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FABRICATION OF SMALL MICROBRIDGES (*)

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Résumé. — On décrit une technique simple pour fabriquer des microponts très petits, solides et reproductibles. Les jonctions ne se détériorent pas pendant de longues périodes même si elles sont exposées à l'air, soumises aux chocs et aux cyclages thermiques répétés. Leurs dimensions minimales sont de l'ordre de 2 000 Å de large sur 1 000 Å de long. On décrit par ailleurs un procédé qui permet d'obtenir des couches minces d'étain, adhérentes, homogènes et à grains fins et de réaliser une protection électrique des jonctions obtenues.

Abstract. — A simple, versatile technique for making very small, sturdy, reproducible microbridges is described. When exposed to air, to mechanical shock, or to repeated temperature cycling, the junctions do not deteriorate over long times. They can be as small as 2 000 Å wide by 1 000 Å long. Methods for obtaining strongly adherent, small-grained, homogeneous tin film, and for the protection of the junctions from electrical pulses, are also described.

1. Introduction. — The only Josephson-type junction which has to date been used for astronomical measurement has been the point contact [1], which is well impedance-matched to the radiation due to its high impedance. Yet the microbridge has the advantage of being intrinsically more reproducible and more mechanically stable than the point contact. In the effort to realize a broad-band millimeter-wave detector for astronomical purposes, we have developed a simple technique for making very small and sturdy microbridges. This technique is simple enough that a number of other research groups have been interested in adapting it to their needs. Our process is similar to, though perhaps easier, more flexible, and more reproducible than that developed independently by the Copenhagen group [2]. Unless otherwise noted, the microbridges mentioned below are of tin.

Our junctions are very rugged in that their characteristics do not deteriorate when exposed to air, to mechanical shock, or to thermal shock. In fact, there is no perceptible change when in the air for months or through innumerable temperature cycles between room temperature and liquid helium temperature. Mechanical shock, even so violent as to break the substrate, has no effect.

It is important that a microbridge be physically small. To show « clean » Josephson behavior, the length of the junction must be much less than twice the temperature dependent coherence length, with

its width less than or comparable to its length [2]. Our typical working junction is 3 000 Å long, 3 000 Å wide, and 1 000 Å thick, satisfying this criterion for tin over a wide temperature range. The electrical shock problem to be discussed below prevents us from using smaller junctions. With these junctions we see microwave enhancement of the critical current, no subharmonic steps, and a variation with power of the size of the microwave-induced steps as described by Russer [3], for as much as a third of a degree below the transition temperature of tin.

Our technique lends itself to making multiple, series-connected junctions. We find that with a series of about one hundred such microbridges both the electrical shock problem and the impedance-matching problem are greatly eased. Since the critical currents of the individual junctions are not identical, this is not suitable for most detection modes. A zero-bias scheme for which such multiple junctions are well suited is described at this conference [4].

2. Preparation of thin films. — Evaporating a satisfactory tin film is not a trivial procedure. The grain size of the evaporated tin must be quite small, smaller than the dimensions of the junction. We find that the resistivity of a large-grained film increases with the grain size, and we expect the superconducting characteristics of such a film to vary. A small-grained film is visibly shiny, rather than hazy. In addition we require strong adhesion between the tin and the glass substrate to prevent the film from chipping while forming the junction. However, pure tin doesn't adhere to a clean glass surface [5]. Some contaminant must be introduced. We find that an evaporated tin oxide layer acts as a suitably strong glue between

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the tin and the glass. The same is true for lead, for indium, and for gallium.

We have developed a procedure to obtain shiny, strong, homogeneous tin films. The substrates are ultrasonically cleaned in an aqueous solution of « Labtone » glass cleaner, rinsed with water, and blown dry with freon. A more extensive precleaning is unnecessary. The substrates are bonded to a copper block heat sink with a thin layer of « Apiezon N » vacuum grease, and placed in the evaporator. They are then cleaned by a thirty minute, 300 V oxygen glow discharge. This step is essential. We find it necessary to freeze the water vapor from the oxygen to obtain the characteristic yellow-green oxygen discharge color.

The substrate temperature during evaporation determines the size of the grains. Uncooled substrates give hazy, translucent films with grain sizes greater than 1 000 Å. Liquid nitrogen temperature substrates give shiny, opaque films with grain sizes about 300 Å. A ten minute wait before each evaporation assures thermal equilibrium with the liquid nitrogen cooled heat sink.

First, the tin oxide layer (~ 40 Å) is formed on the substrate by evaporating tin in an atmosphere of dried oxygen of 2.5×10^{-4} torr. The film grows at about an Angström per second. We find that at this evaporation rate an oxygen pressure greater than 2×10^{-4} torr is necessary for good adhesion, while above 5×10^{-4} torr the evaporation becomes erratic. Alternatively, a tin oxide film can be formed by performing an oxygen glow discharge upon a 40 Å tin film. The tin film is then evaporated to the required thickness upon the tin oxide layer at about 15 Å/s at pressure of about 5×10^{-7} torr. The resulting films cannot be removed from the glass either by stripping tape or by pulling on a soldered wire. Tin films made by this process are perfectly reproducible, strongly adherent, shiny, and homogeneous.

To prevent oxidation, these films are stored in Dow Corning 704 Silicone diffusion pump oil, which can be removed with a stream of ethanol. Many other oils stain the film. Leaving the film in air for a few days seems to destroy the ductility needed in forming the junction. Once the junction has been made, however, further oxidation has no apparent effect. An example of our tin films is evident in figure 1.

3. Scribing. — The microbridge must be formed in a controlled manner. Our technique is basically to scratch a groove with a diamond blade in the glass substrate, evaporate the thin tin film, and then to make a lighter, perpendicular cross-scratch, leaving a small tin neck at the intersection of the grooves. The final geometry of the microbridge is clear in figure 1. The substrate is Corning cover glass no. 2. The two scratches are made with specially sharpened

FIG. 1. — A scanning electron microscope photo of a small microbridge. The bridge is viewed at an angle of 45°.

diamond blades (*), each mounted on the tone arm of a record player. Two record players are used to avoid readjustment between the two scratches. The turn-tables have been modified to move the substrate at about 0.5 cm/s. The first scratch is made with the weight at the diamond typically 4.5 g, making a groove in the glass a few tenths of a micron wide. A thin tin film, typically 1 000 Å, is then evaporated on the scratched substrate. The second scratch is made perpendicular to the first, removing the tin everywhere along its length except within the groove of the first scratch. The second-scratch weight at the diamond is typically 0.65 g. To make the smaller junctions, the second scratch does not cut the glass. The angles and weights of the diamond blades, important for the first scratch and crucial for the second, must be adjusted by trial and error, examining the scratches under an optical microscope. To get a straight, symmetrical scratch, and to avoid skating the blade across the substrate, the diamond blade for the second scratch must be precisely aligned with the direction of scratching. The clearance angle of the blade above the plane of the substrate is typically 10° for the first scratch and 2° for the second scratch. The holder for the second scratch diamond must allow fine adjustment of this angle. The clearance angles and the pressures of scratching determine the depth of the grooves and hence the dimensions of the microbridge.

Many microbridges can be made on a single substrate and then separated with a glass cutter. In this process, in handling the substrates, or merely because of imperfections in the substrate, short circuits can appear across the second scratch. This can be repaired by hand with a diamond stylus under a low power optical microscope. These short circuits can easily be seen and the junction dimensions approximately

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It is essential that junctions not burn out during operation. To this end we have developed the protection circuit illustrated in figure 2. The junction leads are short-circuited with the dual potentiometers whenever any switch in the laboratory is thrown, and whenever the make-before-break rotary switch is used. The voltage leads are harder to protect than the current leads because of the desire to impedance match, maximizing bandwidth, and signal-to-noise.

The diagram shows the input stage of a low-noise amplifier. It features a transformer with a primary resistance $R_J \approx 1 \Omega$. The primary is connected to a 100Ω resistor and a 1Ω resistor. The secondary is connected to a 500Ω resistor and a 50Ω resistor. The output is connected to a constant current source and a preamplifier. The circuit is divided into two sections by a dashed line.

This susceptibility to electrical shock limits the minimum size of microbridges. To our knowledge, the smallest reported in the literature has a width of 3 000 Å [2], [6]. The junction shown in figure 1, in a 1 000 Å thick tin film, is about 2 000 Å wide by 1 000 Å long. This is too small to be electrically tested.

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