# INTERCHANGEABILITY OF DIODE TEMPERATURE SENSORS FOR VARIOUS NON-STANDARD EXCITATION CURRENTS

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Diode thermometers interchangeable to an “average” curve are commonly used in cryogenic thermometry. Typically an excitation of 10 μA is chosen to minimize self-heating at low temperatures while maintaining an acceptable signal-to-noise ratio. For some applications, it is desirable to use a different excitation current but still use the interchangeability feature. Eleven sensors from each of two diode thermometer models, the DT-470 and the DT-670, were calibrated at currents ranging from 0.05 μA to 10 mA at 4.2 K, 30 K, 77 K, and 300 K. This paper examines the “average” curve and interchangeability of diode temperature sensors for non-standard excitations.

## INTRODUCTION

Silicon diodes are widely used as general-purpose cryogenic temperature sensors due to the temperature dependence of the forward voltage drop across a p-n junction. Silicon diodes have many useful features: they are usable over a wide range (1 K to 500 K), have high signal output, have simpler and more rugged packaging, and diodes from each manufacture will all have the same response curve. The last result allows diodes to be binned into tolerance bands with accuracies between ±0.25 K to ±3 K depending on tolerance band and temperature range.

The “average” curve to which the thermometers are interchangeable is developed from the calibration of hundreds or thousands of samples from the particular diode wafer lot. This is an expensive task, and the “average” curve is generally defined only for a single excitation current. For most cryogenic applications the excitation current used to define the voltage response curve is pre-set at 10 µA. This is done to minimize self-heating at the lowest temperature and still maintain a good signal to noise ratio. However, a larger excitation current is desired for some applications (e.g., higher temperatures, instrumentation constraints). While it is impractical to develop a new “average” curve for a new excitation current, it is necessary to estimate the curve and the level to which the sensors remain interchangeable.

## DESCRIPTION AND TESTING

For the testing in this study, eleven DT-470-SD diodes and eleven DT-670-SD diodes from Lake Shore Cryotronics, Inc. were used.

Temperature calibrations from 2 K to 325 K were performed in the Lake Shore commercial calibration facility. Temperature was measured using standards grade platinum and germanium thermometers in conjunction with a Keithley Model 224 current source, a Hewlett Packard Model 3458 DVM, and Guildine Model 9330 standard resistors. The excitation current was varied from a minimum of 0.05 µA to a maximum of 11 mA. In total, 22 discrete excitation currents were tested.

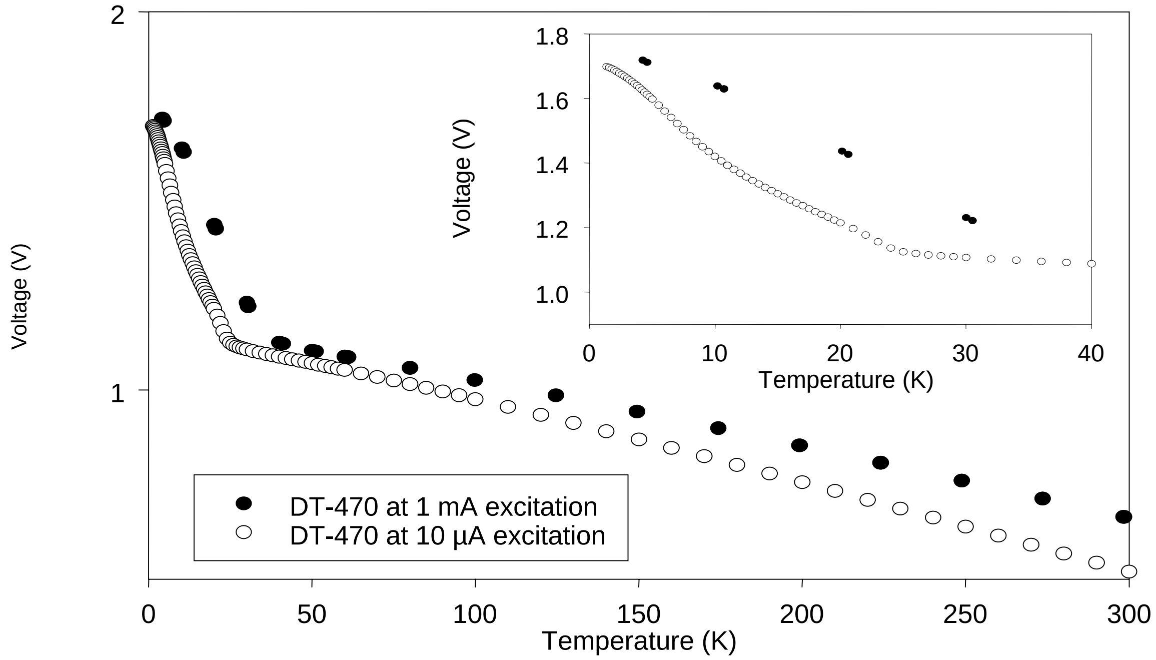


Figure 1. Voltage as a function of temperature for the DT-470 at two excitations: 10 µA and 1 mA. Inset shows detail over a narrow temperature range.

## RESULTS AND DISCUSSION

At the lowest excitation of 0.05 µA, the results showed erratic behavior. It is believed that this excitation is too low to turn on the diode. At the higher excitations—greater than 1 mA—there was obvious evidence of self-heating. The 10 mA excitation showed self-heating effects at 20 K to 30 K. For this paper, discussion is limited to comparison between 10 µA and 1 mA excitation at 4.2 K, 30 K, 79 K, and 305 K.

Voltage response curves are shown in Figure 1 and Figure 2 for the DT-470-SD and DT-670-SD, respectively. Shown are results for 10 µA and 1 mA. What is noticed is that the 'knee' region occurs at higher temperatures. The crossover region is approximately 25 K for 10 µA while it is about 35 K for 1 mA. As the excitation increases, the 'knee' region increases in temperature. Figure 3 shows the voltage verses current for a DT-670-SD at various temperatures. When examining the results at 30 K, a crossover region is observed.

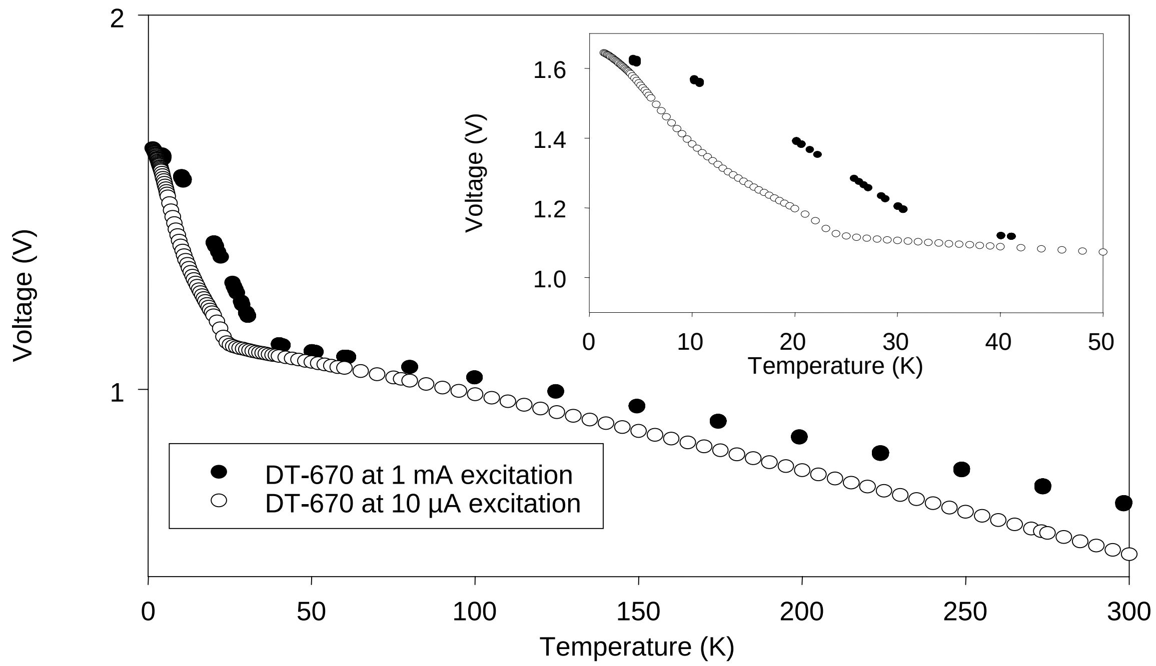


Figure 2. Voltage as a function of temperature for the DT-670 at two excitations: 10 µA and 1 mA. Inset shows detail over a narrow temperature range

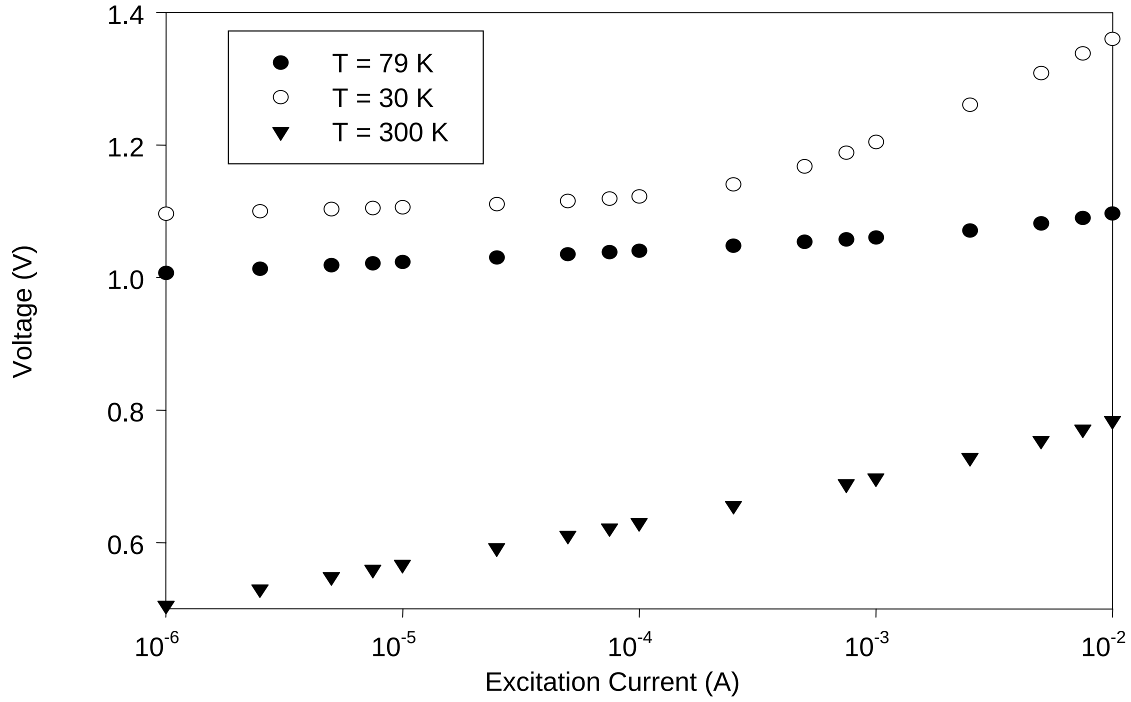


Figure 3. Voltage as function of excitation current for various temperatures. Shown is data for the DT-670.

For the lowest temperatures, there is evidence of self-heating as the sensitivity is significantly decreased at 4.2 K. For a 1 mA excitation the joule heating is 1.4 mW. Using past data for thermal resistance for the SD package at 4 K, this would correspond to a self-heating bias of more than 1 K. However, thermal resistance decreases as $T^{-3}$, and by 12 K the self-heating error is less than 0.05 K. This indicates a 1 mA excitation could be used to 10 K to 15 K without significant self-heating.

With a 1 mA excitation the DT-670-SD sensitivity from 40 K to 300 K is approximately 1.6 mV/K. This is compared to 2.03 mV/K over the same range for a 10 µA excitation. Specifically, at 79 K the sensitivity at 10 µA is 1.75 mV/K while at 1 mA it is 1.4 mV/K. Below 30 K at 1 mA the sensitivity is approximately 18 mV/K. This is slightly greater than the sensitivity with 10 µA below 20 K. This trend appears to continue to 10 K before the self-heating begins to dominate the results.

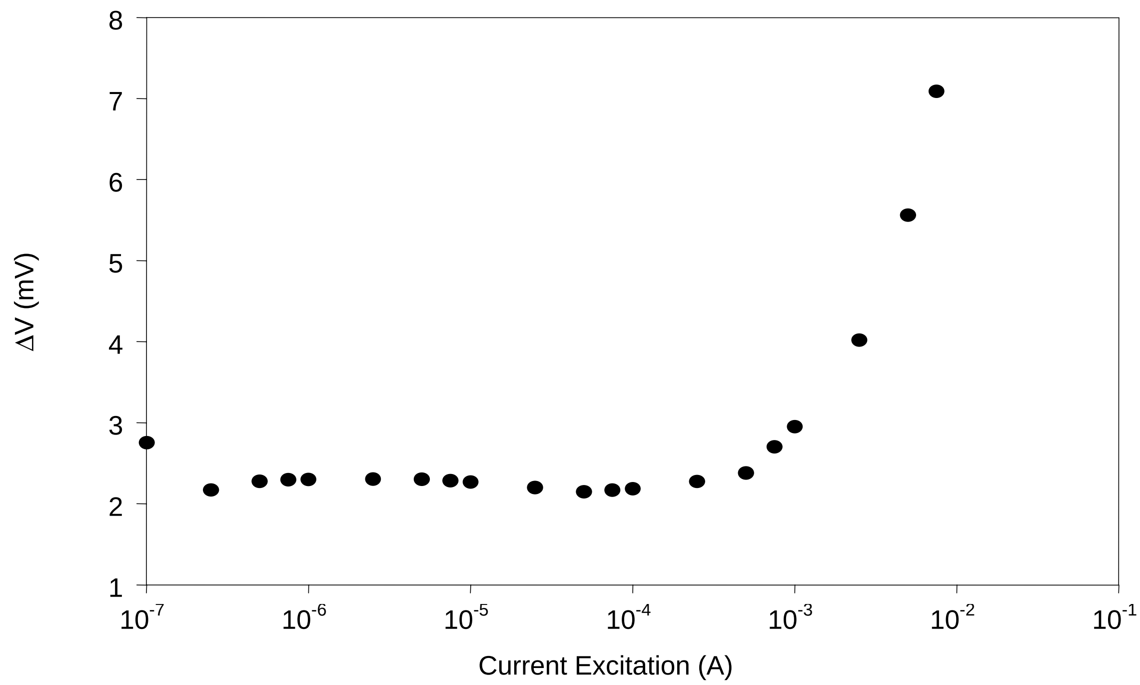


Figure 4. Difference between maximum and minimum voltage for the 11 DT-670s tested at 79 K as function of excitation.

At 10 µA and 79 K, the 11 DT-670-SDs under test had an average value of 1.0234 V at 79 K. The difference between maximum and minimum values was a spread of 0.95 mV. At 1 mA the average value was 1.0603 V with a spread of 0.768 mV. The tolerance in temperature units is about 0.5 K for both 1 mA and 1 µA. In fact, the spread between the maximum value and minimum value of the 11 DT-670-SDs is fairly uniform from the lowest excitation up to 2.5 mA. This is shown in Figure 4. Above 2.5 mA the increase can be attributed to self-heating effects biasing the results.

Similar effects are also seen in the DT-470-SD. The spread at 79 K with 10 µA is 2.26 mV while the spread at 1 mA is 2.94 mV. While the excitation changed by a factor of 100, the tolerance band of the diode only changed by 15%.

The voltage tolerance at 30 K did vary between 10 µA and 1 mA. At 10 µA the tolerance was less than 0.1 mV while at 1 mA it was 1 mV. However, the sensitivity changed from 2 mV/K at 10 µA to 18 mV/K at 1 mA. The order of magnitude change in voltage tolerance is offset by an order of magnitude increase in sensitivity. The result is that the temperature tolerance is unchanged. This is the same for the DT-470-SD at 30 K. The sensitivity increased by a factor of 10 while the voltage tolerance band increased by a nearly equal amount.

For completeness, we looked at the changes at 4.2 K. The voltage tolerance band remained relatively constant from 10 µA to 1 mA. This was seen in both DT-470-SDs and DT-670-SDs.

## CONCLUSIONS

The results of this study show that the tolerance band at 10 µA is predictive of the same tolerance at 1 mA. As expected the I-V curve and V-T curve do change with excitation but the spread, or tolerance bands, of the diodes do not change significantly. The implication is that a Lake Shore standard curve diode with a ±1 K tolerance that is defined at 10 µA will also have a tolerance of about ±1 K at 1 mA excitation. Because the 1 mA “average” curve is only defined by a few sensors, this will introduce some variation in the final temperature accuracy.

The voltage temperature response curve at 1 mA has a slightly lower sensitivity down to 40 K. However, the knee region is seen at a higher temperature than in 10 µA. This allows for the interesting option of increasing the sensitivity in the 20 K to 40 K region by using a larger excitation.

Further studies will examine the dI/dV and the voltage vs. temperature curve of other excitations. Work will continue to develop and provide a basic “average” curve at 1 mA and other excitations.

## REFERENCES


1. Lake Shore Cryotronics Inc. Westerville, OH. 43082