An Experimental Setup for Study of Photoresponse of High $T_c$ Superconductors

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Abstract We have developed an experimental setup that has been proven suitable for the study of photoresponse of high $T_c$ superconductors. The distinguish feature of this experimental setup lies mainly in the data acquisition system which is equipped with computer as well as the IEEE-488 interface bus, which ensures the accuracy to experimental results. Using the experimental setup, the optical response to laser radiation in high-$T_c$ superconductors has been examined, both of bolometric effect and nonequilibrium optical response are revealed.

Key words: high $T_c$, superconductor photoresponse, cryostat

1 Introduction

The detection of infrared and visible light radiation by superconducting films is a well-known phenomenon. It has been known that in conventional superconductors, incident light is reflected from the superconductor surface as a result of the plasma oscillation of free electrons, and can not interact with Cooper pairs. Therefore, a high power level of incident light is required for the generation of quasiparticles, which, in turn, will lead to the heating effects and make the phenomenon more complicated\(^1\). With the discovery of the new oxide superconductor such as YBa$_2$Cu$_3$O$_{7-\delta}$ (YBCO), interest has grown in the prospect of more sensitive optically control superconductive electron devices operating at 77 K. YBCO has a low carrier density of about $10^{27}$/cm$^3$, which is one or two orders of magnitude smaller than that of the conventional superconductors, and a lower reflection coefficient\(^2\). Therefore, light can penetrate into it and effectively excite the quasiparticles by breaking Cooper pairs.

It is believed that optical response of high $T_c$ superconductor (YBCO) can be divided into two categories. One is bolometric response, which is due to a temperature change caused by the heating effect of the incident light radiation. This temperature change introduces a measurable change in some physical properties, for example, the electric resistance of a superconductive material in the vicinity of transition edge. The other is non-bolometric response, which occurs at temperatures below the transition. In this case, the incident photons break the Cooper pairs and cause an increase in the number density of quasiparticles. The non-bolometric response may happen on a time scale comparable to or less than the electron-phonon relaxation time and, in principle, can be used to built fast and sensitive superconducting electron devices.

It is essential to understand the nature of photoresponse of YBCO thin films. Some previous experiments point out that\(^{3-5}\) there is only bolometric optical response in the YBCO epitaxial films, while others reveal that\(^{6-8}\) both bolometric and nonbolometric optic response exist in the same films. In order to investigate deeply the nature of the light response of the high $T_c$ superconductors, we developed an experimental system to study the photoresponse behavior of high $T_c$ superconductors. The system consists of three different parts. A detail description about it is given below.

2 Experimental Setup

As shown in Fig.1, the experimental setup consists mainly of cryostat system, optical system and data acquisition system. Each of them is presented below.

2.1 Cryostat system

At present, various cryostat systems designed specially for the study of superconductivity are available. These can provide a wide range of temperature from 4.2 K to 300 K.
Although being widely used in many laboratories, this kind of cryostat system is sometimes not suitable to optical experiments due to the vibration brought about by the running of refrigerator and will make it difficult to focus the incident light on superconducting samples. The vibration may even be fatal for optical measurements. Therefore, a cryostat system without running vibration is desired for the study of optical response in superconductors. For the purpose of that, we developed a LN$_2$ cryostat based on the "lower temperature by reducing pressure" effect, which can provide a temperature range of 64 K to 300 K. Since the cryostat is not equipped with refrigerator, it does not bring about any vibration while the cryostat system is running. It has been proved completely suitable for the experiments of photoresponse investigation. Fig.2 shows the structure of the cryostat system.

A typical glass liquid-helium Dewar bottle structure is used. The outer glass vessel is filled with liquid nitrogen and the inner is half-filled with liquid nitrogen instead of liquid helium. The space above the surface of liquid nitrogen in the inner bottle is pumped to high vacuum. In this way, the temperature of the inner bottle can be lowered to 64 K, and be maintained with a fluctuation of less than 0.02 K/min in average. This accuracy can meet the requirement for photoresponse investigation in high-$T_c$ superconductors. The cooling head of the cryostat, which is made of copper, is supported by a thin-walled (wall thickness 0.5 mm) stainless-steel tube extended to the top flange plate. Whole component part is immersed in liquid nitrogen. In the state of heat balance, the difference of temperature between liquid nitrogen and the heat sink was evaluated about less than 0.5 K. The structure of the cryostat is similar to the one of that used by Testardi and has been proved suitable for the experiments of photoresponse in high-$T_c$ superconductors.

2.2 Optic system

In our experiment, a narrow strap of high $T_c$ superconducting film sample, with 100 µm wide and 2000 µm long, is used. A He-Ne laser beam at 0.63 µm is focused on the strapped sample with a spot size (diffraction limited beam diameter) about 50 µm. In order to make the laser beam be focused precisely on the sample, an adjustable structure has been worked out, which is composed of two optic mirrors with 45° reflecting angle and a fine tunable component. The optic structure is showed in Fig.3. As shown in Fig.3, the reflecting mirrors $M_1$ and $M_2$ are connected each other with a fixed distance and can be moved in the X-Y plane. The normal direction of the optic screen (imaginary sample plane) is in Y axis. An incident laser beam along X axis will be reflected by the mirror $M_1$ to