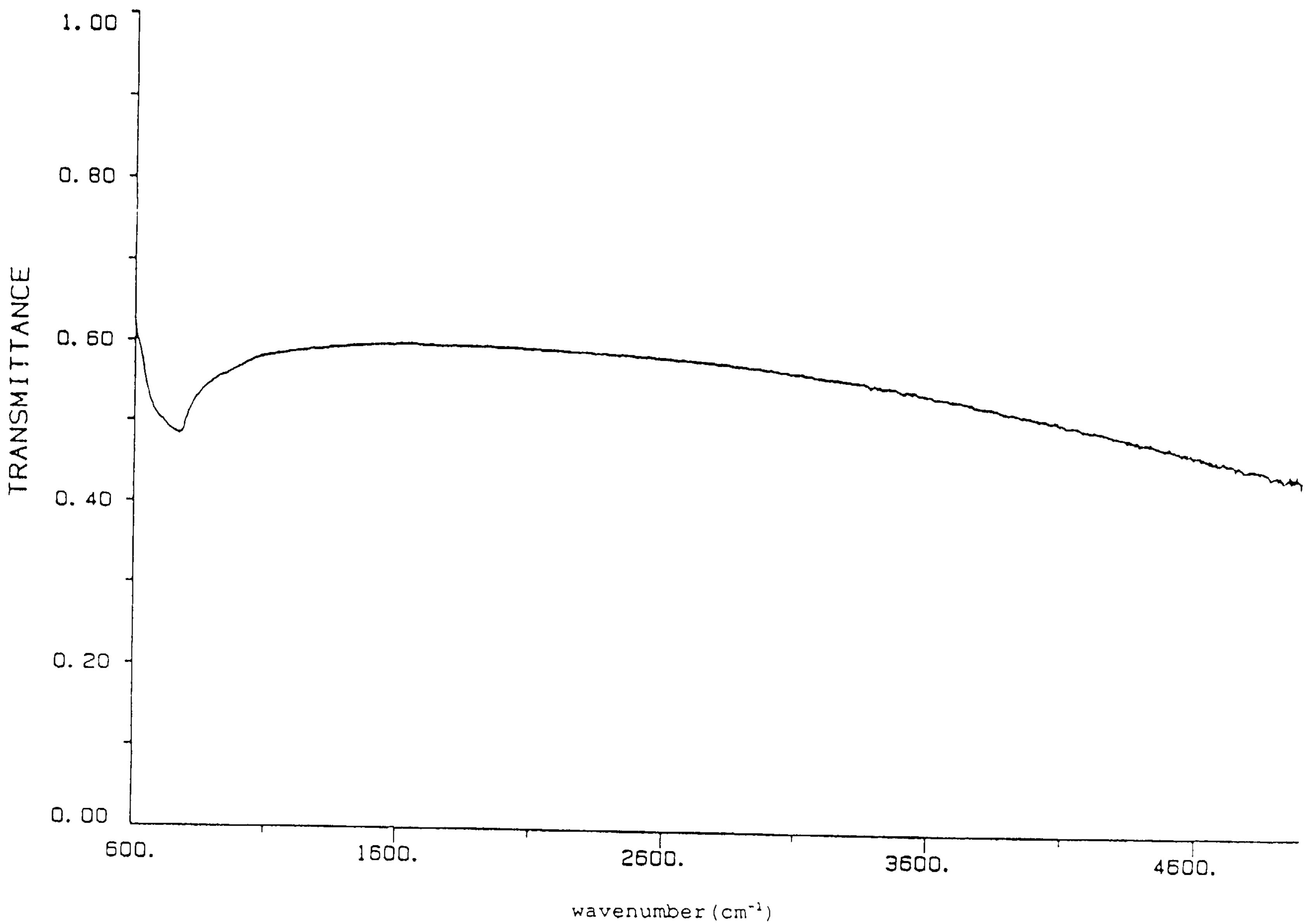
RESULTS AND ANALYSIS

The YBaCuO reflection spectrum of the normal state, the super-conducting state, and the ratio of the superconducting to normal state in the frequency range from 600 to 5000 cm^{-1} are illustrated in Figure 5.1, Figure 5.2, Figure 5.3, respectively. It must be indicated that the valley which appears at around 3150 cm^{-1} in Figure 5.2 is due to the absorbance of ice. Figure 5.1 and Figure 5.2 show that the reflectivities of the normal state and the superconducting state decrease slightly over a frequency range from 600 to 5000 cm^{-1}. Detailed studies over this frequency range by using a Kramers-Kronig transform analysis are reported elsewhere [27].

Since our YBaCuO film sample is only 1200 Å thick, the electric field can penetrate the YBaCuO film and reach the surface of the $SrTiO_3$. Realizing that the spectrum of the sample deposited on $SrTiO_3$ could include the reflectance both from the surface of YBaCuO and the $SrTiO_3$, we considered it necessary to measure the reflectance of the substrate before investigating the spectrum of YBaCuo. Figure 5.4 shows the reflectance spectrum of the $SrTiO_3$. A big absorbance valley was observed in the frequency range from 430 to 570 cm^{-1}, which, according to Frederikse, Thurber and Hosler [28] is associated with a Ti-O stretching vibration.

Figure 5.1

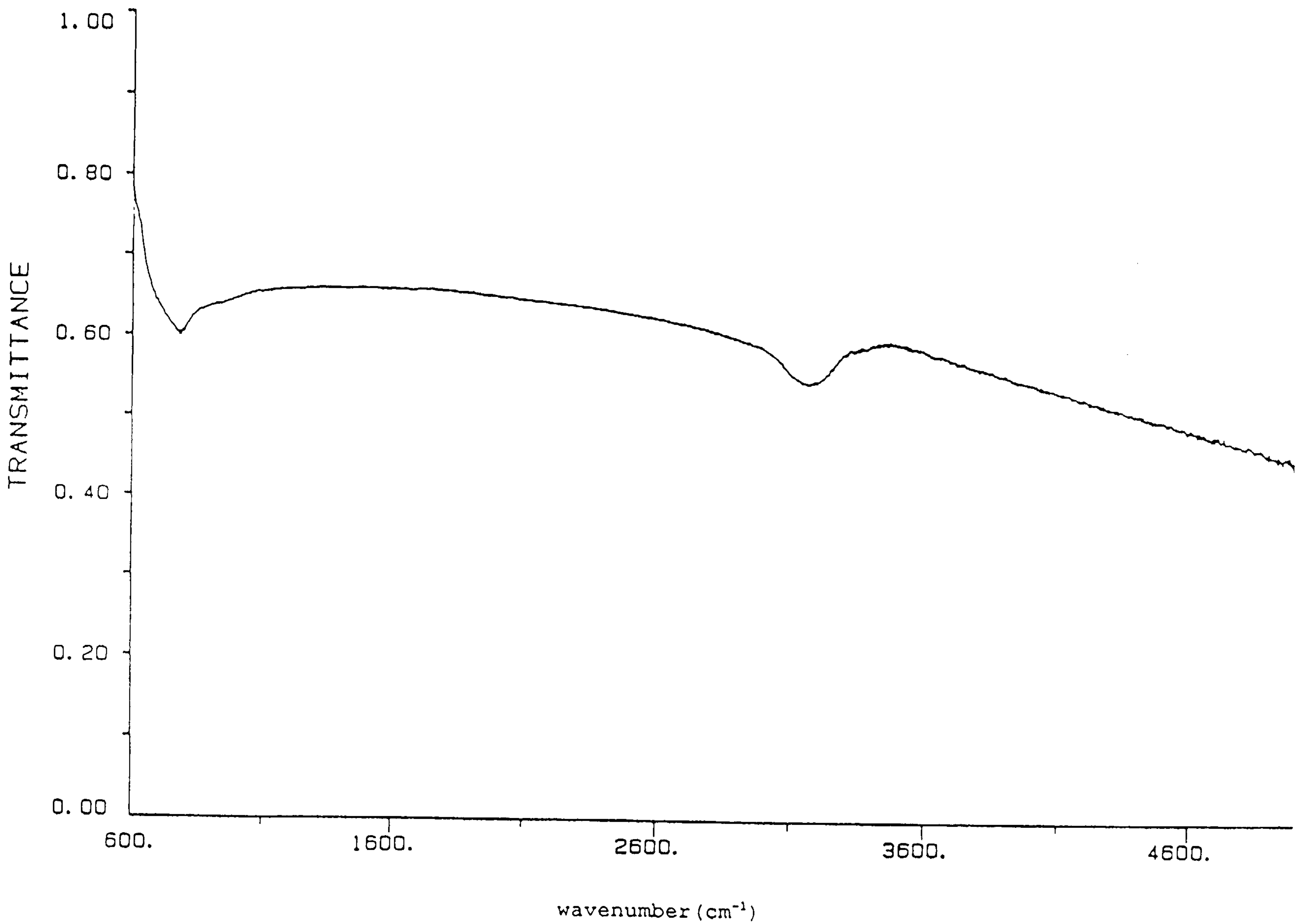
Reflection spectrum of YBaCuO in frequency range from 600 to 5000 cm^{-1} at 310K (normal state).


1.00
0.80
0.60
0.40
0.20
0.00
TRANSMITTANCE
600.
1600.
2600.
3600.
4600.
wavenumber (cm⁻¹)

29A

Figure 5.2

Reflection spectrum of YBaCuO in frequency range from 600 to 5000 cm^{-1} at 77K (superconducting state).


1.00
0.80
0.60
0.40
0.20
0.00
TRANSMITTANCE
600.
1600.
2600.
3600.
4600.
wavenumber (cm⁻¹)

25A

Figyre 5.3

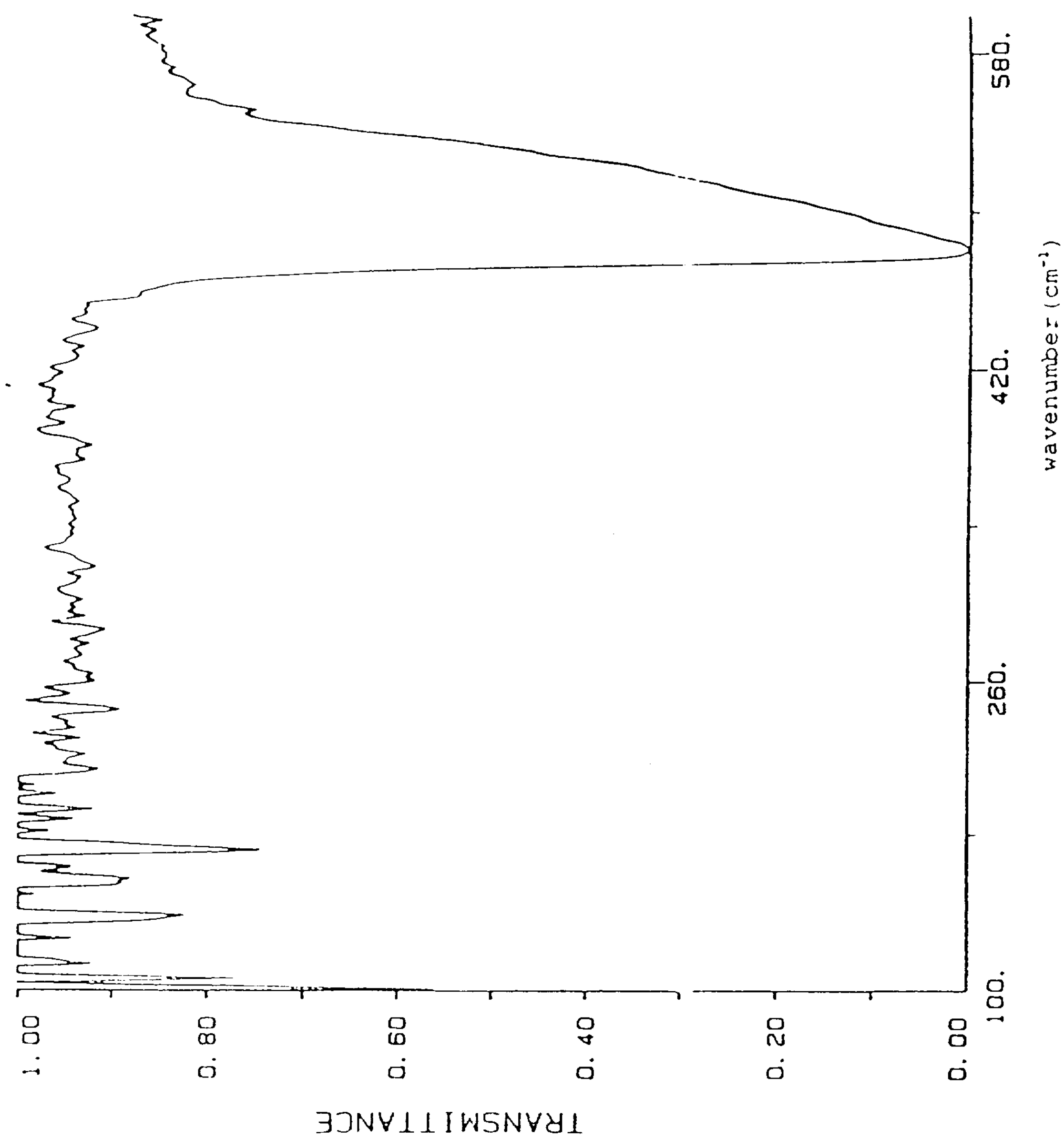
The ratio of the reflection spectrum of the superconducting state to normal state in frequency range from 600 to 5000 cm^{-1}.

2.00
1.60
1.20
0.80
0.40
0.00
TRANSMITTANCE
602.
1602.
2602.
3602.
4602.
wavenumber (cm-1)

26A

Figure 5.4

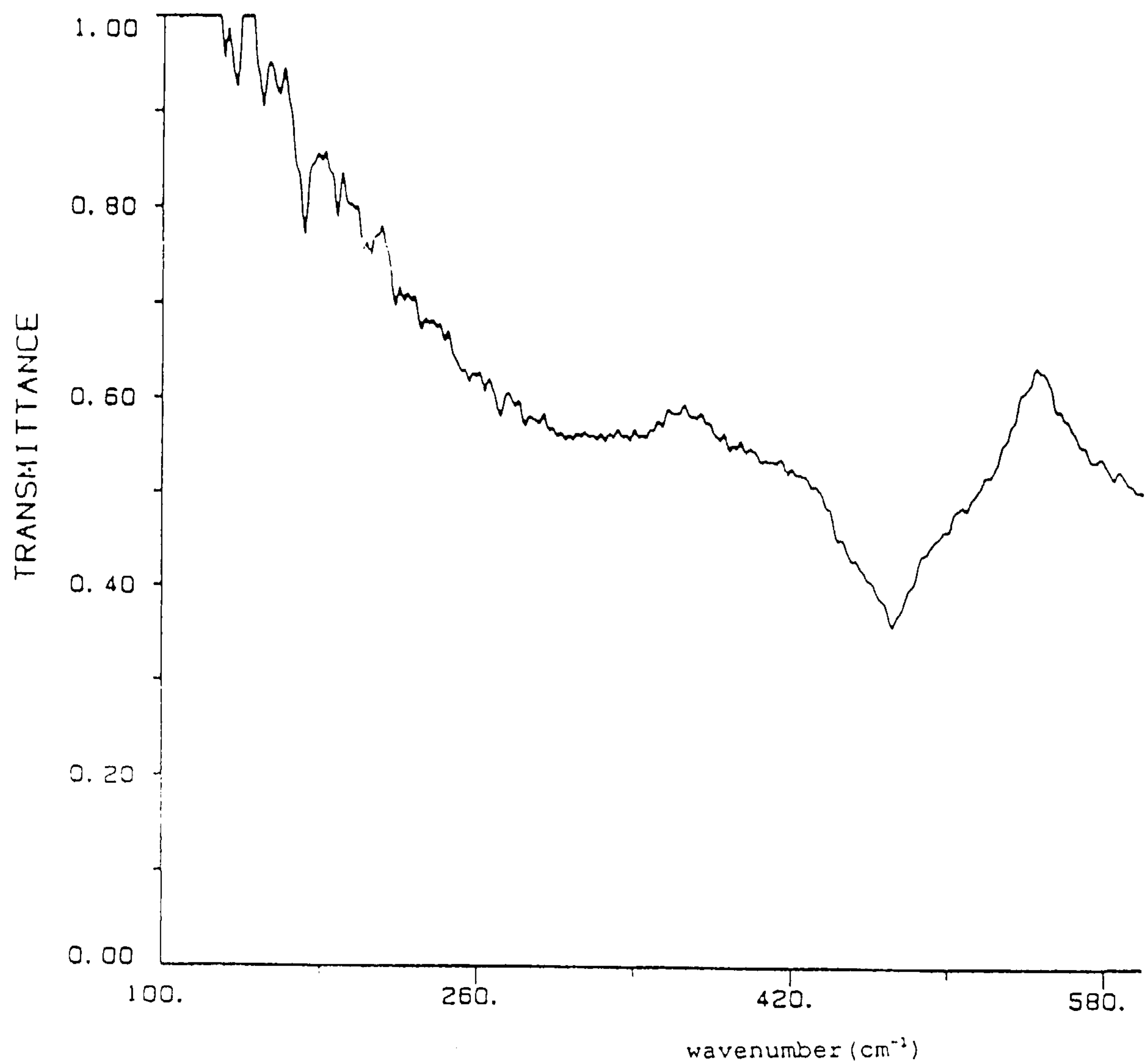
Reflection spectrum of $SrTiO_3$ substrate.


TRANSMITTANCE
1.00
0.80
0.60
0.40
0.20
0.00
100.
260.
420.
580.
wavenumber (cm^{-1})

27A

Figure 5.5

Reflection spectrum of YBaCuO in frequency range from 10 to 600 cm^{-1} at 310K (normal state).

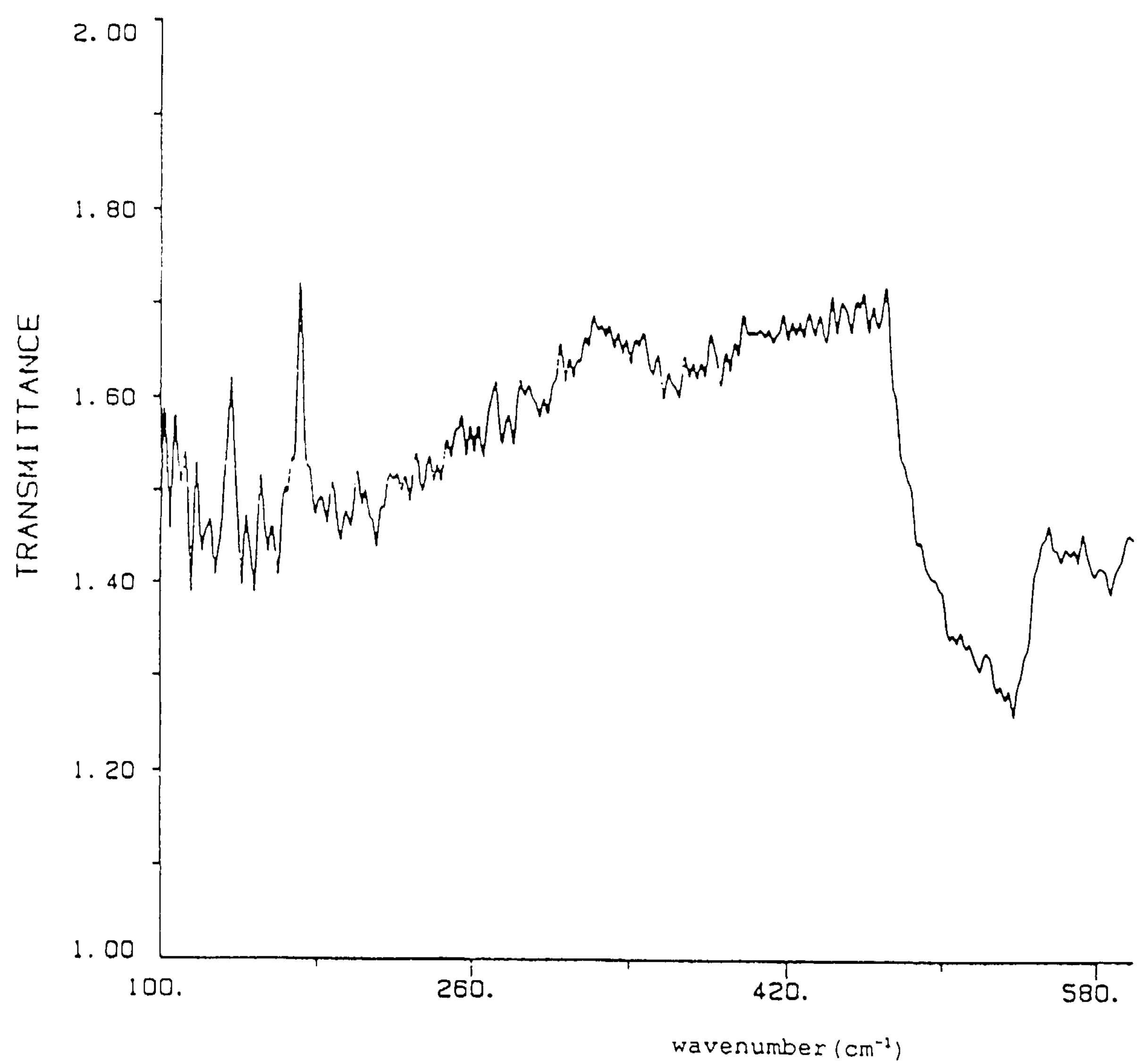


TRANSMITTANCE
1.00
0.80
0.60
0.40
0.20
0.00
100.
260.
420.
580.
wavenumber (cm⁻¹)

28A

Figure 5.6

Reflection spectrum of YBaCuO in frequency range from 10 to 600 cm^{-1} at 77K (superconducting state).


2.00
1.80
1.60
1.40
1.20
1.00
TRANSMITTANCE
100.
260.
420.
580.
wavenumber (cm⁻¹)

29A

Figure 5.7

Ratio of the reflection spectrum of superconducting state to normal state.

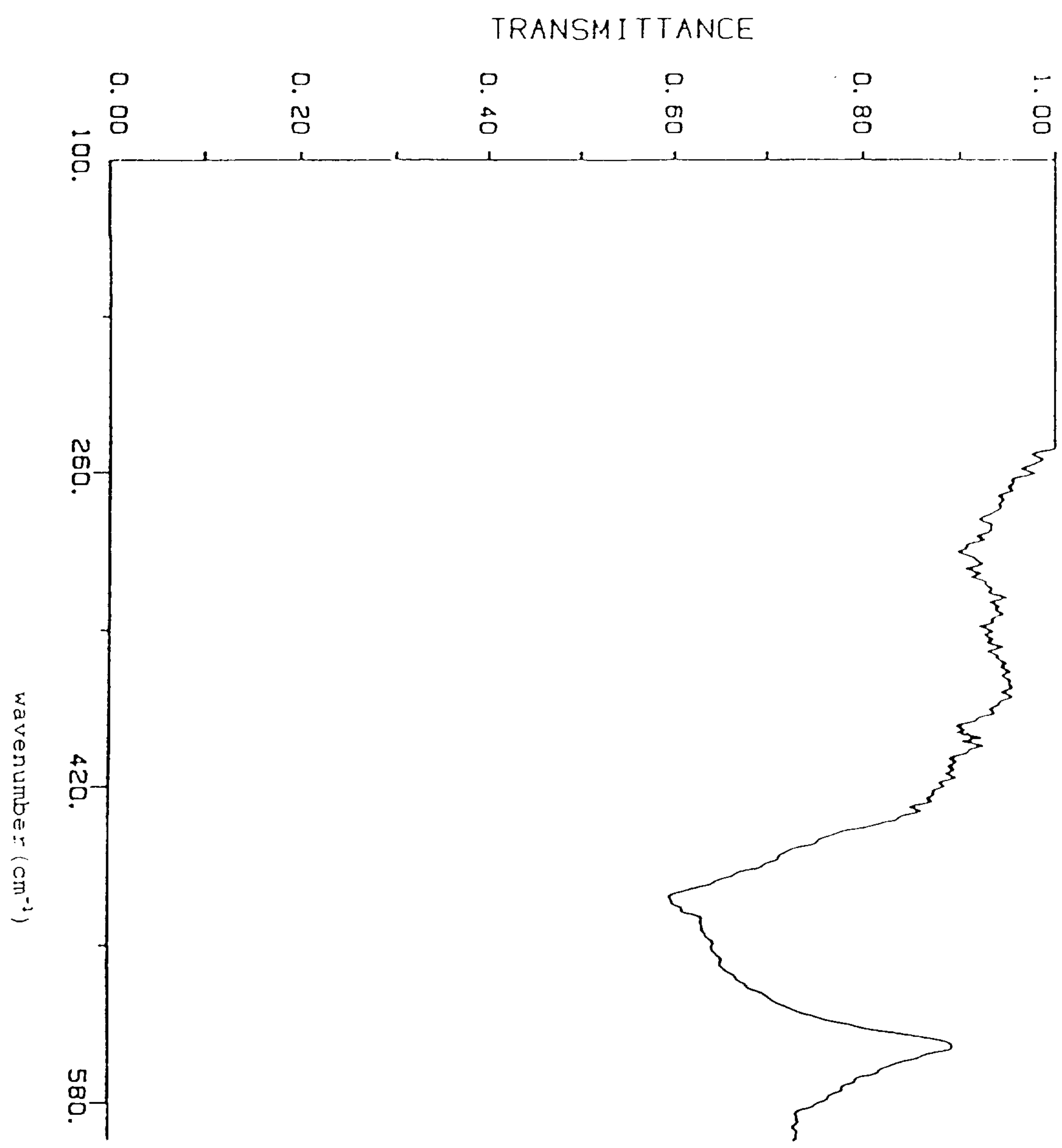

TRANSMITTANCE
0.00
0.20
0.40
0.60
0.80
1.00
100.
260.
420.
580.
wavenumber (cm-1)

Figure 5.5 and Figure 5.6, the reflectance spectra of YBaCuO deposited on $SrTiO_3$ in the normal and superconducting state in the frequency range from 10 to 600 cm^{-1}, show that the reflectivity of both states decrease as the frequency increases. As mentioned previously, these two spectra should include the reflection from the surface of both YBaCuO film and $SrTiO_3$. Significant changes are observed in both spectra in the frequency range around 430 to 570 cm^{-1}. A comparison of these two spectra to Figure 5.4, the spectrum of $SrTiO_3$, tells us that the absorption lines in Figure 5.5 and Figure 5.6 are associated with the absorbance of the Ti-O stretching vibration of $SrTiO_3$.

As the temperature of the sample is reduced below the transition temperature T_c, we expect to see an enhancement in the reflectance spectrum at and below the superconducting energy gap frequency. Looking at the superconducting state reflectivity, Figure 5.6, we can see the reflectivity is almost 100% up to 430 cm^{-1}. The energy begins to be absorbed after that frequency. The greatest absorbance of the $SrTiO_3$ is in the frequency range from 430 to 570 cm^{-1}, as shown in Figure 5.4. Therefore, it is difficult to separate the effects of the $SrTiO_3$ from the superconducting film without obtaining the ratio of the two spectra. By calculating the ratio of the reflectance in the superconducting state to that in the normal state, we can eliminate the influence of the reflectance from the surface of $SrTiO_3$ and study the reflectivity of the superconducting state by comparison. Figure 5.7, the ratio of the reflectivity of the superconducting state to that in the normal state, shows that the reflectivity in the superconducting state is greater than that in the normal state over a broad spectral range. The ratio rises to a maximum at $\omega = 480\ cm^{-1}$ and then drops dramatically. The enhancement at $\omega = 480\ cm^{-1}$ in the ratio demonstrates that the absolute reflection, the superconducting feature, disappears after $\omega = 480\ cm^{-1}$. Based on the BCS theory, it can be inferred that when the incident photon energy reaches $480\ cm^{-1}$ the Cooper pairs are broken, and the electrons absorb enough energy to overcome the energy gap and can be excited from the ground state to a higher state. Thus, we conclude that the superconducting gap of YBaCuO exists for our sample at 480 cm^{-1}.

Using $k = 8.625 \times 10^{-15} ev/K$, $T_c = 88.3K$, $E_g = 480\ cm^{-1} = 59.6\ mev$, we get:

$$E_g/kT_c = 59.6 \times 10^{-13}/(\ 8.625 \times 10^{-15} \times 88.3)$$

$$= 7.83$$

This result is consistent with the result reported by Schlesinger's group [23].

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS

A reflectivity of approximate 100% was observed to frequency, $\omega = 480\ cm^{-1}$, in the reflection spectrum of a YBaCuO sample (T_c =88.3K) at temperature, T = 77K. From this we infer that the superconducting gap exists at 480 cm^{-1}, giving a value of $E_g/kT_c = 7.83$. This result suggests that the high-T_c superconductor YBaCuO, is associated with a very strong-coupling mechanism of superconductivity.

By looking at Figure 5.5 and Figure 5.6, we conclude that the substrate absorbance should be considered in the cases of the superconducting thin films which are thinner than 1500 Å.

2 RECOMMENDATIONS

To eliminate the influence of the substrate on the reflection spectrum of the superconductor, we need additional samples where the thickness of the superconducting thin film is greater than 1500 Å.

The most direct method to measure the superconducting energy gap is to do a transmission measurement, therefore, we hope that we can obtain a YBaCuO thin film sample, which is grown on a substrate that is transparent over the frequency range of interest, and is no thicker than 1500 Å.

REFERENCE

1. G. Bednorz and K. A. Muller, Z. Phys. B64 (1986)P189
2. R. J. Cava, R.B. Van Dover, B. Batlogg, and E. A. Rictman, Phys. Rev. Lett. 58, (1987)P408.
3. C. W. Chu, P. H. Hor, R. L. Meng, L.Gao, Z. J. Huang and Y. Q. Wang. Phy. Rev. Lett. 58, (1987)P405.
4. H. Takagi, S. I. Vchida, K. Kitazawa, and S. Tanaka. Jpn. J. Appl. Phys 26, L1(1987).
5. J. M. Tarascon, L. H. Greene, W. R. Mckinnon, G. W. Hull, and T. H. Geballe. Science 235, (1987)P1373.
6. M. K. Wu, J. R. Ashburn, C. J. Torng, P. H. Hor, R. J. Meng, L. Gao, Z. J. Huang, Y. Q. Wang, and C. W. Chu. Phy. Rev. Lett. 58, (1987)P908.
7. Z. Zhao, L. Chen, Q. Yang, Y. Huang, G. Chen, R. Tang, G. Liu, C. Cui, L. Chen, L. Wang. S, Guo, S. Li, and J. Bi. Kexue Tongbao 8, (1987).
8. C. W. Chu, J. Bechtold, L. Gao, P. H. Hor, Z. J. Huang, R. L. Meng, Y. Y. Sun, Y. Q. Wang, and Y. Y. Xue. Phys. Rev. Lett. 60, (1988)P941.
9. H. Maeda, Y. Tanaka, M. Fukutome, and T. Asano. Jpn. J. Appl. Phys. Lett. 27, L209(1988).
10 C. Michel. M. Hervieu, M. M. Borel, A. Grandin, F. Deslandes, J. Pvovost, and B. Raveau. Phys. B Cond. Matt. 68, (1987)P421.

11. R. M. Hazen, L. W. Finger, R. J. Angel, C, T. Prewitt, R. L. Ross, C. G. Hadidiacos, P. J. Heaney, D. Rl Veblen, Z. Z. Sheng, A. EL. Ali, and A. M. Hermann, Phys. Rev. Lett. 60, (1988)P1657.

12. Z. Z. Shen, A. M. Hermann, A. EL. Ali, C. Almasan, J. Estrada, T. Datta, and R. J. Matson. Phys. Rev. Lett. 60, (1988)P937.

13. Z. Z. Sheng, A. M. Hermann. Nature 332, (1988)P55.

14. K. Rose, C. L. Bertin, and R. M. Katz "Radiation Detectors" in Applide superconductivity, Vol. New house, Academic Press. (1975)P267.

15. J. Talvacchio, M. G. Forrester, and A.I. Braginski. "Photodetection with high-T_c superconducting films" in Science and Technology of Thin-film Superconductors. Plenum Press, New York (1989).

16. J. Bardeen, L. M. Cooper, and J. R. Schrieffer. Phys. Rev. 108, (1957)P1157.

17. P. J. M. Van Bentum, H. F. C. Hoevers, H. Van Kempen, L. E. C. Van De Leemput, M. J. M. F. De Nivelle, L. W. M. Schreurs, R. T. M. Smokers, and P. A. A. Teunissen Phys. C. Vol. 153-155, Superconducty June, 1988 P 1718-1723.

18. R. E. Glover and M. Tinkham Phys. Rev. 104 (1956)P844, and Phys. Rev. 108(1957)P243.

19. P. L. Richards and M. Tinkham. Phys. Rev. 119 (1960)P575.

20. F. E. Pinkerton, B. C. Webb, A. J. Sievers, J. W. Wilkirs, and L. J. Sham. Phys. Rev. Lett. 57 (1986)P1951.

21. P. E. Sulewski, A. J. Sievers, M. B. Maple, M. S. Torikachvili, J. L. Smith, and Z. Fisk. Phys. Rev. B38 (1988)P5338.

22. G. A. Thomas, J. Orenstein, D. H. Rapkine,M. Capizzi, A. J. Millis, R. N. Bhatt, L. F, Schneemeyer, and J. V. Waszczak. Phys. Rev. Lett. 61(11) (1988) P. 1313.

23. R. T. Collins, Z. Schlesinger, F. Holtzberg, D. L. Kaiser. Phys. Rev. Lett. 59(17) (1987)P1958.

24. K. Kamaras, S. L. Herr, C. D. Porter, N. Tache, and D. B. Tanner. Phys. Rev. Lett. 64(1) (1990)P84.

22. R. K. Singh, N. Billnno, and J. Narayan. Appl. Phys. Lett. 53, (1989)P1013.

23. R. K. Singh, J. Narayan, A. K. Singh, and J. Krishnaswamy. Appl. Phys. Lett. 54, (1989)P2271.

24. R. T. Collins, Z. Schlesinger, F. Holtzberg, Chaudhari, and C. Feild. Phys. Rev. B. Vol. 39. No. 10(1989)P6571.

25. Frederikse H. P. R, Thurber W. F. and Hosler W. R. Phys Rev. 134, A442-25(1964).