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## SUPERCONDUCTING PROPERTIES OF IRIIDIUM THIN FILMS

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Résumé.- Nous avons réalisé des microponts supraconducteurs de type Dayem et des jonctions tunnel Al-Al<sub>2</sub>O<sub>3</sub>-Ir à partir de couches minces d'iridium que nous avons préparées ; ces jonctions ont des caractéristiques I-V typiques des jonctions Josephson. Nous avons mesuré la variation avec la température du gap d'énergie de ces couches minces d'iridium en utilisant les jonctions tunnel Al-Al<sub>2</sub>O<sub>3</sub>-Ir.

Abstract.- We have prepared superconducting thin films of iridium from which we have fabricated Dayem-type microbridges and Al-Al<sub>2</sub>O<sub>3</sub>-Ir tunnel junctions that have I-V characteristics typical of these types of Josephson devices. Using the Al-Al<sub>2</sub>O<sub>3</sub>-Ir tunnel junctions, we have measured the temperature dependence of the superconducting energy gap of thin-film iridium.

INTRODUCTION.- We are interested in studying the behaviour of Josephson junctions fabricated from superconducting materials that have small energy gaps. Since theories of the high-frequency behaviour of Josephson junctions are scaled to the energy gap frequency, experiments with junctions fabricated from materials with gap frequencies in the microwave region (i.e. from materials with low transition temperatures) might yield information relevant to the response of high-T<sub>c</sub> devices in the infrared region. The many advantages of operating at microwave frequencies are apparent. Several low-T<sub>c</sub> materials have been investigated at NSB for temperature reference points : W(T<sub>c</sub> ~ 0.015 K), Be(T<sub>c</sub> ~ 0.024 K), Ir(T<sub>c</sub> ~ 0.11 K), AuAl<sub>2</sub>(T<sub>c</sub> ~ 0.16 K) and AuIn<sub>2</sub>(T<sub>c</sub> ~ 0.21 K). Josephson junctions fabricated from these materials should provide a good basis for testing the scaling concept. We chose to begin the project with iridium for the following reasons (1) the T<sub>c</sub> of Ir occurs at a convenient temperature for a <sup>3</sup>He-<sup>4</sup>He dilution refrigerator, (2) the gap frequency of Ir is conveniently at 7 GHz, and (3) most of the bulk superconducting properties of Ir have already been determined [1]. We present here our initial results for thin-film Ir Josephson junctions.

PROPERTIES OF IRIIDIUM FILMS.- We have prepared thin superconducting films of Ir by rf-sputtering and by electron-beam evaporation. Films deposited onto room temperature substrates exhibited elevated

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transition temperatures (T<sub>c</sub>'s ~ 0.16 K - 0.38 K) and relatively small residual resistivity ratios  $\Gamma \equiv R_{300K}/R_{4K}$  (Γ's ~ 1.10 - 1.25). The widths of the superconducting transitions were from 5 to 50 mK. Subsequent annealing in a vacuum furnace (1000 °C, 2 x 10<sup>-8</sup> Pa, 24 h) improved the resistivity ratios (Γ's ~ 2-7) but the annealed films were no longer superconducting. The variations observed in the properties of the Ir films showed no significant correlation with preparation technique (sputtering vs electron-beam evaporation), substrate material (glass vs sapphire), or purity of the bulk starting material (99.9 % vs 99.999 %). We believe that the observed variations in the properties of thin Ir films are due to the effects of differences in impurity content, stress, or degree of disorder. Our most recent sample (a 30 nm film evaporated at 0.5nm/s onto a 500 °C sapphire substrate with the background pressure during evaporation <3x10<sup>-9</sup>Pa) had T<sub>c</sub> = 0.14 K and Γ = 1.4. We anticipate that deposition onto hotter substrates will yield films with T<sub>c</sub>'s even closer to the bulk value.

IRIDIUM JOSEPHSON DEVICES.- In order to compare the results of our microwave experiments with theory, it will be necessary to measure the energy gaps of the thin-film superconductors, which can be done by depositing the low-T<sub>c</sub> films over a base electrode of oxidized aluminum. We evaporated Ir films over thermally oxidized Al to form tunnel junctions with normal resistances between 5 Ω and 33 Ω. Figure 1 (a) shows I-V curves for the 33 Ω junction at

three different temperatures ; both the sum and the difference of the energy gaps of Ir and Al can be discerned.

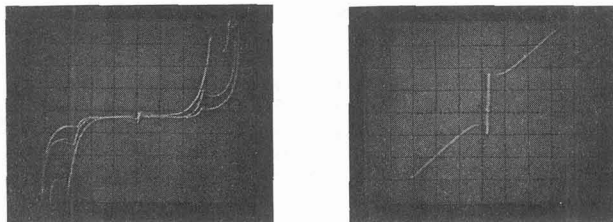


Fig. 1 : (a) Current-voltage characteristics for a  $33 \Omega$  Al-Al<sub>2</sub>O<sub>3</sub>-Ir tunnel junction at three different temperatures (current and voltage scales uncalibrated). (b) I-V characteristic of an Ir microbridge. Vertical scale :  $1 \mu\text{A}/\text{cm}$ ; horizontal scale  $50 \mu\text{V}/\text{cm}$ .

From a series of such curves, we obtained the energy gap of the Ir film as a function of temperature. The data are plotted in figure 2, and the fit to the BCS temperature dependence is good ; the discrepant points near  $T_c$  are probably a result of trapped flux in the junction. However, the experimental values for  $\Delta(0)$  and  $T_c$  give  $2\Delta(0)/kT_c \approx 1.1$ .

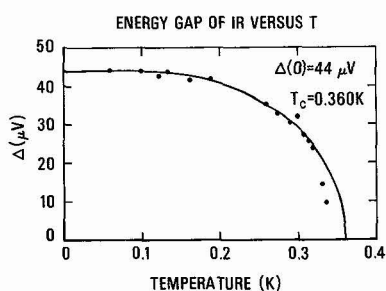


Fig. 2 : The energy gap of a thin iridium film as a function of temperature. The solid curve is the theoretical BCS temperature dependence.

Since the coherence length of bulk Ir is  $4.4 \mu\text{m}$  /1/, microbridges in Ir films having near-bulk properties should exhibit weak-link behaviour down to  $T = 0$ . In such a case the energy gap of the film and the critical current and normal resistance of the microbridge should satisfy the relationship  $I_c(0) = \pi\Delta(0)/2R_n$ . This was not the case for our Ir microbridges, which is not surprising considering the poor resistivity ratios of the films. Like their higher- $T_c$  counterparts, the Ir microbrid-

ges become hysteretic at temperatures not far below  $T_c$ . Figure 1 (b) shows an I-V curve for a Dayem bridge fabricated from a  $40 \text{ nm}$  Ir film using standard photolithographic and sputter-etch techniques. The microbridge was approximately  $1.0 \mu\text{m}$  long and  $2.5 \mu\text{m}$  wide.

DISCUSSION.- The junctions which we have fabricated to date have not been in a configuration suitable for good coupling to applied microwave radiation, and consequently we have not observed the ac Josephson effect in any of our low- $T_c$  junctions. In our next series of experiments, microwaves will be transmitted to the junctions via microstrip transmission line /2/. In addition to our primary goal of obtaining frequency response data which we hope will be germane to high- $T_c$  junctions employed as infra-red radiation detectors, we plan to carry out a number of other interesting physics experiments, such as a study of microwave enhancement of the energy gap in low- $T_c$  superconductors /3/, and observation of the Riedel singularity in low- $T_c$  Josephson junctions./4/.

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