Extended Abstracts of the 1991 International Conference on Solid State Devices and Materials, Yokohama, 1991, pp. 420-422 **S-F-1**

Invited

Applications of High T_c Superconductors to Electronic and Optical Devices

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The electric field effect on the epitaxial (001)YBaCuO film has been investigated. The Al-MgO-YBaCuO MIS diode revealed the gate-voltage-dependent capacitance in the reasonable amount. The YBaCuO MISFET with the channel of 2~3 sound unit cells was prepared by using the selective heteroepitaxial technique. The channel conductance was modulated by the gate electric field. In addition to the electronic application, we here propose a new and highly sensitive photo-detection method based on the inteference of the coherent superconducting electron wave and microwave. We tentatively named this as "ISPD" (Interference type Superconductive Photo Detector).

1. INTRODUCTION

Since the discovery of the oxide superconducting materials, new application methods of the low temperature electronics (working at least at 77 K) have been intensively explored. The high T_c oxide superconductors (HTSCs) have characteristic properties such as the strong anisotropy, low carrier concentration, in-plane carrier localization and large optical absorptivity. Taking those characteristics with the high critical temperature into account, the HTSCs seem to have capability in opening wide application way. However, it is true that the benefit of the way should surpass the cooling handicap unavoidable for the superconducting application.

So far, we conducted the electric field effect experiment for Al-(100)MgO-(001)YBaCuO MIS diode structures[1]. Here, as an advanced stage, the feasibility check of YBCO-MISFETs has been done. The conductance of the ultra-thin YBaCuO channel was sufficiently modulated by the gate electric field.

A new optical detection method using the superconductor has been explored by our group. Our proporsal is characterized by introduction of the interference of the superconductive electron-wave and the microwave, which ensured the highly sensitive optical detection. This detection method is derived, in principle, from our previous experiment where a new three terminal superconducting transistor was closely investigated[2].

In the present report, we shall describe details about the superconductive MISFET and interference type superconcuctive photo detector (tentatively named by ISPD). As to the latter, main results were obtained from the low T_c Nb system at least at present. Measurements on the HTSC system are underway.

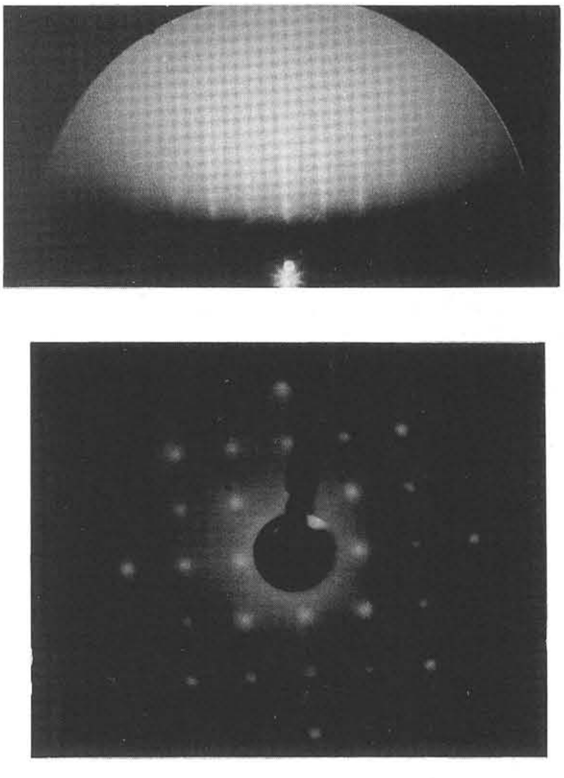

Fig.1 Electron diffraction patterns of the epitaxial YBaCuO film. (a) RHEED (25 kV) and (b) LEED (120 V).

2. EPITAXY OF HIGH QUALITY HTSC FILMS

High-quality epitaxial films are very necessary for the device application anyway. We so far established the high pressure reactive magnetron sputtering technique, which can provide reproducibly the good YBaCuO films with T_c of 87~90 K[3].

Typical RHEED and LEED patterns taken from the standard YBaCuO film on MgO substrate are given in Fig.1(a) and (b), respectively, showing that the film has good crystallinity even at very surface region.

3. YBaCuO MISFET EXPERIMENT

In the fabrication of the YBCO-MISFETs, what we should pay cautions to are the leakage of gate current, interface states and ultra-thin YBaCuO channel. The selective MgO-YBaCuO heteroepitaxy which entirely meets above all was used for the MISFET formation[4]. The (001)YBCO (5~6 nm) and (100)MgO (60nm) were successively grown directly on (100)MgO substrate. The superconducting critical temperature T_{c0} above 50 K was obtained even for the 5 nm thick films directly grown on MgO substrates[5]. The top view of the completed MISFET is shown in Fig.2.

The problem we still face in the MISFET fabrication is the ohmic contact formation because of the absence of selective etching of MgO and/or incomplete YBCO coverage at the edge of the buried contact-metal. Unfortunately at present, the contact resistance increased to ~50 kΩ and higher at lower temperatures. This resistance will mask to large extent the modulation of the channel conductance by the field effect. Nevertheless, the gate field effect on the drain current was observed as shown in Fig.3, though the change was very slight.

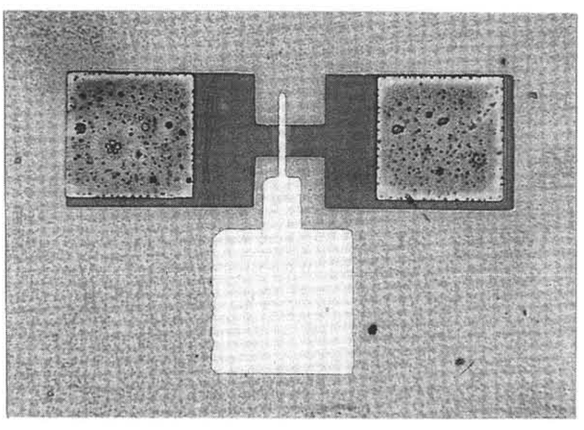

Fig.2 Top view of the completed YBaCuO MISFET. Al-(100)MgO-(001)YBaCuO structure. Drain and source electrodes are buried under the YBaCuO layer.

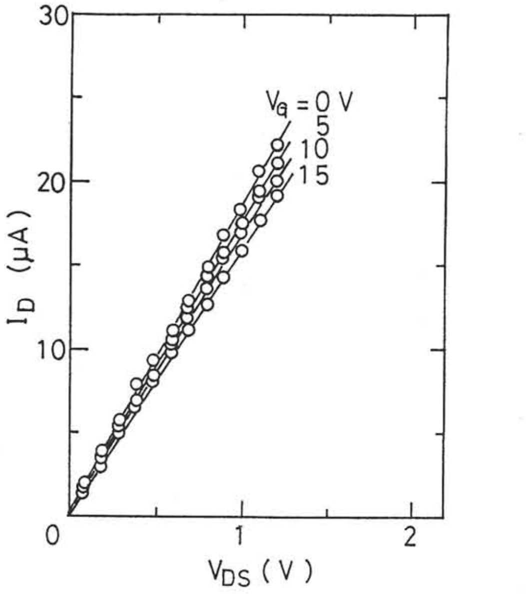

Fig.3 Raw data of drain current vs drain voltage characteristics.

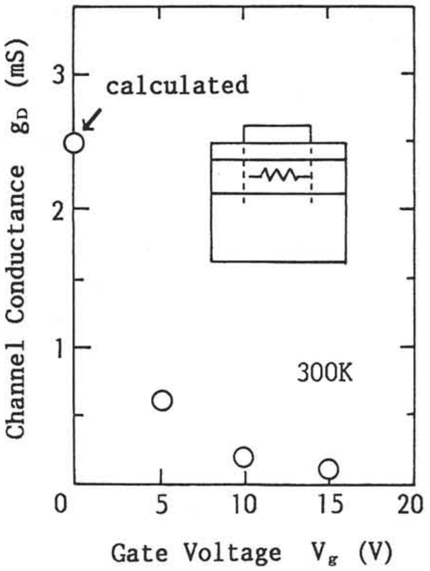

Fig.4 Calibrated field effect on channel conductance. The contact resistance is subtracted from data in Fig.3.

By subtracting the poor ohmic contact resistance from experimental data in Fig.3, we can obtain the net change of the drain conductance due to the gate electric field. The results are plotted in Fig.4 as a function of the applied gate voltage, where one can find appreciable field effect on the conductance. In the present MISFET, at most two YBaCuO unit cells survived in the channel. Therefore, the deep depletion of the conduction band was possible to obtain.

4. NEW SUPERCONDUCTIVE PHOTO DETECTOR

In our previous work[2], we proposed a new current amplifier by an SIS Josephson junction with a hot quasi-particle injector where the microwave interference served as the key role for the efficient amplification. Though the device principle is not known at present, it is expected that the sensitive photo detection may be feasible by simply replacing the quasi-particle injection by a photon irradiation.

To check the feasibility of this view, we made a device with the metal superconductors of Nb and Pb system. The diode was mounted on the TO-5 transistor header and He-Ne laser light was fed to the junction through the glass substrate. The Nb base electrode was 10 nm thick. As shown in the measurement way of Fig.5, the SIS Josephson junction was irradiated with the continual microwave bias.

Since we used the SIS tunneling Josephson junction, we could monitor not only Shapiro step height but also the energy gaps Δ_{Nb} and Δ_{Pb} during the optical irradiation. Throughout the experiment, the optical signal intensity was limited to the value for which we found no sign of changes of the energy gap Δ and zeroth Shapiro step height I_{c0}. Under this condition, the conventional Josephson photo detector can not pick the optical signal up. However, our proposed "ISPD" can well work as described in the following.

As shown in Fig.5, the ISPD is characterized by the microwave bias. Photo-response of the junction was dramatically enhanced by the microwave bias. One can find in Fig.6 the change of zeroth Shapiro step height under the optical irradiation by the biased microwave amplitude. At the null microwave bias, the Josephson critical current did not change at all by the light within the experimental range. With increase in the microwave power, however, the reduced I_{c0} was efficiently released by the photo irradiation. The rate of I_{c0} recovery increased for the small amount of light illumination and for less I_{c0}.

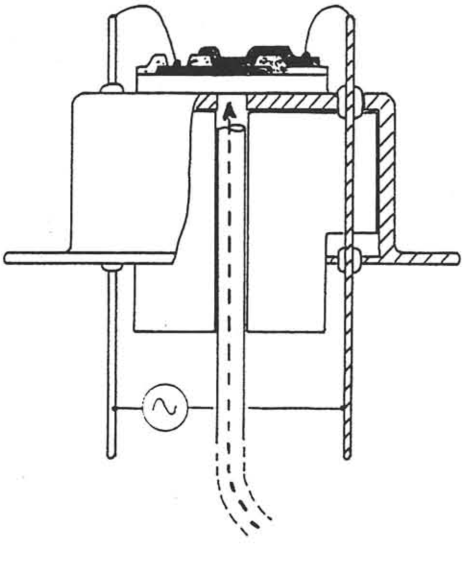

Fig.5 Optical measurement by interference type superconductive photo detector ISPD. The micro-wave was capacitively coupled to the junction.

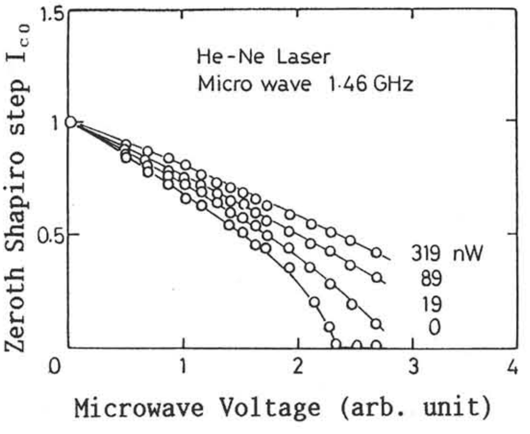

Fig.6 Zeroth Shapiro step height vs incident light as a function of microwave voltage.

The new photo detection ISPD works on the basis of the phase interference of the superconductive electron wave and microwave. The irradiated photon may bring some phase perturvation between two waves, resulting in release of the suppressed I_{c0}.

5. CONCLUSIONS

As new applications of superconductors, the YBaCuO MISFET and interference type photo detector were proposed and demonstrated.

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