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A standardized diode cryogenic temperature sensor for aerospace applications

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ABSTRACT

The model DT-670-SD cryogenic diode temperature sensor, manufactured by Lake Shore Cryotronics, Inc. has been used on numerous aerospace space missions since its introduction nearly 15 years ago. While the sensing element is a diode, it is operated in a non-standard manner when used as a temperature sensor over the 1.4–500 K temperature range. For this reason, the NASA and MIL-type test and performance standards designed to ensure high reliability of diode aerospace parts don't properly define the inspection and test protocol for the DT-670-SD temperature sensor as written. This requires each aerospace application to develop unique test and inspection protocols for the project, typically for a small number of sensors, resulting in expensive sensors with a long lead time. With over 30 years of experience in supplying cryogenic temperature sensors for aerospace applications, Lake Shore has developed screening and qualification inspection and test protocols to provide "commercial off-the-shelf (COTS)" DT-670-SD temperature sensors that should meet the requirements of most high-reliability applications including aerospace. Parts from acceptance and qualified lots will be available at a base sensor level with the ability to specify an interchangeability tolerance, calibration range, mounting adaptor, and/or lead extension for final configuration. This work presents details of this acceptance and qualification inspection and test protocol as well as performance characteristics of the DT-670-SD cryogenic temperature sensors when inspected and tested to this protocol.

1. Introduction

Electronic components intended for use on aerospace missions are subjected to test protocols designed to ensure their reliability under the extreme conditions of launch and space environment. The test protocols are intended to simulate or exceed the expected conditions encountered by the component during the mission. The test protocols and specific test details have been documented for many electrical/electronic component types in NASA, MIL-PRFs, and MIL-STD documents for the purpose of providing a common reference for both NASA and its subcontractors [1–5]. This procedure generally works well, but complications arise when the component type is not addressed in these defined test protocols, as is the case with cryogenic temperature sensors.

This work addresses the development of a standardized aerospace acceptance and qualification test protocol for the Lake Shore Cryotronics, Inc.'s [6] diode temperature sensor (DTS) model DT-670-SD [7] with the end goal of making available a commercial off-the-shelf (COTS) diode temperature sensor suitable for aerospace use.

2. Materials and methods

2.1. Background

Lake Shore Cryotronics, Inc. (Lake Shore) has supplied cryogenic temperature sensors for aerospace applications for over thirty years. During this time frame, however, no standard test protocol from NASA or the Department of Defense has addressed the acceptance or qualification test protocols for these device types. While the most common cryogenic temperature sensors are either resistive or diode in nature, they are operated in a nontraditional manner when used as temperature sensors making the standard resistor or diode test protocols inappropriate for their acceptance and qualification. This lack of a proper test protocol for cryogenic temperature sensors has resulted in turning every procurement into a long and costly endeavor. Customer source inspections require each production lot to be built from beginning and qualification testing completed.

In 2013, Lake Shore worked with NASA and other aerospace contractors to develop a suitable test protocol for the Cernox™ family of cryogenic temperature sensors (CxRTs) to ensure their

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reliability for aerospace use [8]. The test protocol resulting from this collaboration allowed the manufacture of a large production lot of CxRT devices to the specified protocol defining both lot screening and qualification testing. Parts were built and stocked at the base part level while still allowing final configuration (adaptor, lead modification, calibration, etc.) to be specified at time of delivery. This current body of work will lead to development of a similar test protocol for diodes used as cryogenic temperature sensors.

2.2. Sensor selection and properties

Beginning in 2013, a test protocol was first developed for CxRTs because they generally provide superior performance as cryogenic temperature sensors when compared to diodes. CxRT resistance–temperature characteristic can be tailored to maximize performance over various temperature ranges and their high sensitivity allows for sub-millikelvin resolution with absolute temperature uncertainties on the order of tens of millikelvins. CxRTs perform well in magnetic fields, are radiation hard, and typically require less excitation power during measurement. On the other hand, CxRTs are not interchangeable, so they normally require individual calibration, and their wide resistance range typically requires more sophisticated electronics that can scale the current excitation in order to maintain a reasonable signal while avoiding self-heating at colder temperatures or loss of resolution at higher temperatures.

In aerospace applications where stability is important but the absolute temperature accuracy can be relaxed, the model DT-670-SD can provide a cost effective alternative due to their interchangeability to a standard curve and their simpler instrumentation for operation. A discussion of the DT-670-SD properties is given in the following section.

2.3. Model DT-670-SD properties

The DT-600 series die chip is a transistor operated as diode using the base-to-collector p–n junction. The bare die nominally measures 0.406 mm long × 0.432 mm wide × 0.178 mm thick as shown in Fig. 1. The chip is a through-the-body device with a metallized bottom side forming the collector electrical connection and two metallized bond pads on the top side for the emitter and base electrical connections. To provide a robust sensor, the die chips are packaged in Lake Shore's SD package [7]. This package is a flat, hermetically sealed package specially designed for cryogenic thermometry providing a highly efficient thermal connection between internally mounted temperature sensing die chips and the outside world. Construction wise, the package consists of a sapphire base with alumina body and top. All materials are low outgassing and compatible with a 1–500 K temperature range. A top and side view of the SD package with dimensions are shown in Figs. 2 and 3, respectively, while a cutaway side view is shown in Fig. 4. The overall body dimensions are 1.9 mm wide × 3.2 mm long × 1.0 mm high with a small total mass less than 37 mg.

Within the cavity of the package, the DT-600 series die chip is metallurgically bonded to a metallized pad directly on top of the sapphire substrate package base using a gold–silicon eutectic. The metallurgical die attach provides a high mechanical strength interface that far exceeds the minimum die shear strengths required by MIL-STDs for the given die size and die attach area. The DT-600 die chip bottom also serves as the collector electrical connection and the metallized pad to which the die chip is eutectically bonded is connected to an electrical feedthrough that then connects to an external package bond pad. For the connection to the transistor base, a 25 μm diameter gold wire is bonded from base bond pad on the top side of the chip to an internal package bond pad/metallized feedthrough trace which then connects to an external package bond pad. Externally, a flat 0.38 mm wide × 0.1 mm thick × 20 mm long Kovar lead, is brazed to each of the two external package bond pads. The package lid is attached via a gold-tin eutectic solder preform using a commercial sealing oven to form the hermetic seal. The SD package top and bottom are both metallized and the lot date code and serial number scribed into the metallization.

The resulting DT-670-SD sensor can be used over the 1.4–500 K temperature range. In practice, the device is operated at a constant forward current of 10 μA and the output signal is measured as the forward voltage drop, which is a strong function of temperature. The model DT-670-SD temperature sensor's typical voltage and sensitivity response curves are shown in Figs. 5 and 6, respectively. The devices within the series are sufficiently uniform that all devices are interchangeable to a standard response curve. The devices are grouped into tolerance bands ranging from ±0.25 K to

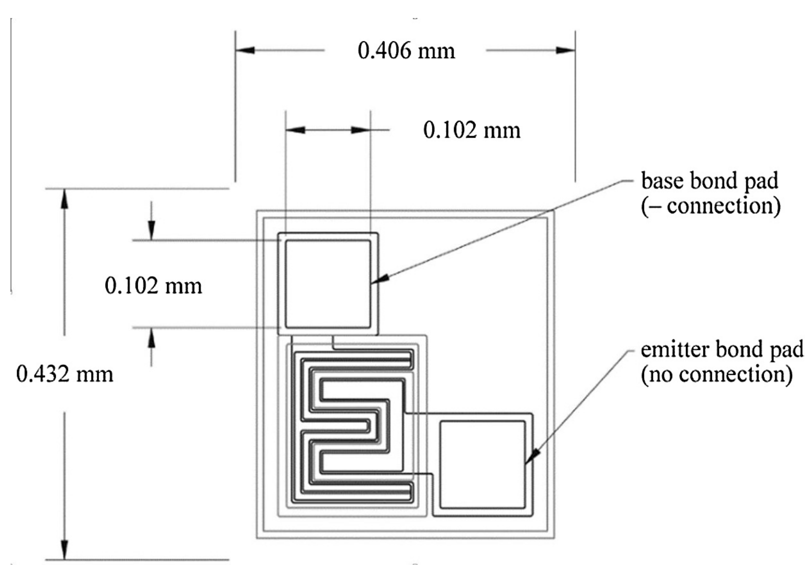

Fig. 1. DT-670 diode temperature bare chip size and dimensions. The die is approximately 0.178 mm thick. Electrical connection is made from the base to the collector on the bottom side of the die chip.