SLAC-PUB-15109

A CRYOGENIC RF MATERIAL TESTING FACILITY AT SLAC*

Jiquan Guo#, Sami Tantawi, David Martin, Charles Yoneda
SLAC National Accelerator Laboratory, Menlo Park, CA, U.S.A.

Abstract

We have developed an X-band SRF testing system using a high-Q copper cavity with an interchangeable flat bottom for the testing of different materials. By measuring the Q of the cavity, the system is capable to characterize the quenching magnetic field of the superconducting samples at different power level and temperature, as well as the surface resistivity. This paper will present the most recent development of the system and testing results.

INTRODUCTION

The advance in the superconducting RF technology makes it more and more attractive for particle accelerator applications. Continuous research efforts are being made to improve the performance of existing superconducting materials or to find new superconducting materials. For accelerator cavity applications, one of the most interested properties is the critical RF magnetic field (also known as quenching field), which currently limits the SRF linear accelerator gradient.

During 2004 to 2008, we developed an SRF testing system to measure the quenching field using a "mushroom" shape copper cavity with a flat bottom, which can host a flat sample disk of 2-3 inches diameter [1, 2, 3]. The system operates at 11.4GHz, using a 50MW klystron with 1-2μs pulses. In the last two years, we changed the cavity shape to hemispheric, which can provide higher H in the bottom. The instrumentation of the system is also improved.

SYSTEM DESCRIPTION

The schematic of the system is shown in Fig 1. The main component of the system is the hemispheric cavity resonant at ~11.424GHz, with the detail shown in Fig 2. The choice of the frequency allows us to use the available RF facilities and components at SLAC. The frequency also makes the system compact, fitting in a small cryogenic chamber. The cavity works under a TE_{013} like mode, which has no E-field on the bottom, so there is no multipacting on the sample surface. This mode also avoids radial currents on the bottom, which allows a detachable bottom plate to host the sample. The exposed part of the sample has a diameter of 1.9inch, and the sample diameter can be 2-3inch. The dome of the cavity is made of copper, which will provide more stable and repeatable surface resistivity at different temperatures, which is important if we need to test high T_c materials. However, the losses are much higher compared to materials under superconducting state, which reduces the precision of surface resistivity measurement to about 0.1mΩ at low temperature. A niobium cavity is needed in the future if precise surface resistivity measurement is necessary.

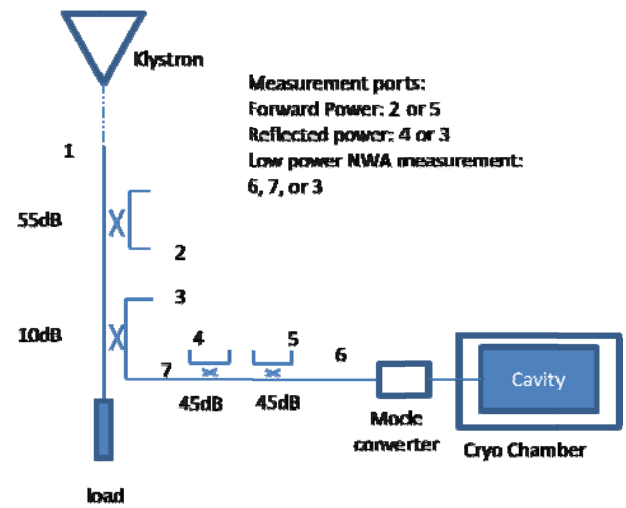

Figure 1: System diagram.

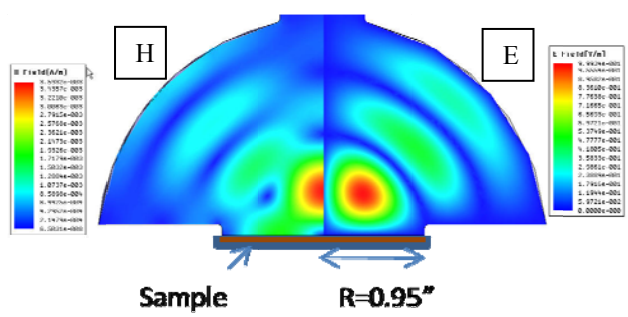

Figure 2: Fields in the hemispheric cavity

One of the most important design goals of the cavity is to have the highest possible peak H field on the sample surface with certain input power. The choice of the hemispheric shape and the TE_{013} mode will highly concentrate the H-field on the bottom plate, with the peak approximately 2.5 times of the peak on the dome. The higher frequency and small size can also reduce the energy needed. The RF loss is also significantly higher on the sample plate; if the sample uses the same material as the dome, 36% of the total loss is on the sample surface, although it accounts for <10% of the total of cavity surface area. The higher ratio of loss on the sample will result in higher precision of surface resistivity characterization. However, this high field makes the cavity sensitive for the step height between the sample

*Work supported by the U.S. Department of Energy
#jqguo@slac.stanford.edu

Presented at the 1st International Particle Accelerator Conference (IPAC 2010)
Kyoto, Japan, May 23 - 28, 2010

Work supported by US Department of Energy contract DE-AC02-76SF00515.

and the larger bottom. With a 0.1mm change in the height, there will be a 15MHz frequency shift.

The cavity is coupled through one circular aperture in the top. At room temperature, Q_0 of the cavity with copper on the bottom is about 50,000. When the sample plate is superconducting, and the cavity temperature is at ~4K, Q_0 of the cavity is approximately 350,000. The external quality factor of the cavity is designed at ~340,000, which approaches critical coupling for superconducting samples. The external Q is sensitive to the radius of the aperture, which makes it possible to be adjusted for a future niobium cavity.

The cavity is fed with a circular waveguide, while the high power and the instrumentation use WR90 waveguide. A rectangular TE_{10} to circular TE_{01} mode converter is used between the waveguides.

Figure 3: Cryo chamber assembly

For the low power network analyzer tests, cavity internal and external Qs are calculated by scanning the reflection coefficients from the cavity. It's preferred to connect the NWA right at the mode converter (point 6 in Fig 1) to avoid the distortion in the waveguides, but that needs to break the vacuum in the WR90 waveguide. The alternative is port 3 in Fig 1, however the reflection of the high power load can be easily add some reflection and oscillation through the 10dB coupler. Although we have a program to partly correct the distortion, currently it does not work well with the oscillation. Point 7 can also be used, without obvious oscillation.

For the high power characterization, forward power from the klystron is fed through the 10dB to the cavity and measured at coupler ports 2. The reflected power can be measured at both port 4 and port 3. The power level trace is recorded with a pulsed power meter. There is also a mixer which can convert the RF into IF, so we can record the relative power level trace with a digital scope. Loaded Q can be calculated from the decay time of the reflected power level traces from the both instrumentations. Currently the power meter has worse linearity, so the mixer data is used. Beta or external Q can be calculated using the integral of the forward power and the emitted power from the power meter, but we can also use the external Q from the network analyzer measurements. With the measured Qs and the forward power, we can calculate the energy stored in the cavity and the peak H-field.

EXPERIMENT RESULTS

Numerous samples have been tested in our system in the past years, including different copper, niobium and MgB2 samples. Only selected results are reported here.

SLAC Copper reference

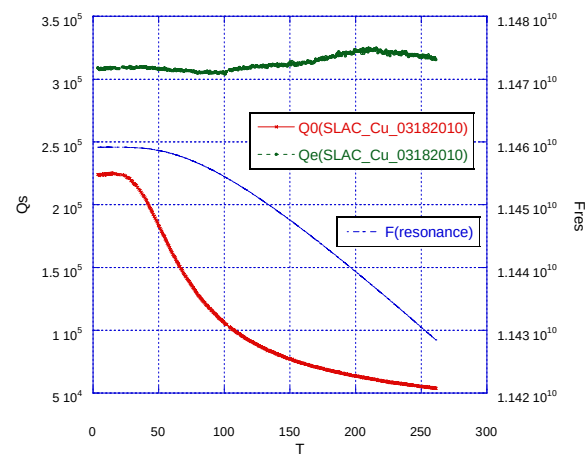

Figure 4: Low power measurement of the SLAC copper sample

Fig. 4 is the results for a SLAC copper sample as a calibration of the cavity. The copper uses same material and finish/annealing as the cavity dome, but not from the same lot. This gives the approximate surface resistivity of the copper at different temperature. Q_0 increased from ~50,000 at room temperature to about 224,000 at 4K. Q_e is around 310,000, changing slightly with temperature. With the measured Q_0 at low temperature, we can estimate that Q_0 will be about 350,000 for superconducting samples.

FNAL small grain Niobium

We have tested a small grain Niobium sample provided by Lance Cooley of Fermi Lab. Results are shown in Fig. 5 and Fig. 6. Fig 5 shows that the 20mT high power test results fit the low power test results very well. However, the surface resistivity is abnormally high in the superconducting state reaching approximately 2mΩ. The reason of this high resistivity needs to be investigated further. Fig 6 indicates that the Nb starts to quench at approximately 65mT. Our calculation shows that it's actually thermal quenching caused by pulse heating of the Nb, since the Nb has an abnormally high resistivity.

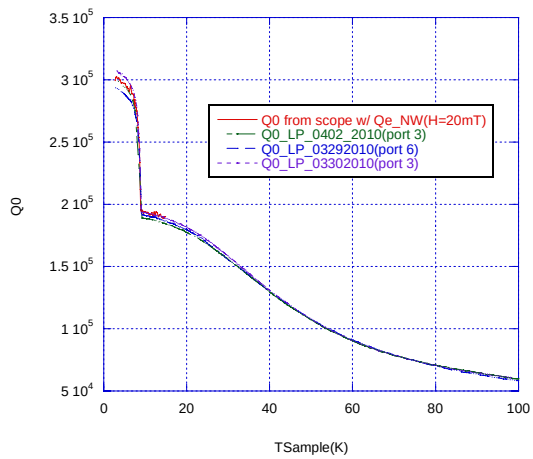

Figure 5: Q_0 vs Temperature, FNAL small grain Nb

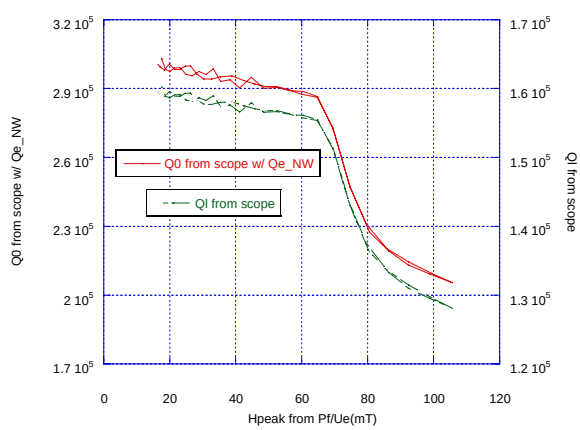

Figure 6: Q_0 vs H-field, FNAL small grain Nb

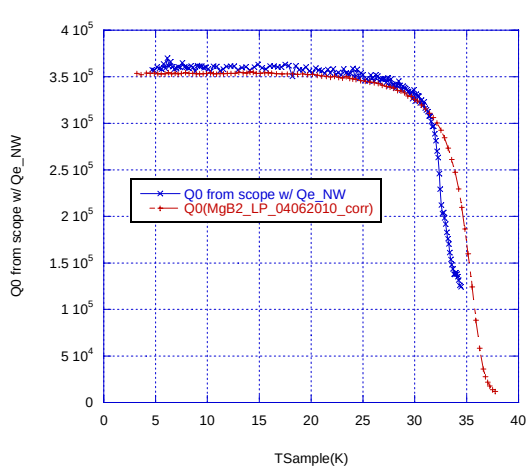

Figure 7: Q_0 vs Temperature, LANL 300nm MgB2 on Sapphire

LANL 300nm MgB2 on Sapphire sample

An MgB2 on sapphire sample was provided by Tsuyoshi Tajima of LANL. 300nm of MgB2 thin film is deposited on a 2 inch sapphire substrate. In Fig. 7, both high power and low power test results show that the cavity has a Q_0 of about 350,000, and R_s is smaller than what the system can measure. Figure 8 shows a quenching H-field of ~25mT.

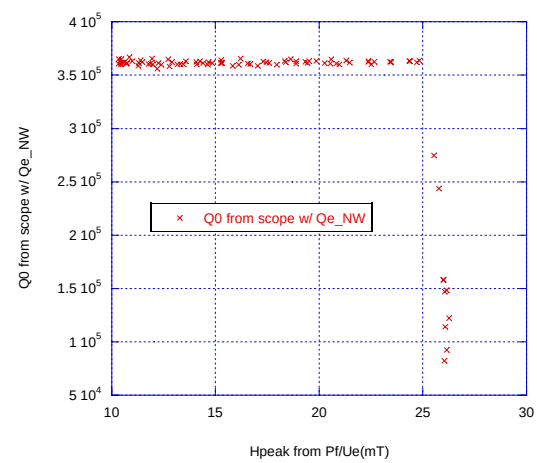

Figure 8: Q_0 vs H-field, LANL 300nm MgB2 on Sapphire

SUMMARY

We have demonstrated a cryogenic RF material testing facility. This facility can characterize the R_s of samples of 2-3 inch diameter disks, with the precision up to 0.1mΩ. The system can precisely measure the quenching magnetic field of the superconducting samples.

ACKNOWLEDGEMENTS

The authors need to thank the SLAC Klystron Test Lab for providing the support for the experiments, especially the maintenance of the klystron. We also owe our gratitude to Richard Talley and Robert Vanderzyl, for helping us installing the samples and changing the RF connection of the system from time to time.

REFERENCES

[1] C. Nantista et al., "Test Bed for Superconducting Materials," Proceedings of the 21st Particle Accelerator Conference (PAC05), Knoxville, TN, May 16-20, 2005, p. 4227.

[2] S. Tantawi et al., "Superconducting Materials Testing With a High-Q Copper RF Cavity," Proceedings of the 22nd Particle Accelerator Conference (PAC07), Albuquerque, NM, June 22-26, 2007

[3] A. Canabal et al., "Critical Magnetic Field Determination of Superconducting Materials", Proceedings of the EPAC08, Genoa, Italy