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RAPID COMMUNICATION

Bonding of a niobium wire to a niobium thin film

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Abstract. A method for bonding a niobium wire to a niobium thin film is described. The bonds are to be used as superconducting connections between wire-wound gradiometers and thin-film coupling coils on DC SQUIDS. The method is characterized by two steps. Firstly, the hardness of the niobium wire is reduced by a heat treatment. Secondly, the niobium film is covered with a thin layer of palladium to prevent it from oxidizing. Superconducting bonds were realized using an ultrasonic bonding technique. We tested the bonds and measured superconductivity (to a sensitivity level of 6×10^{-15} Ω) with currents up to 80 μA, which is equivalent to 10 times the dynamic range of the DC SQUID systems. Even at 80 μA, limited by the measuring set-up, the critical current of the bonds is not reached.

Present SQUID magnetometers are most often equipped with thin-film DC SQUIDs to which external signals can be coupled via spiral-shaped thin-film input coils [1]. Usually a signal is transferred to such a SQUID by means of superconducting wire. Therefore a proper connection between wire and thin-film input coil has to be realized. This superconducting contact can be made with lead [2] or a lead alloy [3]. In this communication an alternative approach is described. We present a method to bond a niobium wire to a niobium thin film. The annealing of the wire is first considered and after that the bonding and a test experiment.

In order to obtain a highly ductile niobium bonding wire, it is first processed in a vacuum annealing step. The niobium bonding wire has a diameter of 50 μm after its insulation layer is removed by sulphuric acid. About 90 cm of the wire is hung in a vacuum chamber in a vertical V-shape with an additional weight of 0.2 g in the centre. The chamber is pumped to a pressure lower than 10^{-3} Pa (typically 3×10^{-4} Pa). Then a DC current of 0.45 to 0.50 A is fed through the wire. We turn on the current in about 20 s. The temperature of the wire follows the current according to the brightness. A stable temperature is thus quickly reached and results from a dissipation in the wire of 90 to 100 W for 1 m length. The wire is heated for typically 5 min. If the heating exceeds 6 min the niobium may recrystallize. This effect was clearly observed after 10 min of heating. We tried to measure the temperature of the wire by means of a pyrometer. However, because the wire is very thin and also located at a relatively large distance from the chamber window, we did not succeed in an accurate measurement. Nevertheless, the wire is bright white and an estimate of its temperature is 2200 °C. After annealing the current is turned off in about 2 s, and the wire is allowed to cool down via its heat exchange with the environment. After this procedure, the ductility of the wire can be inspected directly by simply bending it. Measurements showed that the Vickers hardness of the niobium is reduced from 180 to about 80 kgf mm^{-2} (1 kgf mm^{-2} = 10^7 Pa).

The annealed niobium wire is bonded to the film using an ultrasonic wedge bonder of Mech-EL Industries Inc (model TU 907 X) with a controller of UTHE Technology Inc (model 10G). The operating frequency is 61–65 kHz. On the wedge we apply the maximum weight of 90 g. The other parameters, time and power, are not critical. We achieved good bonding results with times between 40 and 100 ms and powers of 0.5 to 1.0 W in 22 Ω.

The ends of the wire (in our set-up about 10 cm on both ends) are not suitable for bonding. They are not ductile enough because they are not sufficiently heated. Furthermore, the wire oxidizes after its removal from the chamber. After being heated, the wire can be used for about two weeks. We found that after one month, bonding was hardly possible. Oxidation of the niobium pads of our DC SQUIDs [4] is prevented by depositing a 4 nm thick palladium layer on the niobium film via RF sputtering.

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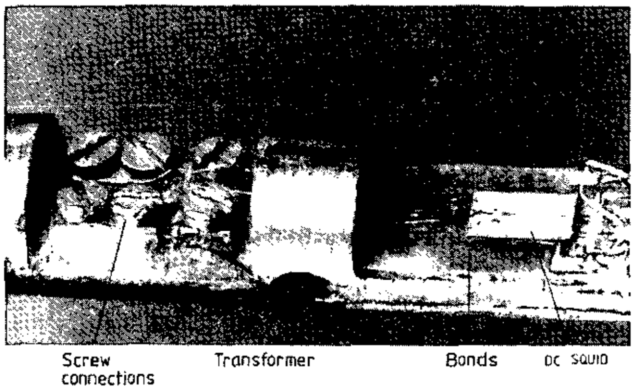

Figure 1. SQUID module with transformer connected to the SQUID input coil.

In order to test the bonds, a small transformer was connected to the bond wires with screws and blocks in our standard SQUID module, see figure 1 [5]. The transformer consisted of a primary coil of about 90 turns having a diameter of roughly 2 mm, and a superconducting secondary coil of 3 turns wound directly on the primary. We fed a current through the primary coil, while the module was being immersed in liquid helium. The flux coupled to the secondary coil was about 2×10^{-11} Wb. As soon as the module is sufficiently cooled by the helium, this flux should be kept constant by the superconducting circuit consisting of secondary coil, screw connections, bonds and SQUID input coil. A few minutes after the module had been immersed in the liquid helium, we therefore turned off the primary current and recorded the output of the SQUID electronics. Any resistance in the secondary circuit should give rise to a decay of the secondary current and thus of the SQUID output. Neglecting fluctuations due to environmental noise coupled to the secondary circuit, we recorded a constant voltage for several hours. The corresponding current in the secondary circuit was about 80 μA, limited by the measuring set-up. The critical current of the bonds is not reached. A current of 80 μA corresponds to about 10 times the dynamic range of the SQUID systems, in which the bonds are to be used. The relative decrease of the secondary current (if any!) is smaller than $10^{-4}\ \mathrm{h}^{-1}$. This results in a time constant larger than 10^4 h. Based on a calculated inductance of the secondary circuit of roughly 0.2 μH, this means a resistance smaller than $6\times10^{-15}\ \Omega$.

The impact of a bond resistance on our 19-channel neuromagnetometer [5] is twofold. Firstly, the system would exhibit a high-pass dynamic behaviour. However, with an input-circuit inductance of slightly below 1 μH, a resistance of $6\times10^{-15}\ \Omega$ gives a characteristic frequency of only 10^{-9} Hz. Secondly, and more important, a thermal-noise contribution would occur, decreasing linearly with increasing frequency. In our situation the resulting noise flux spectral density in the SQUID is less than $5\times10^{-7}\ \varphi_0\ \mathrm{Hz}^{-1/2}$ at 1 Hz. Our DC-SQUIDs have a white-noise level of typically $4\times10^{-6}\ \varphi_0\ \mathrm{Hz}^{-1/2}$ and a $1/f$ corner point at about 1 Hz [6]. Therefore, the thermal-noise contribution of the bonds is below the intrinsic noise of the SQUID system.

The thermal stability of the bonds appeared to be reliable. During the resistance measurements the module was cycled six times between 300 and 4.2 K without any problem. After these measurements the module was cooled several times without affecting the bonds.

References

[1] Ahonen A I, Hämäläinen M S, Kajola M J, Knuutila J E T, Lounasomaa O V, Simola J T, Tesche C D and Vilkman V A 1991 *IEEE Trans. Magn.* **27** 2786–92

[2] Hoenig H E, Daalmans G, Folberth W, Reichenberger H, Scheider S and Seifert H 1989 *Cryogenics* **29** 809–13

[3] Kiryu S, Ogashiwa T, Chinone K, Kasai N, Kado H, Ishikawa N, Nakanishi M and Koyanagi M 1989 *Advances in Biomagnetism* (New York: Plenum) pp 653–6

[4] Houwman E P, Veldhuis D, Flokstra J, Ter Brake H J M, Jaszczuk W, Martinez A and Rogalla H 1991 *IEEE Trans. Magn.* **27** 2955–8

[5] Ter Brake H J M, Flokstra J, Houwman E P, Veldhuis D, Jaszczuk W, Martinez A and Rogalla H 1990 *Physica* B **165/166** 95–6

[6] Flokstra J, Ter Brake H J M, Houwman E P, Veldhuis D, Jaszczuk W, Rogalla H, Martinez A and Rillo C 1991 *Sens. Actuators* **27** 781–5