The Journal of National Chiao Tung University
Vol. I, April 1976
pp. 303-310

趨近理想化的 Josephson 接面之性質
Behavior of A Near-Ideal Josephson Junction

郭義雄 Yih-Shun Gou
Department of Communication Engineering

(Received January 14, 1976)

ABSTRACT — We have fabricated a near-ideal Josephson Sn-SnO-Sn junction, which is needed in the theoretical treatment. We have described how to make the specimens, and we have also presented evidence for the ideality of them in some detail.

I. Introduction

There are two groups of problems in the center of attention in the modern theory of superconductivity. The first is connected with studies of possible new basic mechanism arising in one dimentional system such as the organic solid TTF-TCNQ [1]. A clear picture of what is involved has not emerged in this area so far.

To the second group belong studies of the usual superconductivity of metals based on BCS [2] theory. This theory is extremely effective and can predicte many features of superconductors. An important prediction of this kind is the properties of the so-called "weak superconductivity", including the Josephson effect [3]. This effect has recently received a great deal attention not only for scientific reasons but also in connection with possible practical applications. The aim of this article try to present a near-ideal Sn-SnO-Sn junction, which can be used to study the Josephson effect.

The article will deal with two parts. First, we will mention how to fabricate specimens. Second, we will discuss junction quality, particularly junction uniformity, and also give evidence for the ideality of them.

II. How to Fabricate Junctions

Fig.(1) shows step by step how we fabricate a typical junction: (1) Four gold electrodecontacts are evaporated onto a sapphire substrate (1"x0.5"x0.024"). (2) The first, wider, tin film, 2000 A thick, is laid down in a 10^{-6} torr vacuum onto the same substrate cooled to approximately -50°C. (3) The surface of this film is oxidized in an oxygen glow discharge at 0.07 torr for 7 minutes at the same temperature. The thickness of the resulting oxide is approximately 10 to 20 A. (4) The top, narrow, film is then deposited under the same conditions as (2). (5) The formed specimen is installed on a plastic holder and four wires are connected in order to measure the I-V characteristics. The properties of four specimens that we used in this work are listed in Table 1.

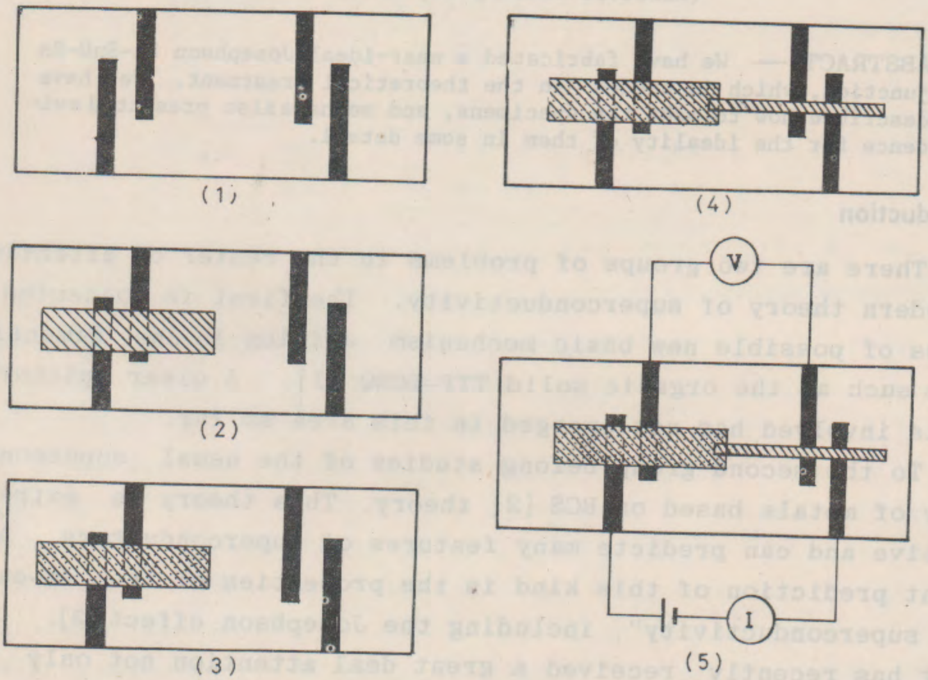

Fig. 1. Step by step procedure to fabricate a typical junction: (1) Four gold contacts are evaporated onto a sapphire substrate (1"x0.5"x0.024"). (2) The first, wider, tin film, 2000 A thick, is laid down in a 10^{-6} torr vacuum onto the same substrate cooled to approximately -50 C. (3) The surface of this film is oxidized in an oxygen glow discharge at 0.07 torr for 7 minutes at the same temperature. (4) The top, narrow, film is then deposited under the same conditions as (2). (5) The formed specimen is installed on a plastic holder and four wires are connected in order to measure the I-V characteristics.

Junction No.	L (Length) mm	W (Width) mm	I_s mA	λ_J mm	$I_{B.C.S.}$ mA	$I_s/I_{B.C.S.}$
21	0.05	0.11	1.75±0.02	0.086		98%±2%
22	0.044	0.11	1.39±0.02	0.090		96%±2%
107	0.10	0.10	1.30±0.02	0.145		98%±2%
109	0.09	0.10	1.41±0.02	0.135		

Table 1. Characteristic of tin-tin oxide-tin junctions

Table 1. Characteristics of our junctions: I_s is the maximum supercurrent at 1.2K, and I_{BCS} is the value of I_s (1.2K) predicted by the BCS theory without strong coupling theory correction. R_N is the normal resistance and λ_J (1.2K) is the Josephson penetration depth.

III. Evidence for Ideality of Specimens

1. Extra-high Zero Voltage Supercurrent

The junction made in our group at Buffalo [4] shows a very high zero-voltage supercurrent, which is close to 98% or more of the value that is given by the BCS theory. This large supercurrent is surprising since Fulton and MuCumber [5], using strong coupling theory predicted that the supercurrent in tin junctions should not exceed 91% of the BCS value. In any case, we take the high supercurrent as evidence that our specimens are close to ideal.

The properties of our four specimens related to the zero-voltage supercurrent are listed in Table 1. Here the values of I_{BCS} were evaluated at 1.18°K from the equation, which was derived by Baratoff, et al. [6],

$$I_{BCS} = \frac{\pi}{2}\left(\frac{1}{eR_N}\right)\ \Delta(T)\tanh\frac{1}{2}\beta\Delta(T) \qquad (1)$$

where R_N is the normal resistance of the tunnel junction, $\beta = 1/KT$ is Boltzmann constant, and $\Delta(T)$ is the energy gap at temperature T, and e is charge of a electron.

The energy gap was measured from an X-Y recorder trace of the I-V characteristics, Using the procedure suggested by McMillian and Rowell [7]. R_N was determined from the asymptotic slope of the recorder trace at large voltage. The total estimated uncertainty of I_{BCS} is within 3% (See Table 1).

2. Nearly Ideal Interference Pattern

If self-magnetic fields are negligible and the tunneling barrier is uniform, the maximum dc current through the barrier at V=0 [3] is

$$I_{max} = I_o \left| \frac{\sin \pi X}{\pi X} \right| \qquad (2)$$

where $X=\frac{\Phi}{\Phi_o}$, is the total flux through the barrier, $\Phi_o=\frac{hc}{2e}$ is the flux quantum, $I_0=J_1L$, and J_1 is the supercurrent density distribution and has assumed to be constant, and L is the length of the barrier.

In practice, we can infer the degree of uniformity of the barrier and of the supercurrent density distribution J_1 by using Eq. (2). The interference pattern, I vs X, is shown in Fig. 2 for one of typical junctions. The negative field directions is not shown in this figure, but we find the complete pattern to be symmetric. Also the field spacings of all of the minima are almost the same. However, the experimental I_{max} shows two minor deviations from the ideal form of Eq. (2). The first two minima do not reach zero, and the secondary maxima are somewhat small. These characteristics are typical of a relatively smooth oxide barrier but with a somewhat thicker oxide at the edge of the film. [8] The flattering out of the pattern at larger fields is propably a result of decoupling of the phases on the two sides of the oxide barrier due to noise. [8] Since these defects are very small, we regard the tunneling barrier as nearly uniform.

3. No Shorting Current In The I-V Characteristic

Both the I-V curves and the interference pattern indicate that there are no metallic shorts across the barrier. A typical I-V curve for the junction is shown in Fig. 3; In this figure, current is vertical and voltage is horizontal. A short would give rise to a zero-voltage supercurrent on both the increasing and decreasing portions of the current cycles. In the figure, we see that there is no supercurrent on the decreasing cycle. Also such a short would show up clearly in an interference pattern such as Fig. 2 since it would not have zero-voltage supercurrent even in larger fields. In fact, Fig.2 is shows no observable current at the third minimum.

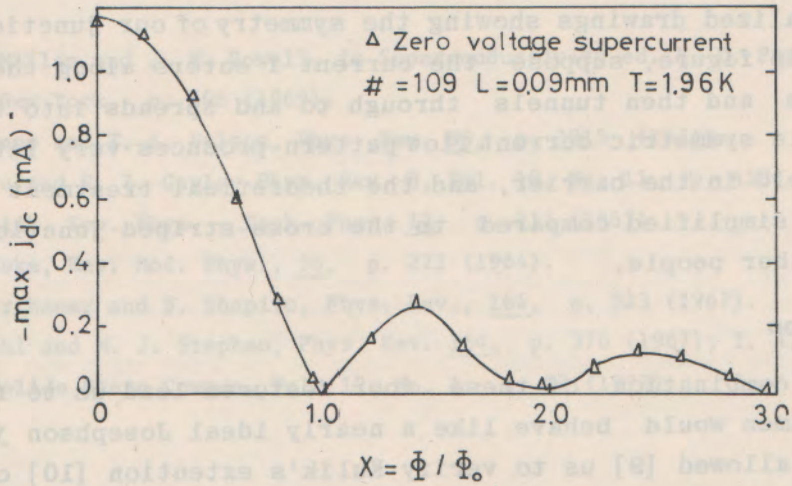

Fig. 2. Dependence of the step height of the first step on applied magnetic field. The negative field direction is not shown, but we find the complete pattern to be very symmetric.

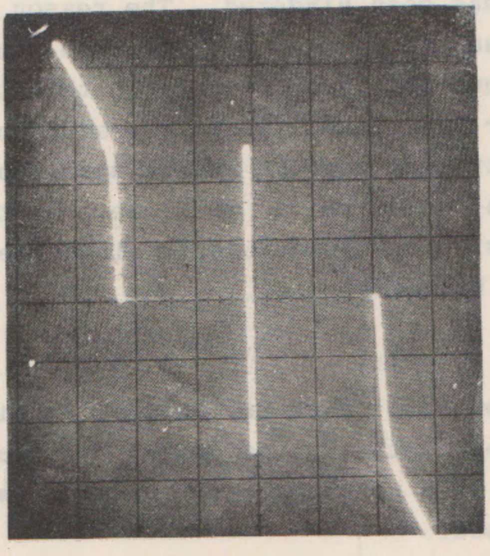

Fig. 3. I-V characteristic of one of our junctions #22, showing a very high dc Josephson current at V=0. The vertical axis is current and the horizontal

is voltage. Vertical 0.5mA/div; horizontal 0.5 mV/div. The ambient field is less than 3 mgauss and the temperature is 1.2K.

4. Idealized Symmetric Configuration Of Junction

Idealized drawings showing the symmetry of our junctions in Fig. 1. In this figure, suppose the current I enters along the top, narrower film and then tunnels through to and spreads into the lower film. This symmetric current flow pattern produces very little magnetic field in the barrier, and the theoretical treatment is considerably simplified compared to the cross-striped junctions used by many other people.

IV. Conclusion

The combination of these four features lead us to feel that each specimen would behave like a nearly ideal Josephson junction. This has allowed [9] us to verify Kulik's extention [10] of Fiske mode [11] theory, which has not previously tested.

Now let us recall the historical development of the study of the Josephson effect. Even though there are many well-developed theories, such as the theories of Fiske modes and [10-12] of one dimentional vortex [13] in Josephson junctions, the experimental study of these questions has been hindered. The reason is the difficulty in obtaining high quality junctions. From the good agreement with the Fiske modes in our work [9], we believe that this difficulty has been overcome in our junctions. Since the study of the Josephson effect represents a striking chapter in the unfolding research into superconductivity in recent years, we believe that further valuable experimental study with our junctions to elucidate the features of superconducting can be anticipated.

Acknowledgments

I especially wish to thank Dr. Gayley for his help and encouragement while I stayed in the United States. I would like to mention that the techniques used to prepare my junctions were developed by S. Paley and J. Wilson.

References

1. L. B. Coleman, M. J. Cohen, D. J. Sadman, F. G. Yamagishi, A. F. Gavito and A. J. Heeger, Solid State Commun. (1973)

2. J. Bardeen, L. N. Cooper and J. R. Schriffier, Phys. Rev. 108, p.1175 (1957).
3. B. D. Josephson, Phys. Letter. 1, p. 251 (1962).
4. S. Paley, J. Wilson, R. I. Gayley, Phys. Letter Vol. 41A, No. 4, p. 311 (1972).
5. T. A. Fulton and D. E. McCumber, Phys. Rev. 175, p. 585 (1968).
6. V. Ambegaokar and Baratoff, Phys. Rev. Lett. 10, (1963); 11, (1963) 104 (erratum).
7. W. L. McMillan and J. M. Rowell, in Superconductivity ed. R. D. Parks, Marcel Dekker, New York, p. 596 (1969).
8. R. C. Dynes and T. A. Fulton, Phys. Rev. B3, p. 3015 (1971).
9. Y. S. Gou and R. I. Gayley Phys. Rev. B, Vol. 10, No. 11, p. 4584 (1974).
10. I. O. Kulik, Sov. Phys. - Tech. Phys. 12, p. 111 (1967).
11. M. D. Fiske, Rev. Mod. Phys., 36, p. 221 (1964).
12. N. R. Werthamer and S. Shapiro, Phys. Rev., 164, p. 523 (1967).
13. P. Lebwohl and M. J. Stephen, Phys. Rev. 164, p. 376 (1967); T. A. Fulton and Dynes, Solide State Commun. Vol. 12, No. 1, p. 57 (1973).