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Niobium flex cable for low temperature high density interconnects

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ABSTRACT

This work describes the fabrication and characterization of a Niobium on polyimide flex cable suitable for sub-Kelvin temperatures. The processing used can be extended to high density interconnects and allows for direct integration with printed circuit boards. Several key parameters such as RRR, T_c, current carrying capability at 4 K and thermal conductivity in the range from 0.15 to 10 K have been measured. The average T_c was found to be 8.9 K, with a minimum of 8.3 K. Several samples allowed for more than 50 mA current at 4 K while remaining in the superconducting state. The thermal conductivity for this flex design is dominated by the polyimide, in our case Pyralin PI-2611,[2] and is in good agreement with published thermal conductivity data for a polyimide called Upilex R.[3]

1. Introduction

For various space applications there is an ongoing effort to develop large detector arrays operating at sub-Kelvin temperatures. The read-out of these arrays typically requires a large amount of wiring. These need to provide high quality, low Ohmic electrical connections while also providing enough thermal insulation to maintain the proper cold stage temperature with the limited available cooling power. Examples of such detector systems are the Focal Plane Arrays (FPA's) of the SAFARI instrument [1] for the JAXA SPICA mission. Its short wavelength FPA requires around 240 interconnections. These need to cross a temperature difference from 1.7 K to 50 mK. At these low temperatures superconducting tracks can be used, well below T_c. This has the benefit that electrical conduction and thermal resistance become decoupled, whereas for normal metals these are directly related by the Wiedemann–Franz law. For this purpose superconducting flex cable interconnects have been successfully developed using MgB_2 [2], Nb, Al [3] and for a different application similar structures are attempted using YBCO [4] conductors. In this work we use photolithographically fabricated Nb tracks fully packed in a 20 μm polyimide carrier. The fabrication process differs from [2–4] and is suitable for track widths as small as 15 μm, while at the same time allowing flex cable total lengths in the order of 130 mm.

2. Fabrication and integration

Fig. 1 shows a schematic representation of the flex cable layering. The cables are fabricated using a 6″ square glass substrate as carrier for the production process. After application of a release layer an initial 12 μm Pyralin PI-2611 polyimide film is spin-coated on the glass substrate. After curing at 350 °C the polyimide is activated using a plasma treatment after which a 50 nm Ti adhesion layer is applied. Next a 250 nm Nb film is deposited. Using standard lithography techniques 10 tracks each 15, 20 or 25 μm wide are patterned, depending on the particular flex. A second 7 μm polyimide layer is applied on top of the Nb and cured to the same temperature. Holes are patterned in the polyimide at the solder pad locations using RIE. The pad areas are filled with a stack of 100 nm sputtered Ti, 300 nm sputtered Cu, 1.5 μm electroplated Ni and finally 1.5 μm electroplated Au.

After all processing is finished the polyimide flex is released from the glass substrate and cut to the appropriate outline, in this case 35 × 6.5 mm. In addition to the process described above a second panel has been processed using the same process but with an additional Ti adhesion/protection layer on top of the Nb tracks.

The flex is integrated with printed circuit boards (PCB) at both ends using a modified reflow soldering process, see Fig. 2a. Prior to soldering both PCB's and flex cable are cleaned in Topklean EL-20A.[4] The flex is visually positioned with a microscope and clamped to the PCB's using a mechanical fixation. Next the flex is folded back and Ecorel easy 803S solder paste is applied to the PCB pads using a injection syringe. After carefully returning the flex to the original position a weight is placed on top of the PCB's with a

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[4] Registered trademark of Inventec performance chemicals.

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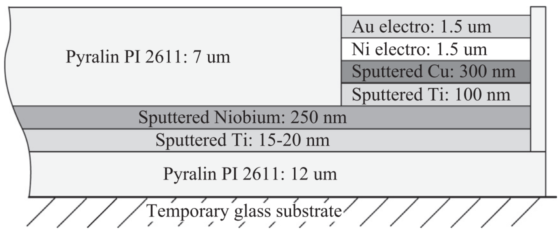
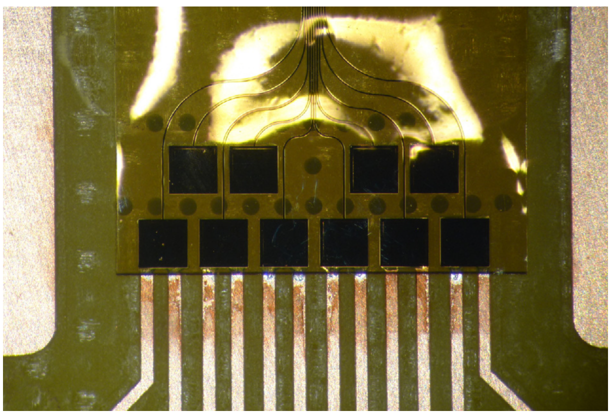
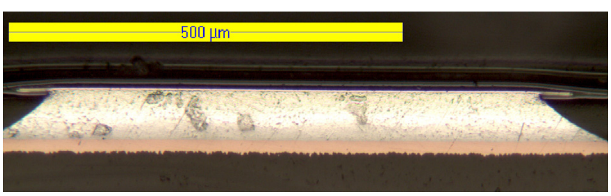


Fig. 1. Schematic representation of the layer build-up of the flex cable (left) and solder pads (right).



(a) Flex top view at reflow solder location



(b) Microsectioning of solderpad

Fig. 2. Solder interconnect between the Nb flex and the PCB. (a) Close-up image of the soldered sample at the pad area. Two PCB tracks are routed to each bottom row pad on the flex. The narrow dark lines indicate the Nb tracks on the flex. (b) Microsection showing a cross section of one of the reflow soldered pads.

slight recess at the location of flex. This recess is dimensioned such that it allows for a final solder height of 50 μm. See Fig. 2b. After reflow soldering the assembly is cleaned using the same fluid. In order to allow good access of the fluid to the regions with flux residue, the PCB is equipped with holes around the pad locations. Due to the partial transparency of the polyimide the result of this cleaning step can be verified by visual inspection.

The above described processes have been used to produce 2 panels, one with an additional Ti adhesion/protection layer as described above and one without. All flex cables on both panels contain 10 tracks with an identical track width of 15, 20 or 25 μm. From each panel 4 samples for each track width were used, resulting in a total of 12 flexes per panel. All these samples were checked on open or short circuits at room temperature, none were found. Subsequently 6 samples were soldered, one sample was damaged during handling. The remaining 5 samples were used to perform the Cryogenic measurements.

3. Superconducting properties

For 5 different samples the RRR and current carrying capability at 4 K has been measured. The results are shown in Table 1. Three samples were capable of carrying above 50 mA, as expected based on critical current data from literature [5] and track width. Two of the measured samples became resistive at a current below 10 mA. In addition there is a reasonable spread in RRR between the various samples, the Ti/Nb/Ti samples having higher values. However, based on these measurements the low current carrying capability cannot be correlated to the spread in RRR.

Table 1
RRR and current carrying capability of the measured samples.

Layer build-up	Track width (μm)	RRR (–)	Current (mA)
Ti/Nb	20	3.3	>55
Ti/Nb	20	2.9	4
Ti/Nb	15	2.9	>60
Ti/Nb/Ti	25	3.9	>55
Ti/Nb/Ti	20	4.6	7

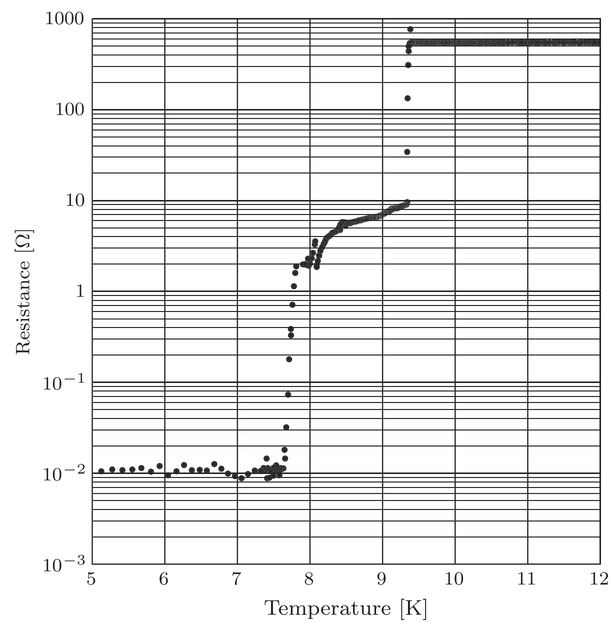


Fig. 3. Superconducting transition of a Ti/Nb/Ti flex cable, 25 μm track width, RRR = 5. The low temperature resistance of 10 mΩ is consistent with zero, taking the calibration error of the used equipment into account.

Fig. 3 shows the transition of a Ti/Nb/Ti flex cable, 25 μm track width which had an RRR of 5. The measurement shows 2 transitions, the first close to the transition temperature of bulk Niobium [6], the second around 7.8 K. The second transition is for only a fraction of the total resistance, possibly related to the SnPb (Tc 7.1–7.8 K [7]) soldered contact areas. The residual resistance measured below 7.5 K is consistent with zero, taking the calibration error of the used equipment into account.

4. First order measurement of the thermal conductivity

A first order thermal conductivity measurement on the flex was performed using the setup shown in Fig. 4. The upper part of the assembly is thermally connected to the cold stage of an insertable probe, which can be cooled to a temperature T_1 of about 50 mK, depending on the heat load. This temperature is measured using a 10 KΩ RuO2 SMD resistor as thermometer. The lower PCB is connected to the upper part via the flex cable. The dangling construction ensures that the very low intrinsic heat conductivity of the flex cable is not obscured by a support structure. However, some vibrations are induced by the pulse tube cooler. The geometric ratios between the dangling PCB and the flex cable are such that the