# Thermal, electrical properties and microstructure of high purity niobium for high gradient superconducting cavities

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For controlling niobium properties for the fabrication of superconducting cavity, the systems for quick measurement of Nb thermal conductivity and residual resistivity ratio RRR are created. Thermal conductivity test can be done in a 100 l transport liquid helium tank. A DC RRR measurement for Nb samples and a specially developed AC method for nondestructive RRR measurement of the cavities in situ are presented. Thermal conductivity, RRR distribution and the microstructure of electron-beam welding seam of high purity niobium are investigated.

## INTRODUCTION

Niobium is the favorite metal for the fabrication of superconducting accelerating cavities[1]. The project TESLA XFEL plans to use 1000 niobium superconducting cavities[2]. The proposed TESLA Linac needs over 21,000 niobium cavities[3].

Thermal break down is one of the main limitations on the way to high gradient superconducting cavity. To avoid thermal break down, high thermal conductivity of niobium is needed[4]. For niobium quality control, a cryogenic thermal conductivity measurement system, a DC and an AC RRR measurement techniques are developed. The thermal conductivity, RRR distribution and microstructure of electron beam welding niobium were investigated, and their correlation was obeserved by experiments.

## DEPENDENCE OF CAVITY BREAKDOWN FIELD ON THERMAL CONDUCTIVITY

A normal conducting spot triggers quench when it heats the Nb above $T_c$. Breakdown field is given by [5]

$$H_{tb} = \sqrt{\frac{4k_T(T_c - T_b)}{R_d}} \qquad (1)$$

Where $K_T$ - Thermal conductivity of Nb. $R_d$ - Defect surface resistance. $T_c$ -Critical temperature of Nb. $T_b$ - Bath Temperature.

## THERMAL CONDUCTIVITY DEPENDENCE ON RRR

The empirical formula (2) can be used to estimate the thermal conductivity of superconducting niobium in a wide temperature range [6] :

$$\lambda(T,RRR,G)=R(y)\cdot\left[\frac{\rho_{295K}}{L\cdot RRR\cdot T}+a\cdot T^2\right]^{-1}+\left[\frac{1}{D\cdot\exp(y)\cdot T^2}+\frac{1}{B\cdot G\cdot T^3}\right]^{-1}\quad(3)$$

Where $y=\alpha\bullet T_c/T$, α=1.76, L=2.45×$10^{-8}$ $WK^{-2}$, a = 2.3 × $10^{-5}mW^{-1}K^{-1}$, 1/D=300 $mK^{-3}W^{-1}$, B=7.0 ×$10^3 Wm^{-2}K^{-4}$ , G - grain size. From the curve in [6], $R(y)$ can be roughly fitted as

$$R(y)=-0.28401y^3+4.6281y^2+0.7787y-0.0131\qquad(4)$$

With formula (3), a theoretical value of thermal conductivity dependence on RRR is calculated and compared to the experimental data. In the range between 4K and 10K, the experimental data are roughly the same as the theoretical values, as shown in Fig.2.

## A CRYOGENIC THERMAL CONDUCTIVITY MEASUREMENT SYSTEM

A cryogenic thermal conductivity measurement system is created, as shown in Fig. 1. To avoid the trouble of transferring liquid helium, a 100 litre liquid helium storegy transfer tank is applied as the cryostat. Its advantage is that a simple and quick test can be realized in industry. Due to the limited inlet diameter of the cryostat, the high vacuum sample chamber has a limited space for sample and sensors. It is a challenge to minimize the losses produced by radiation and wires. To block the radiation from the top, a copper flange is fixed on the top of the sample chamber. It has a good contact with liquid helium. To minimize the losses from wires and provides a good tenacity, 0.1 mm diameter of NbTi wires are applied. The steady state method is used to determine the thermal conductivity k. $k=Q/A\bullet dx/dT$, where Q is the heat source power, A the section area of sample, $dT/dx$ the temperature gradient along the sample. To check the system accuracy, a series of niobium samples with known RRR are measured. The results are shown in Fig.2. Comparing the results with the theoretical value and the results measured by the former different system in the range between 4K and 10 K, the results are quite convincing.

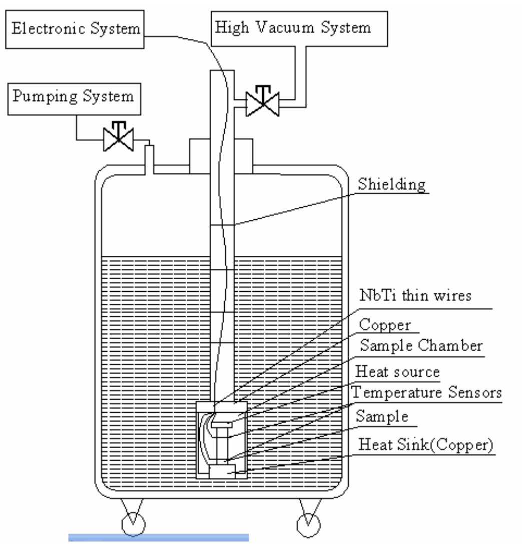



Fig. 1 Cryogenic thermal conductivity measurement apparatus

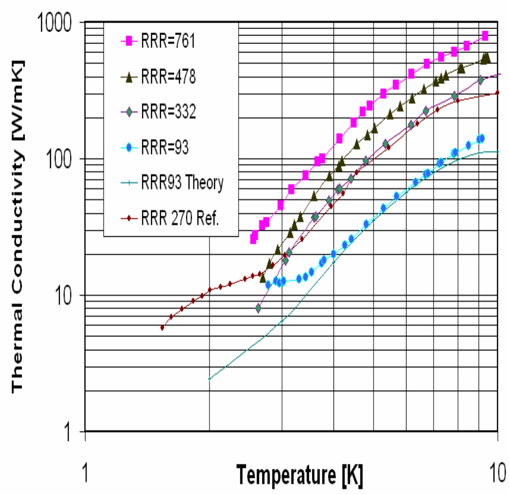
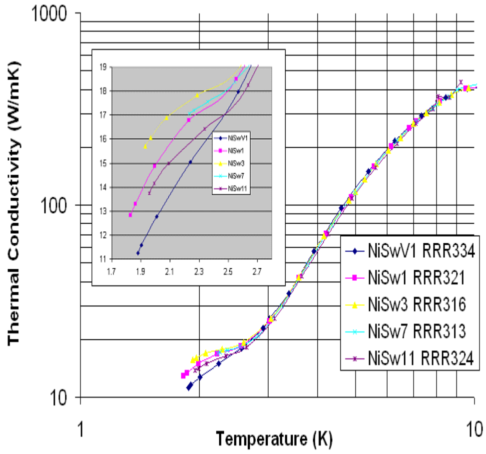



Fig. 2 Comparison with theoretical value and the results done by conductivity

## THERMAL CONDUCTIVITY AND MICROSTRUCTURE OF EB WELDING HIGH PURITY NIOBIUM

Electron beam welding(EBW) is applied in cavity production for welding all parts together with high quality. Its influences on high purity niobium is investigated by measuring its RRR and



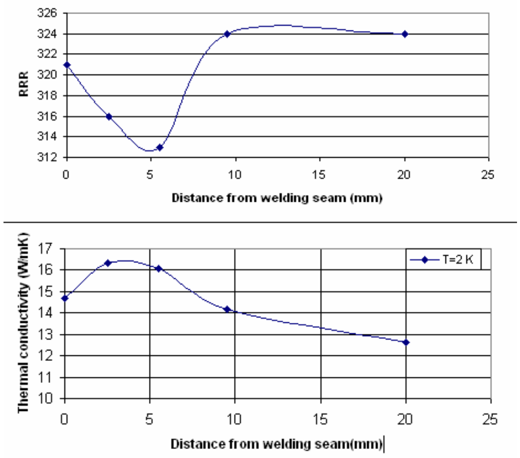
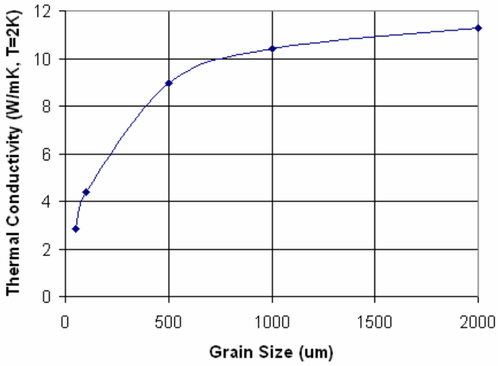




Fig.3 EB welding niobium thermal conductivity

Fig.4 RRR in the welding seam versus distance from the welding seam

thermal conductivity distribution. The influences of EB welding on high purity niobium RRR distribution have already been reported in Ref. [7]. Fig.3 shows the thermal conductivity distribution on an EB welding niobium sample, which was done earlier in a specially designed device. In the range below 3 K, the thermal conductivities are quite different. Fig.4 shows the thermal conductivity distribution in EB welding at 2K. The thermal conductivities in this region do not depend on RRR, but on grain sizes. Except the first point, other points have the same relationship as Fig.5, which gives the theoretical thermal conductivity dependence on grain size at 2K. Fig.6 gives a typical microstructure of EB welding sample. The grain size in the welding seam is much bigger.



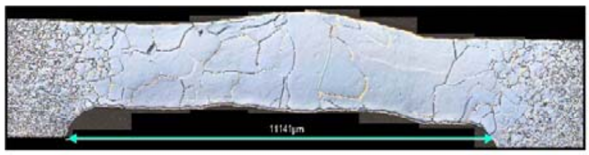



Fig.5 Theoretical thermal conductivity dependence on grain size at 2 K, for RRR=320

Fig.6 Microstructure of the EB welding area. The grain size G=50-2000 µm

## RESIDUAL RESISTIVITY RATIO RRR CONTROL

Since that thermal conductivity of niobium can be estimated by RRR and grain size, RRR can be a tool for estimating the thermal conductivity of niobium. Therefore, a DC RRR system for niobium quality control and an ac RRR test system with eddy current method for cavity RRR control are created, as shown in Fig.7. AC RRR test system is described in Ref. [8].

A DC RRR measurement system with a 1.1 Tesla superconducting magnet, was created recently. With the superconducting magnet, niobium will be kept on normal conducting state at 4.2K, so that we can measure the sample resistance at 4.2K directly. By measuring the sample's resistance at room temperature and 4.2K, we get the RRR=R(295K)/R(4.2K). In practice, we found that the surface layer of the sample has a big influence on the penetration field, as shown in Fig.8. For samples without etching, the penetration field is much higher than the etched samples. The reason may be that the surface contamination makes more pinning centers and cause a bigger pinning magnetic field. Therefore, for keeping the magnetic field completely penetrate the sample

Fig.7 Cavity RRR measurement system

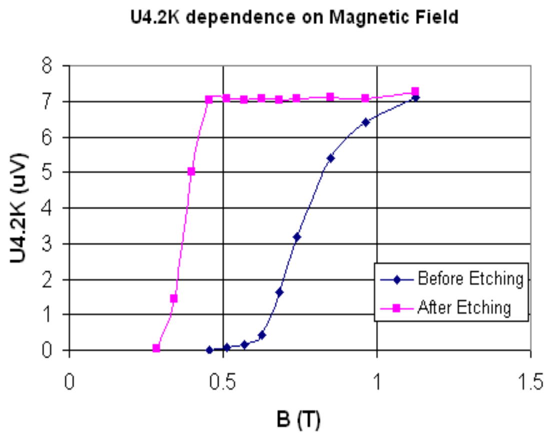



Fig.8 Magnetic field penetration in Niobium Sample

and keep the sample in normal conducting state, the magnetic field is fixed at 1.1 T, much higher than the critical field 0.23 T.

## SUMMARY

- An innovative cryogenic thermal conductivity measurement system based on transport liquid helium cryostat was described.
- Thermal conductivity distribution of electron beam welding sample was investigated. Below 3K, the thermal conductivities dependence on grain sizes was observed.
- A RRR measurement system with a 1.1 Tesla superconducting magnet was described. The experiences show that the backgound field up to 1.1 T for niobium is necessary.

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