TESTING AND CHARACTERIZATIONS OF INFRARED SENSORS OVER THE TEMPERATURE RANGE OF 2 KELVIN TO 300 KELVIN

Robert G. Hansen

R. G. Hansen & Associates
1324 "C" State Street
Santa Barbara, CA 93101

ABSTRACT

To properly evaluate "state-of-the-art" electro-optic devices in a timely and convenient manner, various cryogenic techniques have been employed. As research, development, and production demands require more sensitive testing techniques, faster test results, and higher production through-put, the emphasis on supporting cryogenic systems increases.

This presentation discusses the three traditional methods currently utilized in electro-optic device testing, those being:

(1) liquid containment dewars
(2) liquid transfer systems
(3) closed cycle refrigeration systems.

Advantages, disadvantages, and the current "state-of-the-art" of each of these cryogenic techniques is discussed.

INTRODUCTION

With continued emphasis on the use of passive infrared sensors for both military and commercial applications, the need to evaluate semiconductor materials and devices through the various stages of material development, device testing and ultimate system checkout has placed considerable emphasis on the cryogenic aspects of device testing. Since the latter part of the 1960s, sensing systems have changed from active to passive techniques. Detecting techniques such as radar, microwave, acoustic and visual sensors have given way to "state-of-the-art" infrared semiconducting materials. As longer wavelength sensors are developed, the need for lower cryogenic temperatures has advanced the technical disipline of cryogenics in order to keep abreast with advancements in detector materials, semiconductor processing and electro-optic systems design.

As technology entered into the 1970s, detector materials such as doped germanium and doped silicon sensors required cryogenic systems capable of achieving and maintaining temperatures in the sub-20 Kelvin region. Through Federally sponsored research and development programs supporting end-use cryogenic refrigeration systems were developed. Recently, however, emphasis is being placed on the ability to rapidly test, evaluate, select, integrate and finally test electro-optic systems of varying complexities over the temperature range 2K to 300K. The purpose of this presentation is to discuss the various cryogenic cooling techniques along with their advantages and disadvantages. Although hybrid systems comprising various cryogenic techniques have been developed, this paper will confine itself to the more traditional techniques:

(1) pour-fill type dewars
(2) liquid cryogenic transfer systems
(3) closed cycle cryogenic refrigeration systems.

DEWARS FOR ELECTRO-OPTIC DEVICE TESTING

Dewars, since first constructed by the Scottish chemist James Dewar (1842-1923), have changed little since their introduction in 1892. Dewars are designed to provide a means of conductively cooling samples by mounting them on the inner vacuum well of the storage dewar which is under an insulating vacuum. While working at liquid nitrogen temperatures, from 77K to 300K, dewars are not only convenient, but also the preferred method for evaluating devices in a conductively cooled cryogenic state. To use liquid containment storage dewars for testing below 77K presents problems of convenience and temperature stability. Conveniently speaking, the most commonly used cryogen employed to cool devices below 77K is liquid helium. In order to achieve dewar cooldown one must first precool the dewar flask with liquid nitrogen and then perform the liquid helium transfer via a siphon from the primary vacuum storage dewar to the research or test dewar. Once achieved, one experiences difficulty in achieving temperature controllability above 4.2K unless a thermal balance or heat station is designed with an appropriate heater circuit and cryogenic feedback sensor. An additional problem arises with the restricted orientation of liquid containment dewars. One may use them in either end-looking or side-looking configurations but each dewar is limited to its inherent design.

In recent years, multi-element infrared arrays have been traditionally tested by the use of rather sophisticated liquid containment dewars. Typically, test cycle times with traditional dewars resulted in the ability to test one or two devices per day at helium temperatures thereby restricting the production of electro-optic systems requiring helium temperatures.

In addition to problems associated with long test sequences was the inherent low yield factor on "state-of-the-art" electro-optic devices. The need arose to pre-test or evaluate semiconductor devices as early in their production cycle as possible so as to increase ultimate yield. Cryogenic testing on a rapid turnaround cycle was mandatory and, in most cases, dewars would not meet the demands.

LIQUID CRYOGENIC TRANSFER SYSTEM

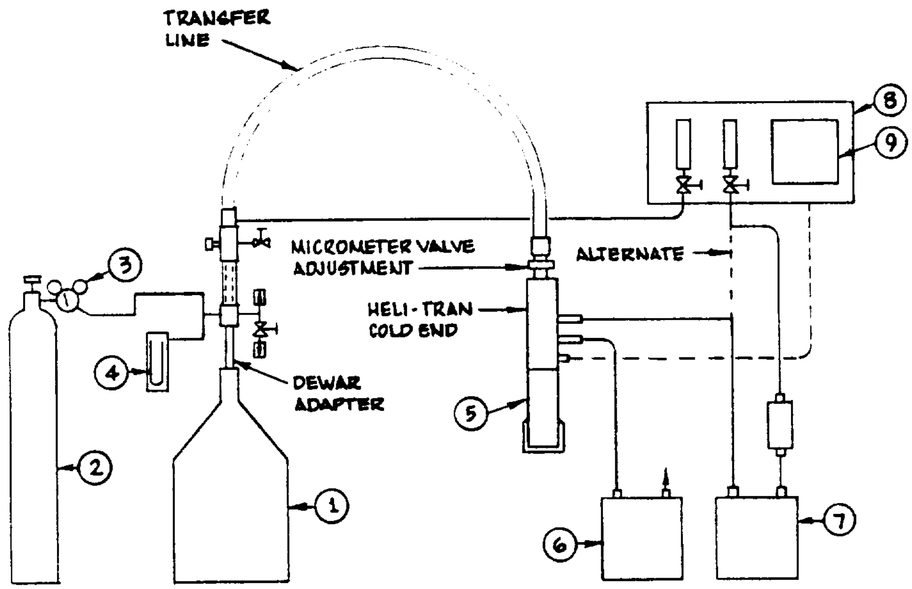
Recognizing the inherent difficulties with conventional dewars, a series of liquid transfer systems was developed which employed the technique of direct transfer of cryogenic fluids from their storage dewars to cryogenic heat sinks or cold stations. These systems were designed to utilize very small flows of cryogen which allowed the user to integrate cryogenic sensors and heating circuits to rapidly and conveniently achieve temperature excursion from room temperature to helium temperature and in between with ease, convenience, and accuracy. The first such system developed in this country was the Heli-Tran^R designed and manufactured by the Advanced Products Department of Air Products and Chemicals, Inc. This system allowed the user to operate in any orientation, i.e.: end-looking, side-looking, horizontal, vertical, et cetera, without the fear of costly and dangerous cryogenic spills. By using the helium transfer systems, manual temperature stabilities of ±0.01K are achievable from 2-20K, ±0.1K from 20-77K and greater than ±0.3K from 77-300K. Through implementation of automatic temperature controllers, stability factors of ±0.01K can be achieved from 2-300K.

An additional feature responsible for the wide acceptance of the Heli-Tran^R was the rapid cooldown from ambient temperature to 4.2K in less than 20 minutes time. Liquid helium consumption rates of approximately 0.75 liters per hour at 4.2K with corresponding refrigeration capability of several hundred milliwatts is easily achieved. For requirements demanding higher refrigeration capacity, liquid transfer of up to three liquid liters per hour of helium can be provided with a corrsponding refrigeration capacity of two watts of refrigeration at 4.2K.

The schematic on the following page illustrates a typical liquid transfer system in a basic configuration. (Diagram A)

In the mid-1970s, requirements for infrared device testing of multi-element arrays necessitating up to 260 individual feedthroughs required the design of specially modified liquid transfer systems. Developments such as ribbon cable technology, microphonic dampening techniques, rapid cycling and ease of handling resulted in the further dependence of the electro-optic industry on the modified liquid transfer systems.

With the recent breakthroughs in CCD and CID devices, a demand was created for a low noise infrared device test station which could serve as an industry standard. A system was needed that would standardize on air industry accepted device carriers, exhibit low noise characteristics, have a minimum of 68 coaxial feedthroughs, cycle times of from 300K to 4.2K to 300K of one hour or less. Additionally, supporting temperature indication and control was required which provided computer interface and addressability.



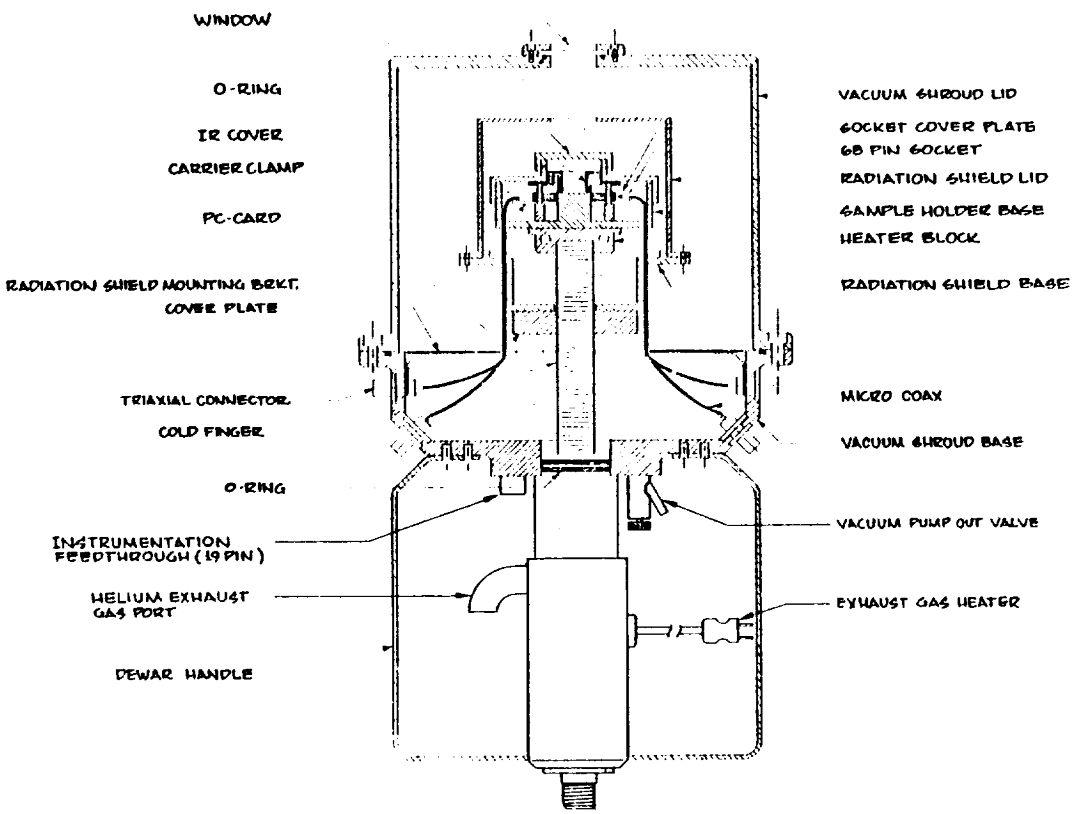
1. HELIUM DEWAR
2. HELIUM CYLINDER
3. PRESSURE REGULATER
4. MERCURY MANOMETER, 0 TO 20" Hg OR PRESSURE GAUGE ON HELIUM DEWAR
5. VACUUM SHROUD
6. VACUUM SHROUD PUMP
7. VACUUM PUMP FOR OPERATION BELOW 4.2°K
8. ACCESSORY FLOW CONTROL PANEL
9. ACCESSORY TEMPERATURE CONTROLLER, MANUAL OR AUTOMATIC

TYPICAL LIQUID TRANSFER SYSTEM

(Diagram A)

To satisfy these needs we developed a modified liquid transfer system which we believe is the answer to not only today's cryogenic device testing, but also meets the needs of the future.

The following interface outline depicts the salient features of our modified liquid transfer system. (Diagram B - 68-Pin Leadless Carrier Infrared Device Test Dewar).



68 PIN LEADLESS CARRIER
INFRARED DEVICE TEST DEWAR
(2-300 KELVIN-CONTROLLABLE)

(Diagram B)

CLOSED CYCLE REFRIGERATION SYSTEMS

Although liquid transfer systems provide the necessary refrigeration stability for electro-optic device testing, the use of closed cycle refrigeration systems to perform device cooling over the temperature range of 10K to 300K is gaining wide acceptance. Although several manufacturers supply closed cycle refrigeration systems, each capable of achieving 0.250 watts of refrigeration at 10K, several distinct advantages have been realized by utilizing a pneumatically balanced, nonmechanically driven displacer design.

In testing sophisticated infrared arrays, charge couple devices and, in some cases, even individual detectors, the problem of microphonics is usually associated with mechanical refrigerators. This microphonics, being a generic term, defines two major constituents, i.e.: linear displacement and thermophonics. As the closed cycle refrigeration systems perform their work cycle a very minute temperature cycle is generated which can alter the performance of sensitive electro-optic devices. Furthermore, linear displacement produced by the traveling mass of the displacer generates signals which can interfere with the desired sensing signal. In recent years this problem has been virtually eliminated by the incorporation of a lead attenuator on the base of the refrigerator, incorporation of a microphonic dampener or the unbalancing of the refrigerator's cold head by reducing the differential pressure between the inlet supply and return flow of helium. This latter technique is also an accepted technique for determining the threshhold level for acceptable microphonic levels in "noise" sensitive electro-optical systems driven by mechanical refrigerators.

The closed cycle refrigeration concept of detector device cooling offers similar advantages to the liquid transfer technique. The system may be operated in any orientation, may be left unattended for long periods of time, exhibits a meantime before maintenance interval of approximately 10,000 hours and requires no consummable cryogens to perform its cooling function.

Although the initial cost for a closed cycle refrigeration system is approximately twice that of a liquid transfer system or four times that of a conventional storage dewar, we are finding that more and more "state-of-the-art" detector development programs are using this technique. At the present time, the advent of closed cycle refrigerators into cryopumping technology has substantially increased inherent reliability of the systems as well as contributed greatly to the reduction of their price based on larger manufacturing throughput.

At the present time our firm is undergoing an internal development program whereby a 68-pin leadless carrier closed cycle refrigeration system is being developed which should provide device turnaround from 300K to 10K to 300K in less than one hour's timespan. Through the integration of this system with programmable temperature indicator/controllers, we believe that several test stations can be run in parallel which would allow a single operator to support and control multiple closed cycle cryogenic test stations.

An additional subcategory to closed cycle refrigeration systems is the single stage configuration of a closed cycle expansion module. By the elimination of the second stage of a two-stage expander one achieves rapid cooldown, higher refrigeration capacities, and the ability to perform device cooling over the temperature range of 40K to 300K. Depending on required capacities, various single stage refrigeration systems are available to provide approximately one watt of refrigeration at 77K or, in some instances, approximately 100 milliwatts at 77K a series of commercially available rather inexpensive refrigeration systems have been developed which provides many of the advantages of end-use cryogenic military systems.

For example, the single stage Air Products and Chemicals' Displex^R Model CS 1003 was recently integrated into a calibration laboratory to provide the cooling of a common module FLIR device. Although the specification for the end system is a refrigerator with a lifetime of approximately 1,000 hours, this particular system can be operated at lower noise levels, lower temperature, rapid cooldown and may be conveniently operated for 12,000 hours prior to maintenance interval. Associated cost with such a system is approximately comparable to that of a military cryogenic cooler yet provides a factor of 25 in the system's ultimate lifetime.

SUMMARY

In summarizing this presentation, we believe that many advancements have been made in the field of cryogenics over the last ten (10) years as a result of the industry's demand for highly reliable, rapid cooldown systems which may be conveniently operated by both skilled and unskilled test technicians.

With the rapid advancement of charge couple devices (CCDs), further progress will be made in the immediate future.