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STUDY ON COMMERCIAL DIODES AS THERMOMETERS AT LOW TEMPERATURE FOR TEMPERATURE MAPPING SYSTEM OF Nb_3Sn SUPERCONDUCTING RADIOFREQUENCY CAVITIES

R. Wanison†, [1, 3], K. Takahashi[2], K. Umemori[1,2], T. Yamada[1]
[1]High Energy Accelerator Research Organization (KEK), Tsukuba, Japan
[2]Graduate University for Advanced Studies (SOKENDAI), Tsukuba, Japan
[3]Department of Mechanical Engineering, Chiang Mai University, Chiang Mai, Thailand

Abstract

Nb_3Sn Superconducting radiofrequency (SRF) cavities has been researched and developed at Center for Applied Superconducting Accelerator (CASA), KEK. One of effective tools for research on the performance of SRF cavities is a temperature mapping (T-map) system for detecting small increases in temperature. It is a thermometer array positioned precisely on an outer surface of cavity wall. Thermometer should cover at least from the range of typical operating temperature of 4 K to the transition temperature of 18 K, for the Nb_3Sn SRF cavities. Therefore, carbon resistor can not be used as a cheap thermometer due to low sensitivity at this temperature range. In this proceeding, we report the results of the test for various commercially available diodes as a thermometer for T-map system. The sensitivity, stability and the repeatability are measured, cooled by a GM cryocooler.

INTRODUCTION

The key parameter of a superconducting radio frequency (SRF) cavity are quality (Q) factor and accelerating gradient. One of effective method to investigate the performance of SRF cavity is a temperature mapping (T-map) system for detecting small increases in temperature while operating SRF cavity [1, 2]. The T-map system consists of thermometer arrays positioned precisely on external surface of a cavity wall. The number of thermometers used in ranges from hundreds to thousands. There are commercially available thermometers with high accuracy and long-term stability. The price is, however, costly to use for the T-map system. Previously, the T-map system has been researched and developed by using resistor as a thermometer for low temperature. Many articles have been published describing their properties, such as resistance R and temperature T (R-T curve) data [3, 4]. One of the advantages of a resistance thermometer is that they can use a current-reversal technique to cancel the effects of thermal electromotive force (thermal EMF). Nevertheless, the disadvantage is the small change of resistance with temperature. It was found that the resistance thermometer has a good accuracy and reproducibility at temperature below 4 K [5]. In contrast, the use of a diode as thermometer makes wider operating temperature. The advantage of diode is that they have high sensitivity thermometer over the 1 K to 500 K temperature range [6].

Center for Applied Superconducting Accelerator (CASA) at KEK has researched and developed next generation of surface material for SRF cavities, that is Nb_3Sn. Owing to a higher critical temperature (T_c) of Nb_3Sn (~18 K) comparing to Nb (~9 K), Nb_3Sn has allowed it to achieve higher Q factor than Nb in an operating temperature of ~4 K.

In this research, therefore, we focus on experimentally investigate the behaviour of commercially available diode as a cheap thermometer for low temperature use. The scope of this research is to examine sensitivity, stability and repeatability of many types of commercially available diodes from 2.7 K to 77 K cooled by a GM cryocooler.

EXPERIMENTAL SETUP

The experimental set up is shown in Figure 1. It consisted of a GM cryocooler inside the cryostat to maintain the operating temperature from 2.7 K to 77 K, and a test section for installing diode sensors. As described later, commercially available diodes were installed to the test section. The stainless steel plate (3mm-SUS), with a dimension of 120×120 mm, and 3 mm in thickness, was inserted between 2^{nd} stage of a cryocooler and the test section for thermal barrier, and thermal stability.

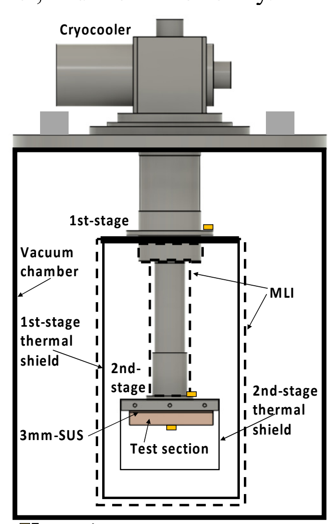

Figure 1: The experimental set up.

Test Section

The test section is shown in Figure 2. It has a dimension of 120×120 mm, and 20 mm in thickness, made by copper. It was designed for installing of nine diodes. There were different sizes of holes for several types of the diodes, and area for calibrated temperature sensor (DT-670 Silicon

† ramnarong.wanison@cmu.ac.th

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diode from Lake Shore) at the middle. There were also four resistance heaters, with 10 ohm and 25 W, for controlling the temperature of the test section.

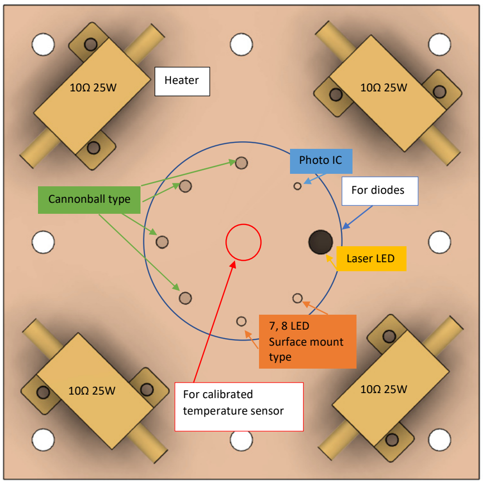

Figure 2: The test section.

Commercially Available Diode

Several types of diodes were tested, namely, light emitting diode (LED), Schottky barrier diode (SBD), Zenner diode, and Photo IC diode. There were seventeen of diodes tested which are four LED cannonball types, four LED surface mount types, an LED laser type, four SBD surface mount types, an SBD SiCSBD type, a Zenner diode surface mount type, a Zenner diode normal type, and a Photo IC diode.

EXPERIMENTAL PROCEDURE

In order to ensure the experimental setup cooled by a GM cryocooler, all diodes were also cooled by liquid nitrogen and their output voltage were compared at 77 K. Identical results were obtained for both cases. The diodes voltage was measured with the function of a temperature by excitation constant current 10 µA to determine the sensitivities from 2.7 K to 77 K. Nine diodes that have good sensitivity were selected to test the stability and the repeatability. The stability, which is defined as standard deviation of diodes voltage with sampling rate of 2 Hz for 10 minutes (1,200 data) at each temperature. Finally, the repeatability was also evaluated, by comparing the measured diodes voltage of several test process rounds (test process round: cooling down → experiment → warming up).

RESULT AND DISCUSSION

The experimental results of sensitivity, the stability, and the repeatability of the diodes were reported in this section.

Sensitivity

Here, the sensitivity of a diode is defined as the change in the diode voltage per unit change in temperature. The diode voltage was measured at steady state for each temperature between 2.7 K to 77 K. Figure 3 shows plot of the diode voltage and temperature (V-T curve) for seventeen diodes. The data of DT-670 silicon diode from Lake Shore was also plotted as a reference calibrated temperature sensor. The diode voltages increase with decreasing of the

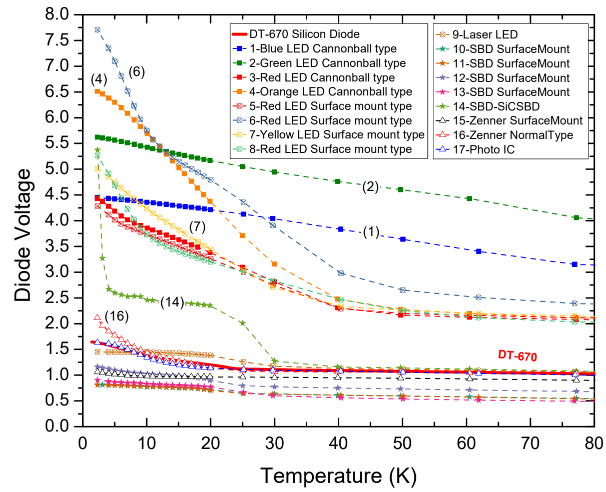

Figure 3: Diode voltage versus temperature curve.

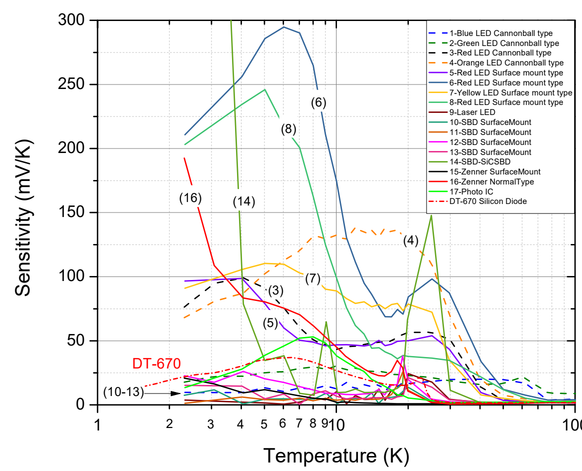

Figure 4: Sensitivity versus temperature curve of selected diodes for stability and repeatability test.

temperature, and dramatically increase below the temperature of 40 K. In the Figure 3, it can be found that the same type of diodes has similar temperature response. The LED laser type and the photo IC diodes have temperature response similar with DT-670 silicon diode. Figure 4 shows the sensitivity versus temperature for seventeen diodes. In the Figure 4, it can be found that when consider temperature higher than 4 K, Two-red LED surface mount type (6 and 8) have high sensitivity of 294 mV/K (highest sensitivity) and 246 mV/K at 6 K and 5 K, respectively. They have good sensitivity at the range of 3–40 K. Two LED cannonball types (3 and 4), two LED surface mount type (5 and 7), and Zenner diode normal type (16) have sensitivity of 50–125 mV/K, approximately, at the range of 3–20 K. Two LED cannonball types (1 and 2), LED laser type (9), all SBD surface mount types (10–13), Zenner surface mount type (15) and Photo IC diode (17) have low sensitivity of 5–25 mV/K, approximately, at the range of 3–20 K but still this value is consistent with the one for DT-670.

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Remarkably, the sensitivity of the SBD SiCSBD type (14) significantly increases at 30 K and again at 3 K. It could be useful for an application below 3 K.

Stability and Repeatability

Before testing the stability and repeatability of diodes, six diodes were selected (limited number of diodes installed in the test section) by considering of 1) high sensitivity: especially around 4 K to 20 K, 2) shape: for mounting and low heat capacity, and 3) low heat generation: low diode voltage (this experiment used current of 10 µA). It found that the selected diodes mostly were LED surface mount type since they have high sensitivity and shape may be suitable for installing at external surface of cavity wall. It would also be better to select several types of diodes to test and compare the results, thus one of LED cannonball type, Zenner diode normal type, and one of the highest sensitivities of SBD surface mount type (even low sensitivity) were also selected. Therefore, diode number 4, 6, 7 ,8, 12, and 16 were selected.

Figure 5 (a)–(f) show experimental result of six-selected diodes, in which stability (solid data) and repeatability (open data) are plotted. The data for DT-670 silicon diode are also shown as the reference. The stability and repeatability were evaluated as the standard deviation (SD) of measured data. The value of SD of diode voltage was cali-

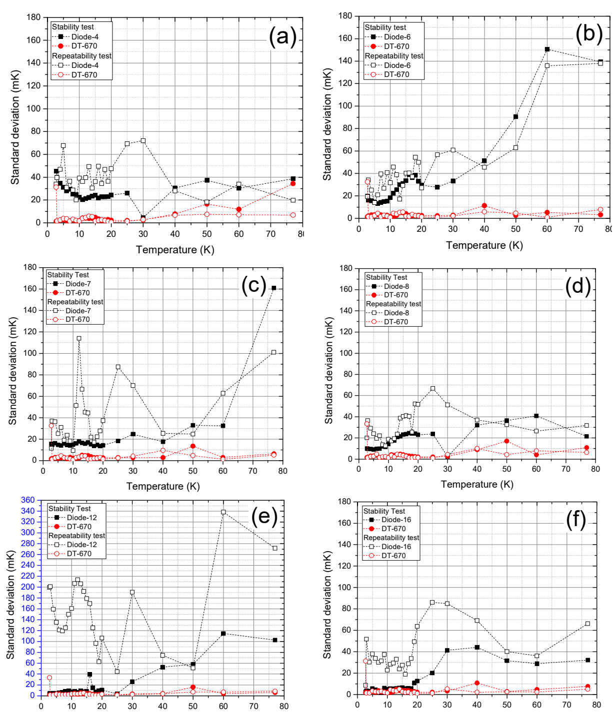

Figure 5: Standard division of stability and repeatability tests: (a) LED cannonball, (b) Red LED surface mount, (c) Yellow LED surface mount, (d) Red LED surface mount, (e) SBD surface mount, and (f) Zenner diode.

brated to temperature using the data in Figure 3. It is the SD of measured diode voltages with sampling rate 2 Hz for 10 minutes (1,200 data), and the SD of four-rounds of test process (4 data), in case of stability and repeatability tests, respectively. The value of SD for stability test are flat and tend to decrease, except for case of orange LED cannonball types (4), as show in Figure 5(a) when the temperature below 20 K. This temperature range is highly satisfied for operating Nb_3Sn SRF cavities. Some of repeatability is also rather flat. On the other hand, SBD surface mount (12), Figure 5(e), show quite high value of SD for repeatability test compared with other diodes. The values of SD for repeatability test are higher than that of stability test since temperature ranges for testing was different. The stability test was focused on the temperature range between 2.7–77 K. While the repeatability test included temperature range from room temperature (test process round: cooling down → experiment → warming up). In the future, we would like (also suggest others) to test longer time for the repeatability, for several months, and test for reproducibility such as remove and install diodes in same experimental set up. We hope this may be able to ensure the possibility using a diode as a thermometer for low temperature.

SUMMARY

The experiment results, with excitation current 10 µA, show that the sensitivities at 4 K are 224, 22, 112 mV/K for LED, SBD, and Zenner, respectively. Their stability and repeatability are respectively 10 mK and 50 mK. The experimental result of commercially available diodes with sensitivity, stability, and repeatability are satisfied to employ the diode as a thermometer not for only T-map of Nb_3Sn, which cool by a GM cryocooler, but also for general purpose of low temperature experiments.

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