Modular Cryogenic System for Radiation-Hardened Device Testing

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***Abstract*—Electronic devices are susceptible to enhanced degradation in cryogenic and radiation environments like space. To ensure reliable performance at low temperatures, the IRLabs Rigel Dewar system was developed. This characterization method enables data collection on total ionizing dose (TID) effects from 300K to 77K, utilizing liquid nitrogen cooling, while temperatures other than 77K can be reached by using other cryogens. Its modular design allows customization for various device packages, including leadless chip carriers (LCC) and dual in-line packages (DIP). The system interfaces with a Keysight B1500A parameter analyzer, supporting both standard DC and custom noise characterization tests. Initial results demonstrate the system's effectiveness in capturing TID-induced degradation trends in a cryogenic environment, with an excellent signal to noise ratio allowing for precise DC and low frequency noise testing. These features make it suitable for advanced dosimetry and the analysis of radiation-induced traps in field-effect transistors.**

Keywords—Characterization, Cryogenic, Total ionizing dose, RADFET, Signal to Noise Ratio, Random Telegraph Signals

I. INTRODUCTION

As the space industry continues to grow, companies are investing heavily in technology that can withstand the harsh radiation environment that exists in space. Devices must be specifically designed to mitigate radiation-induced effects like total ionizing dose (TID) effects, single event effects (SEE), and displacement damage. These effects can damage electronics in space and other environments, leading to degraded performance, data corruption, or even functional destruction [1, 7].

Radiation is not the only challenge faced by space-bound electronics. Many applications, particularly those in deep-space exploration, require electronics to operate reliably at cryogenic temperatures. For example, temperatures as low as 40K may be encountered in missions to the outer planets or in certain spacecraft like the James Webb Telescope [2]. These combined environmental stressors—high radiation levels and extremely low temperatures—pose significant risks to device functionality and reliability. Without robust testing methods that replicate these conditions, it becomes impossible to fully understand the critical performance metrics of radiation-tolerant devices, such as their electrical stability, degradation mechanisms, and overall reliability.

In order to ensure proper performance of electronic components in extreme temperature and radiation environments, specialized device characterization systems must be built to simulate these harsh environments, terrestrially. However, most methods fail to emulate the combination of cryogenic temperatures and radiation environments thus limiting their ability to fully replicate the operational conditions faced by these parts in space [3]. It is important to have testing environments that mimic these extreme conditions so critical performance metrics can be quantified.

Fig. 1. Rigel dewar from I.R. Labs in Tucson AZ. The side profile of the dewar shows how compact it is as well as some location calibration marks. The front view (right side of picture) shows the cold finger as well as the temperature sensor.

To address this need, IRLabs has developed the Rigel Dewar system, shown in Fig. 1. This system makes it possible to do irradiation at cryogenic temperatures with a focus on modularity and versatility. This system utilizes custom printed circuit boards (PCBs) to interface with the device within the dewar allowing for in-situ characterization at cryogenic temperatures. By combining cryogenic cooling with customizable testing capabilities, the Rigel dewar system offers a unique solution to the challenges of space electronics testing. The authors would like to acknowledge IRLabs for their contribution in designing and providing the physical dewar, which forms the backbone of this system. Thanks to this collaboration and the system's adaptability, a myriad of device packages can be accommodated and designed around, ensuring broad compatibility and use.

II. Test System Discussion

Two critical design principles for the system were portability and versatility. Thanks to the compact size and light weight of the Rigel dewar, it is easy to mount the entire setup—including the B1500 Parameter Analyzer and switching matrix—onto a mobile cart. This mobility allows for quick reconfiguration and deployment in different laboratories and workspaces, making it well-suited for shared or space-constrained facilities. The dewar can maintain cryogenic temperatures for approximately twelve hours. This extended hold time eliminates the need for a continuous vacuum pump or intermittent liquid nitrogen refills during standard testing periods, reducing both operational complexity and maintenance requirements.

The modular design of the Rigel dewar system allows for adaptation to various device configurations. Two 41-pin mil-spec connectors located at the rear of the Rigel transmit signals to the external environment through six 2.54mm IDC connectors. These serve the input and output needs of the entire system. This modular interface supports flexibility in testing, as custom PCBs designed with these connectors can seamlessly integrate with the Rigel system. Internally, the PCB uses two 40-pin ribbon cable connectors to transmit signals from the device under test to the mil-spec connectors, ensuring reliable data transfer during characterization. This adaptability enables the system to accommodate a wide range of device packages, such as leadless chip carriers (LCC) and dual in-line packages (DIP), further enhancing its utility in diverse testing scenarios.

While the Rigel dewar is the central feature of a system that maintains cryogenic temperatures for extended periods, the supporting equipment plays a vital role in enabling accurate and efficient device characterization. Shown in Fig. 2 is a flowchart detailing the setup and usage of the system. The system uses a Keysight B1500A Parameter Analyzer, which allows for the development of custom characterization programs to collect device parameters within specific manufacturer-defined limits. This flexibility makes it possible to tailor testing conditions to individual devices, ensuring both accuracy and compliance with device specifications. Additionally, the B1500 supports importing existing workspaces tailored to specific devices, facilitating seamless integration with previously developed setups and reducing the time required to configure new experiments [4].

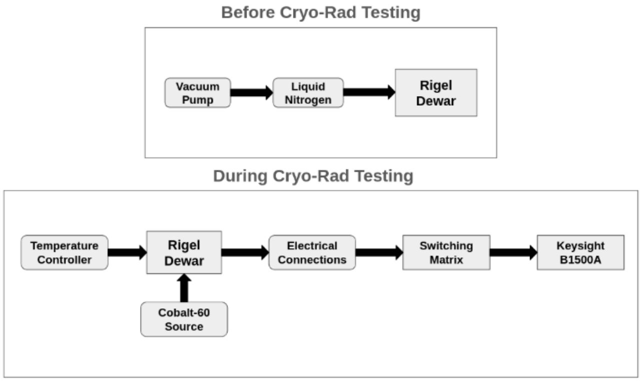

Fig. 2. Flowchart of Rigel DSTAT setup

To minimize noise and improve device yields during testing, a programmable switching matrix was developed to interface with the B1500 via GPIB commands. This switching matrix sends commands to connect and disconnect specific coaxial terminals after each individual device completes testing. This capability is especially valuable for highly delicate devices, as it eliminates the need for manual intervention, which can introduce noise or risk physical damage. The system's automated switching also supports batch testing of multiple transistors or devices in a single session, significantly improving efficiency. Moreover, the system supports remote operation, allowing users to control and monitor the system from a distance once it is fully configured. This feature not only streamlines the testing process but also enhances usability for researchers working in controlled environments or remotely accessing laboratory facilities.

Fig. 3. System preparation before beginning cryo-rad testing

To begin cryo-rad testing, the Rigel dewar must first be evacuated and filled with liquid nitrogen. This process is accomplished using an Agilent TPS-mini Turbo Pumping System, which is connected to the Rigel dewar as seen in Fig. 3. This vacuum pump can reduce the internal pressure to below 10^{-5} mbar. Achieving this vacuum level ensures improved thermal conductivity between the liquid nitrogen and the cold finger that contacts the devices, while also preventing condensation from forming within the dewar. Once the interior reaches the desired pressure, around $4x10^{-4}$ mbar, liquid nitrogen is introduced into the Rigel dewar. The system is then sealed with a top plate, allowing for safe placement within ASU's Shepherd ^{60}Co radiation source—seen in Fig. 4—while ensuring proper ventilation for evaporated nitrogen gas outside the radiation source chamber.

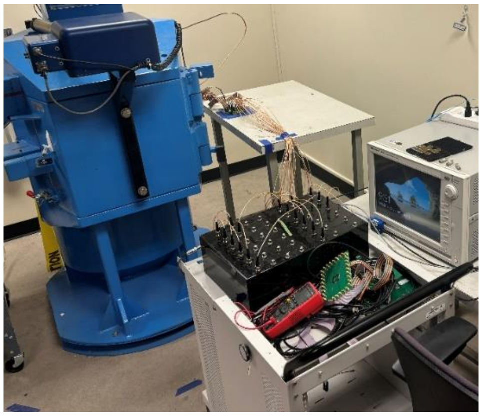

Fig. 4. Full system during cryo-rad testing. The Rigel dewar is enclosed within the radiation source's chamber

III. SYSTEM RESULTS

Some of the most critical aspects of this system are its high signal-to-noise ratio (SNR) and its ability to support low current testing applications. To evaluate these capabilities, a radiation sensing field-effect transistor (RADFET) was tested within the system. While the RADFET was irradiated, its threshold voltage shifted in direct proportion to the absorbed radiation dose, enabling highly accurate real-time dosimetry measurements [5, 8]. These shifts enabled precise measurements of the total ionizing dose (TID) effects under cryogenic conditions, providing valuable insights into device behavior at extreme temperatures.

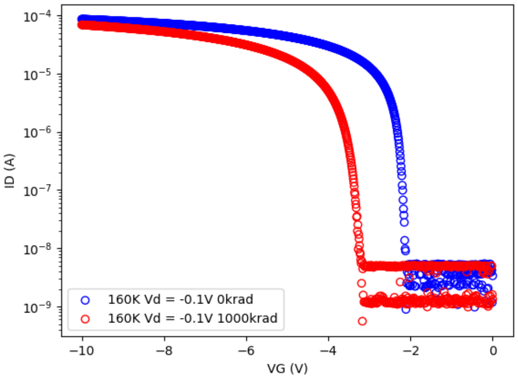

Fig. 5. IV Sweep of RADFET pre and post radiation at cryogenic temperatures. During sweep, V_d = -0.1V and V_g swept from 0.5V - -10V. Test was conducted at 160K.

As shown in Fig. 5, a RADFET's current voltage characteristics were recorded before irradiation and after a cumulative dose of 1 Mrad (SiO_2). The system consistently delivered low-resistance measurements at cryogenic temperatures, with this specific experiment performed at 160K. Additionally, the system achieved stable current measurements as low as two picoamps, indicating excellent noise performance and sensitivity. These low-current capabilities are crucial for characterizing radiation-induced traps and other subtle effects that require a low-noise environment.

One of the key tests conducted with the system was random telegraph signal (RTS) testing, which is critical for identifying traps in field-effect transistors. RTS noise appears as discrete, step-like fluctuations in current caused by the capture and emission of charge carriers at defect sites within the semiconductor material [6]. The system's low series resistance and high SNR made it particularly well-suited for this application, enabling the detection of individual trap states and their associated energy levels. This type of testing is essential for understanding the impact of radiation on device performance, particularly in radiation-sensitive applications like analog front-ends and read-out ICs (ROICs).

Beyond RADFETs, additional tests were conducted on other MOSFETs to evaluate the versatility of the Rigel dewar system. These tests revealed consistent performance across a variety of device technologies (e.g. advanced CMOS, RRAM), confirming the system's adaptability and reliability in accommodating different device configurations. Notably, the system maintained its low noise floor and stable measurements, even when testing devices with varying current ranges and structural complexities.

The thermal stability of the Rigel dewar system also played a critical role in the accuracy of these tests. By maintaining cryogenic temperatures for extended periods, the system minimized thermal fluctuations that could otherwise introduce noise or measurement errors. This stability was particularly beneficial for long-duration tests, such as those required for cumulative radiation dose measurements, where consistent conditions are essential for reliable data collection.

In summary, the results confirm that the Rigel dewar system is capable of meeting the stringent demands of cryo-rad testing. Its combination of high SNR, low noise floor, and thermal stability makes it a powerful tool for real-time dosimetry and advanced device characterization. Future work will focus on expanding these capabilities to include a wider temperature range and integrating additional measurement instruments to further enhance the system's utility.

IV. CONCLUSION

With the increasing need to ensure the reliability of radiation-hardened electronics in extreme environments, the IRLabs Rigel dewar system sets a new standard for cryogenic radiation-hardened device characterization. Supporting accurate testing from 300K to 77K, its small form factor enables the capability to simulate harsh space environments with ASU's Shepherd ^{60}Co radiation source. Testing with RADFETs and other transistors demonstrated precise, low-noise measurements, excellent SNR, and stable current readings down to two picoamps. Its capability for RTS testing underscores its utility for detecting radiation-induced traps and studying TID effects. The system's modular design supports diverse configurations, while its portability and thermal stability ensure reliable, long-duration experiments. Planned improvements, including a smaller form factor, lower temperature capabilities, and increased automation, will further enhance its versatility. The Rigel dewar system offers a robust, adaptable platform for advancing radiation-hardened electronics testing, ensuring their reliability in extreme conditions.

REFERENCES

[1] A. H. Johnston, “Radiation effects in advanced microelectronics technologies,” IEEE Transactions on Nuclear Science, vol. 45, no. 3, pp. 1339–1354, Jun. 1998

[2] M. T. Menzel *et al.*, “The Design, Verification, and Performance of the James Webb Space Telescope,” *Publications of the Astronomical Society of the Pacific*, vol. 135, no. 1047, pp. 058002–058002, May 2023, doi: https://doi.org/10.1088/1538-3873/acbb9f.

[3] M. Citterio, S. Rescia, and V. Radeka, “Radiation effects at cryogenic temperatures in Si-JFET, GaAs MESFET, and MOSFET devices,” IEEE Transactions on Nuclear Science, vol. 42, no. 6, pp. 2266–2270, Dec. 1995

[4] Keysight EasyEXPERT Software User’s Guide Edition 5 Volume 1

[5] M. M. Pejović, “Dose response, radiation sensitivity and signal fading of p-channel MOSFETs (RADFETs) irradiated up to 50 Gy with 60Co,” Applied Radiation and Isotopes, vol. 104, pp. 100–105, Oct. 2015

[6] Francesco Maria Puglisi and P. Pavan, “Guidelines for a Reliable Analysis of Random Telegraph Noise in Electronic Devices,” IEEE Transactions on Instrumentation and Measurement, vol. 65, no. 6, pp. 1435–1442, Jun. 2016.

[7] R. Keller, B. Sierawski, and R. Schrimpf, “Total Ionizing Dose Effects in Silicon Bulk FinFETs at Cryogenic Temperatures,” 2017. Accessed: Sep. 1, 2024

[8] Varadis, "TECHNICAL DATA VT06 100nm RADFET in 8L Side Braze Ceramic package For doses between 1Gy (100rad) and 10kGy (1Mrad)," Revision 2.3, June 2024