New type of zinc heat switch by diffusion bonding

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Abstract

A new type of heat switch for a nuclear demagnetization refrigerator has been prepared by diffusion bonding of zinc and copper foils. The details of the fabrication and its performance are described.

Key words: heat switch; nuclear refrigerator

A heat switch is an essential part in the ultra-low temperature equipments to disconnect various parts at will. Type-I superconducting materials are usually used for this purpose, for example, Pb, Sn[1], In, Al [2], Zn [3] et al.. Among them, the latter two are most often used at temperatures below 1 K because of their low superconducting transition temperatures. In addition, their rather low critical fields are beneficial in the heat capacity measurement at ultra-low temperatures to reduce a heat release associated with the superconducting transition. On the other hand, the thermal contact with the counterpart material, usually copper or silver, is a little bit troublesome. Gold plating on their surface has been used to get rid of surface oxidization and to improve the thermal properties in the normal phase. This technique is very effective in case of a demountable switch, but a special skill is necessary to have a good quality of plating especially for Al. Even for Zn, the preplating of Cu is important. Very small pinholes in the Cu film seems to cause the disappearance of the upper gold plating probably due to diffusion of Au into Zn while leaving in the atmosphere, resulting into the unexpected deterioration of thermal contact. To avoid such a problem, a diffusion welding technique has been developed for Al-Cu contact by Bunkov [4]. Here we apply the same technique to a Zn-Cu system. This combination is attractive as a second heat switch between the sample and the nuclear stage because of its lower

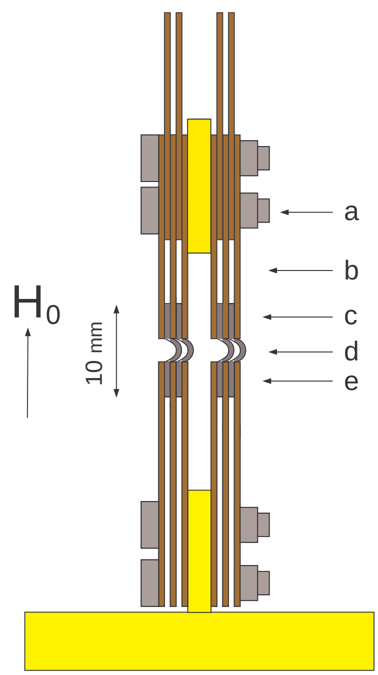

Fig. 1. Design of Zn heat switch. a: screws, b: Cu foils, c and e: bonding part, d: Zn foils

critical field ($H_c = 5$ mT) than Al. In addition, no existence of large screws helps us design the switching field magnet with a small bore.

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Table 1
Contact resistance of test piece for several combinations of P and T

P (ton/cm^2)	T (℃)	Contact resistance ($n\Omega/cm^2$)
7.3	220	25
2.0	200	21
0.62	200	14
0.31	200	26
0.31	180	- [1]
0.31	160	- [1]

[1] unsuccessful

An original Zn foil (99.999 % pure and 0.25 mm thick) has a residual resistance ratio (RRR) of a few thousand as supplied, and the heat treatment is not essential at all. A few short samples (5 mm wide and 15 mm long) were cut and lightly etched in a dilute HCl solution. The counterpart copper foils (99.999 % pure and 0.50 mm thick) were independently annealed at 900 ℃ in 10^{-4} torr of O_2 atmosphere for two days. The RRR was measured to be over 3000. A test piece is made of a zinc foil sandwiched by two copper foils at both ends (5 mm). It was put into two thick SUS blocks with 20 μm Ta foils on both sides and tightly fastened with two SUS screws (8 mm in diameter) while being pressed up to a maximum pressure of 4 ton with an oil piston cylinder. The clamped block was then heat treated in a big furnace which was heated up to about 200 ℃ within 15 min and then turned off. It took about 12 hours to come back to the room temperature.

The higher the pressing pressure (P) and the treating temperature (T), the bonding is mechanically stronger. On the other hand, the deformation of Zn and Cu and the expansion of alloying area of zinc into copper cause an increase of the residual electrical resistance and therefore a deterioration of thermal conductivity. To find out a compromising condition between a mechanical strength and a good thermal conductivity, we measured the electrical resistance at 4.2 K for several P and T. In addition, such a measurement was repeated after several rapid thermal cycles between room temperature and 77 K. The results are summarized in Table I. For small pressing pressure and low temperatures below 180 ℃, a fabricated test piece was apt to be easily taken apart. On the other conditions, the contact resistance is more or less the same order. Hence we chose the highest pressure and temperature within the tested region for an actual heat switch.

A small heat switch fabricated based on the above data is shown in Fig.1. A zinc foil (8 mm wide and 10 mm long) has a small bend in the middle such that a heat flow is orthogonal to the magnetic field. Two of them were sandwiched at both ends by 4 mm with three copper foils (0.5 mm thick). Each piece was processed according to the above recipe. Two pieces were put in parallel, and were mechanically fastened to each stage. The overall residual resistance at 4.2 K is about 50 nΩ which is mainly determined by the contact resistance between Zn and Cu. We have four contact areas (32 mm^2 each) on each side, and the contact resistance is estimated to be about 40 $n\Omega/cm^2$. The value is worse than that reported for Al-Cu system [4], but is good enough for the actual use. The present switch was successfully used for a second heat switch between the nuclear stage and the sample.

References

[1] V.P.Peshkov, A.Y.Parshin, Sov. Phys. JETP **21** (1965) 258.

[2] R.M.Mueller, C.Buchal, T.Oversluizen, F.Pobell, Rev.Sci. Instrum. **49** (1978) 515.

[3] M.Kurusius,D.N.Paulson, J.C.Wheatley, Rev.Sci. Instrum. **49** (1978) 396.

[4] Y.Bunkov, Cryogenics **29** (1989) 938.