The thermal conductivity of C17510 beryllium-copper alloy below 1 K

A. Woodcraft* and R. V. Sudiwala
Department of Physics and Astronomy, University of Wales,
Cardiff, 5, The Parade, P.O. Box 913, Cardiff, CF24 3YB, UK.

R. S. Bhatia
Observational Cosmology, California Institute of Technology, Pasadena, CA 91125, USA

We have measured the low temperature thermal conductivity of the beryllium-copper alloy C17510 TF00. This is a high conductivity (low beryllium content) alloy. Measurements were made at temperatures between 100 mK and 1 K. A conductivity of 2.39 $(T/1\mathrm{K})^{0.99}\mathrm{Wm}^{-1}\mathrm{K}^{-1}$ was found. The linear variation with temperature and good agreement with the prediction from the electrical resistivity at 4.2 K suggest that thermal conduction is predominately electronic. The conductivity is considerably higher than for high strength (2% beryllium) beryllium-copper alloys. This is therefore a useful material when high strength and thermal conductivity are both required. The accuracy of the measurements was checked by measuring the thermal conductivity of aluminium 6061-T6 above the superconducting transition temperature; good agreement was seen with data in the literature.

Keywords: Thermal conductivity, beryllium copper, sub-Kelvin

Cryogenics 41: 603-606 (2001)
Available at http://www.sciencedirect.com/science/journal/00112275

1. INTRODUCTION

Beryllium-copper alloys are amongst the strongest of copper alloys. They are commonly used at cryogenic temperatures where, like other copper alloys, they do not become brittle. They can be machined relatively easily, and are readily joined by soft soldering or brazing. Handling and most machining operations on beryllium-copper alloys are considered non-hazardous [1].

Two types of beryllium-copper are in commercial use, described as high strength and high conductivity alloys. With increasing beryllium content, the strength increases, while the electrical and thermal conductivity decreases. We report thermal conductivity measurements of the high conductivity type C17510 alloy below 1 K. This material has been chosen for detector modules for the high frequency instrument (HFI) [2] on the Planck cosmic microwave background imaging satellite [3].

2. MEASUREMENTS

Measurements were made on samples machined from C17510 beryllium-copper extruded rod. The nominal composition (by weight) is 0.2-0.6% Be, 1.4-2.2% Ni, and the remainder copper. The alloy was supplied as temper TF00 (solution annealed and precipitation hardened). The sample configuration is shown in Figure 1. One end of the sample (the "cold end") was screwed to a copper support mounted on the cold stage of an adiabatic demagnetisation refrigerator. The other end (the "hot end") was suspended freely.

Neutron transmutation doped (NTD) germanium (type #12 [4]) thermometers were mounted on each end of the sample. Such thermometers have the advantage of a simple analytical expression for resistance versus temperature, improving the ease of accurate calibration. A germanium standard thermometer[1] was used for absolute calibration. Each thermometer was screwed into a copper block which was in turn screwed to the sample. A separate copper heater block was screwed to the hot end. The heater was a 4.7 MΩ metal film resistor epoxied[2] into a tightly fitting hole in the block.

This configuration is the thermal equivalent of an electrical four wire measurement, and ensures that contact resistances to the heater and to the cold stage are not included in the measurement. The only unwanted thermal path to the hot end of the sample was via the thermometer and heater wires. These were 50 μm diameter constantan wire, thermally anchored to the cold stage. The estimated total heat leak due to the wires was under 4 nWK^{-1} at 100 mK [5]. The sample was enclosed in a gold plated copper radiation shield maintained at 1.8 K. Measurements in this cryostat with a sensitive bolometer have shown that the radiative power inside the shield is less than 1 pW, and therefore negligible. All mounting and support components were gold plated to reduce emissivity and improve thermal contact. Exchange gas was not used to cool down the cryostat.

Measurements were taken at various cold end temperatures from 100 mK to 1 K. At each temperature, the equilibrium temperature of the hot end was recorded for a range of heater powers. Two samples were measured. Sample 1 had width and thickness 0.5 mm, while sample 2 had width 2.05 mm and thickness 1.24 mm. For this sample it was not possible to use a thermometer on the cold end.

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*Corresponding author: Fax: +44 29 2087 4056, Email: adam.woodcraft@physics.org

[1] Model GR-200A-30; Lake Shore Cryotronics Inc, Westerville, Ohio, USA

[2] Epotek 920; Epoxy Technology, Billerica, Massachusetts, USA

In addition, the electrical resistance of sample 1 was measured at room temperature and 4.2 K, using a four wire method.

3. ANALYSIS

The measured conductance for a given temperature was taken from the slope of a graph of the hot end temperature as a function of heater power. For each cold end temperature, a linear dependence was seen, passing through the origin. This provides a good consistency check on the data, and in particular suggests that, as expected, the extra heat load due to the thermometer and heater leads was negligible.

For both samples, it was assumed that the entire measured temperature gradient took place over the narrow part of the sample. This is a good assumption for sample 1. For sample 2, the width of the narrow section is 20% of the width of the end "platforms". The effective length will therefore depend on where the heater, support and thermometer blocks actually make contact with the sample. Finite element analysis suggests that in the worst possible case, where all contacts are made entirely at the outer ends of the sample, the effective length increases by less than 15%. The true conductance should thus be higher than the calculated value by no more than 15%. An additional problem is that the heat flow may not be completely parallel through the cross section of the narrow region. This should reduce the effective length by 2.5% at worst (this is the only source of error discussed which *increases* the calculated result from the true value).

For sample 2 there is also the problem that the cold end temperature is not known. Instead, a thermometer on the cold stage (of a similar design to the sample thermometers) was used. The measured conductance therefore includes an excess thermal resistance through the mechanical contacts and copper support between the sample cold end and the stage thermometer. It is thus a lower limit on the true sample conductance. An attempt at compensating for the excess resistance was made, based on a measurement at 100 mK during the sample 1 measurements. This suggests the excess resistance is 10% of the sample 2 resistance. Since the excess resistance is likely to vary at least linearly with temperature [6], the error should be no larger at higher temperatures.

It should be noted that all the errors discussed here are very likely to be within the variation between different lots of alloy with nominally the same specifications and heat treatment [7].

As a check on the validity of the results, conductivity measurements were made in a similar fashion on a sample of aluminium 6061-T6 alloy. Unlike a pure metal, the heat treatment/cold working history of such an alloy should not cause order of magnitude variations in conductivity. It is therefore reasonable to use it as an approximate "standard" material. We measured an approximately linear conductivity above the superconducting transition (measured to be 0.97 K in zero field), with a value of 2.5 $\mathrm{Wm^{-1}K^{-1}}$ at 1 K. This is close to a literature value of 2.7 $\mathrm{Wm^{-1}K^{-1}}$ [8] (extrapolated from 1.3 K).

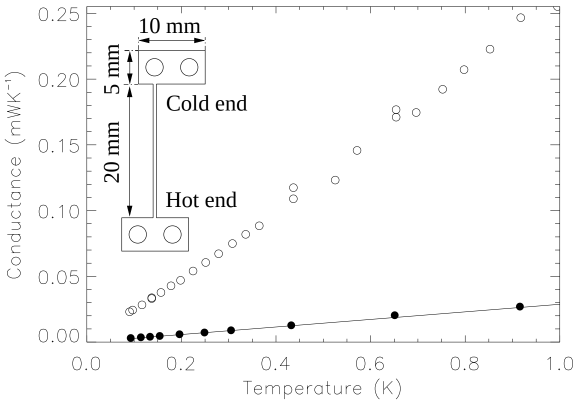

FIG. 1: Conductance measurements. Sample 1 data (●), sample 2 data (○). The solid line shows the conductance predicated from an electrical resistance measurement at 4.2 K using the Wiedemann-Franz law. The insert shows the shape of the samples used.

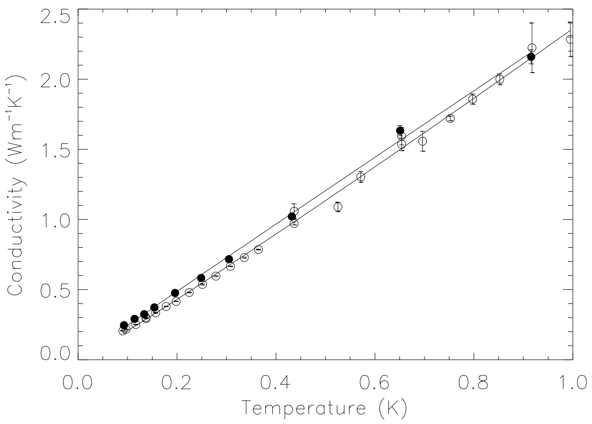

FIG. 2: Conductivity values (sample 2 values are corrected for the excess thermal resistance - see text). Sample 1 data (●), sample 2 data (○). Solid lines are power law fits to the two datasets.

4. RESULTS

The measured conductance values are shown in Figure 1. The sample 2 results have not been corrected for the excess thermal resistance between the sample and the cold stage thermometer. Calculated conductivity values are shown in Figure 2. Here the sample-stage resistance correction has been made, assuming a linear temperature dependence of the excess resistance. Fits to the data assuming a single power law variation with temperature produce $\kappa = 2.39 \pm 0.03$ $(T/1\mathrm{K})^{0.99}\mathrm{Wm^{-1}K^{-1}}$ and $\kappa = 2.36 \pm 0.02$ $(T/1\mathrm{K})^{1.06}$ $\mathrm{Wm^{-1}K^{-1}}$ for conductivity, κ, of samples 1 and 2 respectively. Results for the two samples are in good agreement, bearing in mind the uncertainty in the correction made to the sample 2 data. The conductivity temperature variation is ap-

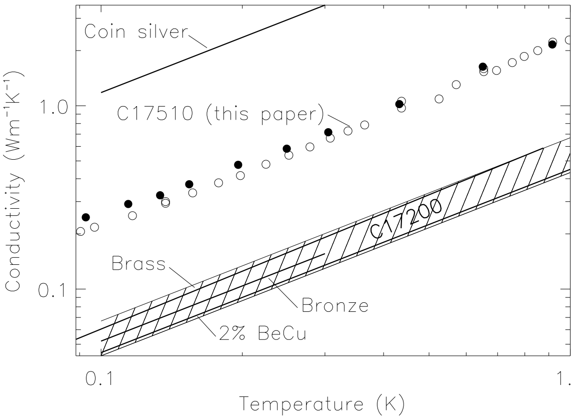

FIG. 3: Measured thermal conductivity of BeCu 17510, compared with literature values for various copper alloys: Coin Silver (90% silver, 10% copper) [10], Brass (composition unspecified) [11], Bronze (85% Cu, 5% Sn, 5% Zn, 5% Pb) [12], 2% BeCu [13], BeCu C17200 (hatching shows range of values for different heat treatments) [14]. The literature BeCu data is extrapolated from data above 1 K.

proximately linear, and there is thus no evidence of any lattice (phonon) contribution to the conductivity.

The electrical resistivity of sample 1 was 29.9 nΩm at room temperature; this is close to the value from the manufacturers of 32 nΩm. At 4.2 K, the resistivity was 10.6 nΩm. This corresponds to a thermal conductivity, calculated using the Wiedemann-Franz law [6], of $\kappa_{wf} = 2.29 \pm 0.05$ $(T/1\mathrm{K})$ $\mathrm{Wm}^{-1}\mathrm{K}^{-1}$. This is in good agreement with the thermal measurements as shown in Figure 1. Again, this suggests that lattice conduction is negligible. A value of 15 nΩm has been measured for cold-worked and aged C17510 at 4 K [9]. The difference between this and our measured value is small enough to be due to different heat treatment and cold working of the samples - the results given here are only valid for the particular temper (TF00) measured.

We are unaware of any other thermal conductivity measurements on beryllium-copper at these temperatures. There is a limited amount of data above 1 K, for high strength alloys only. Berman et. al [13] measured an annealed 2% beryllium alloy (claimed in reference [9] to be C17200) above 2 K, while Gröger et. al [14] measured C17200 above 1 K after a range of different heat treatments. These results, extrapolated below 1 K, are shown in Figure 3, along with data for some other copper alloys. It can be seen that the high strength alloys have considerably lower conductivity than C17510 at these temperatures, as would be expected given the difference in conductivity at room temperature.

The conductivity of the high-strength alloy measured in reference [13] was found to be in good agreement with the prediction from the Wiedemann-Franz law. Along with our measurements, this suggests that electrical resistance measurements will provide an accurate value for the thermal conductivity of any commercial beryllium-copper alloy at these temperatures.

5. CONCLUSION

The thermal conductivity of C17510 beryllium-copper alloy has been measured, and found to be predominately electronic. Our results suggest that the Wiedemann-Franz law can be used to predict the thermal conductivity of any commercial beryllium-copper alloy from the electrical resistance.

Beryllium-copper C17510 is a good choice when high strength and thermal conductivity are required at cryogenic temperatures. The conductivity is higher than for high-strength beryllium-copper alloys and brass, while being under an order of magnitude less than for coin silver, which has a lower strength.

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[1] Safety practices for machining copper beryllium alloys. Brush Wellman Safety Note SF101.

[2] Lamarre JM, Ade PAR, Benoît A, et al. The high frequency instrument of Planck: Design and performances. Astro. Lett and Communications 2000;37:161.

[3] Mandolesi N, Villa M. FIRST/Planck mission. In Proceedings of the 16th IEEE Instrumentation and measurement technology conference (ICMT/99), 1999;2:975–980

[4] Haller EE, Itoh KM, Beeman JW. Neutron transmutation doped (NTD) germanium thermistors for sub-mm bolometer applications. In Proc. 30th ESLAB Symp. “Submillimetre and Far-Infrared Space Instrumentation”, 24-26 September, ESA 1996; SP-388:115.

[5] White GK. Experimental techniques in low-temperature physics. Oxford: Clarendon Press, 1979.

[6] Pobell F. Matter and Methods at Low Temperatures. Berlin: Springer, 1992.

[7] Hust JG. Materials at low temperatures. American Society for Metals, 1983; page 159.

[8] Mittag K. Kapitza conductance and thermal conductivity of copper, niobium and aluminium in the range from 1.3 to 2.1K. Cryogenics 1973;13:94.

[9] Simon NJ, Drexler ES, Reed RP. Properties of copper and copper alloys at cryogenic temperatures. NIST Monograph 177, 1992.

[10] Degrift CTV. Coin silver as a construction material in low-temperature experiments. Physica B & C 1981;107:605.

[11] Lounasmaa OV. Experimental principles and methods below 1K. London: Academic, 1974.

[12] Beduz C, Meijer HC. The heat conductivity of bronze and sintered bronze below 0.3K. Cryogenics 1974;14:437.

[13] Berman R, Foster EL, Rosenberg HM. The thermal conductivity of some technical materials at low temperatures. Brit. J. App. Phys. 1955;6:181.

[14] Gröger V, Stangler F. Thermal conductivity of the copper beryllium alloy CuBe2 at low temperatures. Zeitschrift fur Metallkunde 1981;72:487.