IRHC9Ax160 - SEE Test Report

SEE Test – R9, 100V, N-channel MOSFET, Die size 6 - VIH

About this document

Scope and purpose

This document describes the heavy-ion Single Event Effects (SEE) radiation tests and results for International Rectifier HiRel Products, Inc. 100V, R9, Die Size 6, N-channel power MOSFET. The part numbers validated based on these tests are: IRHNS9A7160, JANSR2N7653U2A, IRHNS9A3160, and JANSF2N7653U2A.

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Intended audience.

This document is intended for customers seeking to understand the radiation tests performed on power MOSFETs.

Summary of results

IRHC9Ax160 devices were irradiated to heavy-ion Single Event Effect (SEE) using the ion source K500 Cyclotron at Texas A&M University (TAMU). Irradiation was performed at a target fluence of 3×10^5 ions/cm^2 and a flux of 2×10^4 ions/cm^2/s. The ion beam parameters utilized during testing, along with the corresponding SEE performance results, are summarized in figure 1. The product performance demonstrates its suitability for use in space applications.

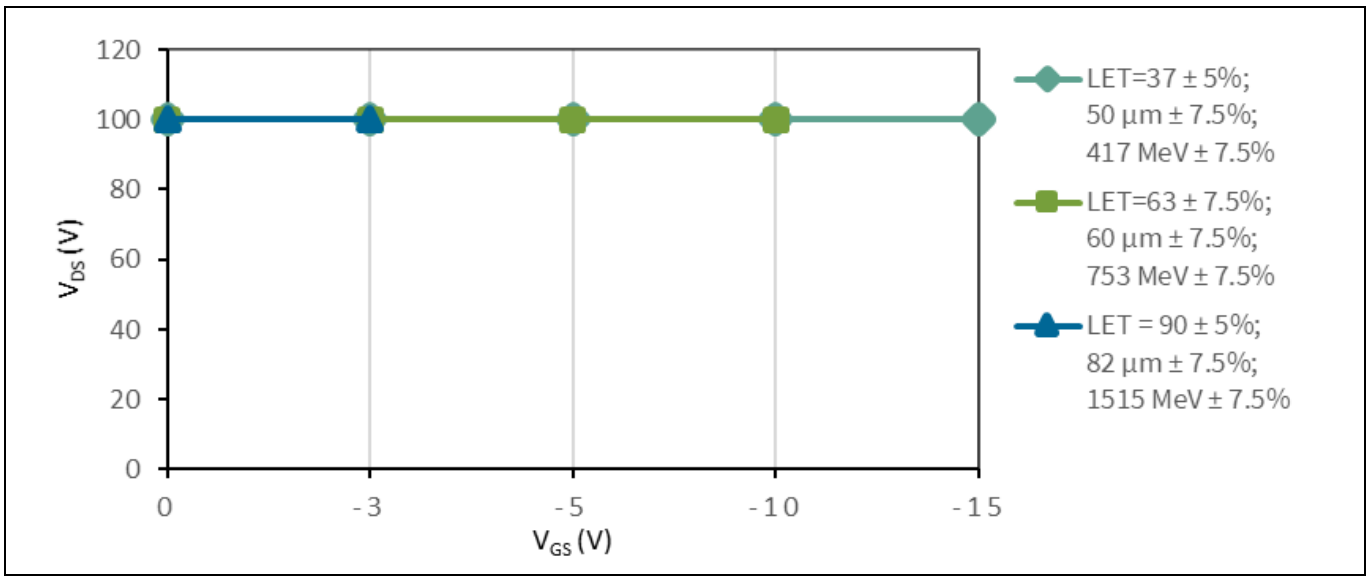

Figure 1 **Typical SEE-SOA of IRHC9Ax160**

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1 Device Description

The IRHC9Ax160 is an N-Channel rad hard MOSFET for space applications. The MOSFET is designed using the R9 technology platform. The device is a Superjunction technology MOSFET and is intended for use in applications such as DC-DC converter, motor drives, etc. It is rated at 100V BV_{DSS} and the dimension of bare die is approximately 6.858mm x 9.393mm. The 100V design architecture has been qualified for the given die size.

Table 1 Device Characteristics

Device	Generation	Channel	BV_{DSS}	$I_{D(max)}$ [1]	$R_{DS(on)}$ [1]	$Q_{g(max)}$ [1]	Die Size	Package
IRHNS9A7160 JANSR2N7653U2A	R9	N	100V	100A	6.5mΩ	195nC	6.858x9.393 (mmxmm)	SupIR-SMD™
IRHNS9A3160 JANSF2N7653U2A	R9	N	100V	100A	6.5mΩ	195nC	6.858x9.393 (mmxmm)	SupIR-SMD™

1.1 Reference Documents

Datasheet: IRHNS9A7160, JANSR2N7653U2A, IRHNS9A3160, JANSF2N7653U2A.
Standard(s): MIL-PRF-19500 - TM1080, JESD57A.
IR HiRel Radiation Test Methodology: B119-I1318-V1-7600-NA-EC

1.2 Device Preparations

All test samples were subjected to electrical characterization to verify nominal performance across key parameters, including BV_{DSS}, $V_{gs(th)}$, $R_{DS(ON)}$, V_{SD}, I_{DSS}, I_{GSS} (shown in Table 3) prior to arrival at the radiation testing facility. The samples were assembled in TO-3 packages using aluminum wire bonding and left without a lid, ensuring direct exposure of the die surface to the heavy-ion beam during irradiation testing.

[1]Refer to datasheet for test conditions and typical values

2 Single-Event Effects (SEE) Test Overview

2.1 Test Objectives

The goal of this SEE testing is to establish that the IRHC9Ax160 material is capable of withstanding exposure to various heavy ions and determine the threshold LET (linear energy transfer) required to cause a single ion-induced failure under bias conditions. Heavy-ion radiation tests for SEE characterization were performed at Cyclotron Institute, Texas A&M University using the K500 Superconducting Cyclotron.

Table 2 Overview of SEE tests – Worst-Case Beam Conditions

Run No.	Ion	Air gap [cm]	Beam Energy [MeV]	LET [MeV·cm²/mg]	Range [µm]	Fluence [ions/cm²]	Test Date	Wafer Lot (SEEID)
1118 – 1128 1129 – 1139 1140 - 1149	^{84}Kr	1.5	417.0	38.5	51.5	3x10^5	July, 2023	VE304281.1 (63A) VE308539.1 (64A) VE308540.1 (65A)
1087 – 1096 1097 – 1105 1106 - 1114	^{129}Xe	1.5	809	66.0	61.1	3x10^5	May, 2023	VE304281.1 (63A) VE308539.1 (64A) VE308540.1 (65A)
513 – 520 521 – 529 530 - 536	^{197}Au	1.5	1425	90.5	80.1	3x10^5	May, 2023	VE304281.1 (63A) VE308539.1 (64A) VE308540.1 (65A)

Table 2 highlights the test overview indicating run number, ion species, air gap between the beam and DUT, beam energy, LET in Si, range in Si, fluence, test date and wafer lot number. These Worst-Case beam conditions were defined by the ion Bragg peak being in close proximity to the Epi-Substrate interface.

IR HiRel confirms the sensitive area of the transistor is exposed to a LET higher than:

- 90.5 MeV·cm2/mg using a ^{197}Au ion species
- 66.0 MeV·cm2/mg using a ^{129}Xe ion species
- 38.5 MeV·cm2/mg using a ^{84}Kr ion species

2.2 Test Setup

During the heavy-ion exposure, test samples were measured using a LabVIEW graphical user interface (GUI) custom-developed by IR HiRel. The GUI controls a DAQ to turn on and off relays that allow to select the DUT for heavy-ion exposure on a multisite board, also, it controls the power supplies that deliver regulated biases for V_{GS} and V_{DS}. Additional information regarding test setup can be found in the *IR HiRel Radiation Test Methodology*.

3 Test Criteria

All the tests were done at normal incidence which has been determined to be the worst case for Superjuntion power MOSFETs. To achieve the desired energy/penetration depth, aluminum foil degraders and adjusted air distances were used. The measurements and irradiation runs were performed at room temperature (25 °C), with average flux and fluence of $2x10^4$ ions/cm^2/s and $3x10^5$ ions/cm^2, respectively. The test procedure was based on MIL-STD-750, Method 1080. For more detailed description on test methodology employed by IR HiRel, refer to the *IR HiRel Radiation Test Methodology* document.

Three passes were required for qualification (including post-electrical test) and two failures for characterization of each SEE-SOA test point. This was validated for samples from three different wafer lots. This sequence was repeated for the next ion species. The detailed logsheet for each run is provided in Sections 4.2 – 4.4. The combination of SEB-SOA and SEGR-SOA yields the SEE-SOA.

3.1 Characterization Test Bias Sequence for SEB-SOA

1. V_{GS}: 0 V
2. V_{DS}: Start at 80V. Increase in steps of 10V until $V_{DS(max)}$ or FAIL occurs

3.2 Characterization Test Bias Sequence for SEGR-SOA

1. V_{DS}: Keep V_{DS} at maximum (at which PASS value was obtained for previous test bias sequence i.e. SEB)
2. V_{GS}: Start at -1V. Decrease in steps of 1V until $V_{GS(max)}$ or FAIL occurs

3.3 Qualification Test Bias Sequence for SEB/SEGR-SOA

1. Based on the results of the characterization, product was qualified by testing three samples of each wafer to the closest passing V_{GS} and V_{DS} voltages.
2. All samples MUST pass qualified specificiation biases (V_{GS}/V_{DS}).

3.4 Post-Electrical Test Criteria

- Post Irradiation Gate Stress (PIGS) test: $V_{GS} = V_{GS(max)} = -20V$ at $V_{DS} = 80V$ was applied to verify the gate integrity after each irradiation run.
- Pass/Fail criteria are based on I_{DSS}, I_{GSSf} and I_{GSSr} limits (shown in Table 3)

Table 3 Electrical Parameters Limits

Parameter	Test Conditions	Limit
I_{DSS}	V_{DS} = 100V, V_{GS} = 0V	≤ 0.95µA
I_{GSSf}	V_{GS} = 20V, V_{DS} = 0V	< 90nA
I_{GSSr}	V_{GS} = -20V, V_{DS} = 0V	< -90nA
$V_{GS(th)}$	$V_{DS} = V_{GS}$, I_D = 6.0mA	2.05V to 3.95V
BV_{DSS}	I_D = 1.0mA	≥ 101.5V
$R_{DS(ON)}$	V_{GS} = 12V, I_D = 75A	< 8mΩ
V_{SD}	I_S = 75A	≤ 1.2V

4 Test Results

4.1 Destructive SEB/SEGR Test Results

IRHC9Ax160 devices have been tested using the ion source K500 Cyclotron at TAMU and typical SEE-SOA for V_{DS}/V_{GS} combinations established. Each point on the graph, or insitu bias condition, has been verified by irradiating and subsequent electrical testing of a minimum of 3 devices, with no valid failures allowed.

Table 4 SEE-SOA of IRHC9Ax160 – Worst-Case Beam Conditions (TAMU)

	V_{DS} (V)		
V_{GS} (V)	LET = 38.5; 51.5 µm; 417 MeV	LET = 66; 61.1 µm; 809 MeV	LET = 90.5; 80.1 µm; 1425 MeV
0	100	100	100
-3	100	100	100
-5	100	100	
-10	100	100	
-15	100		
-20	100		

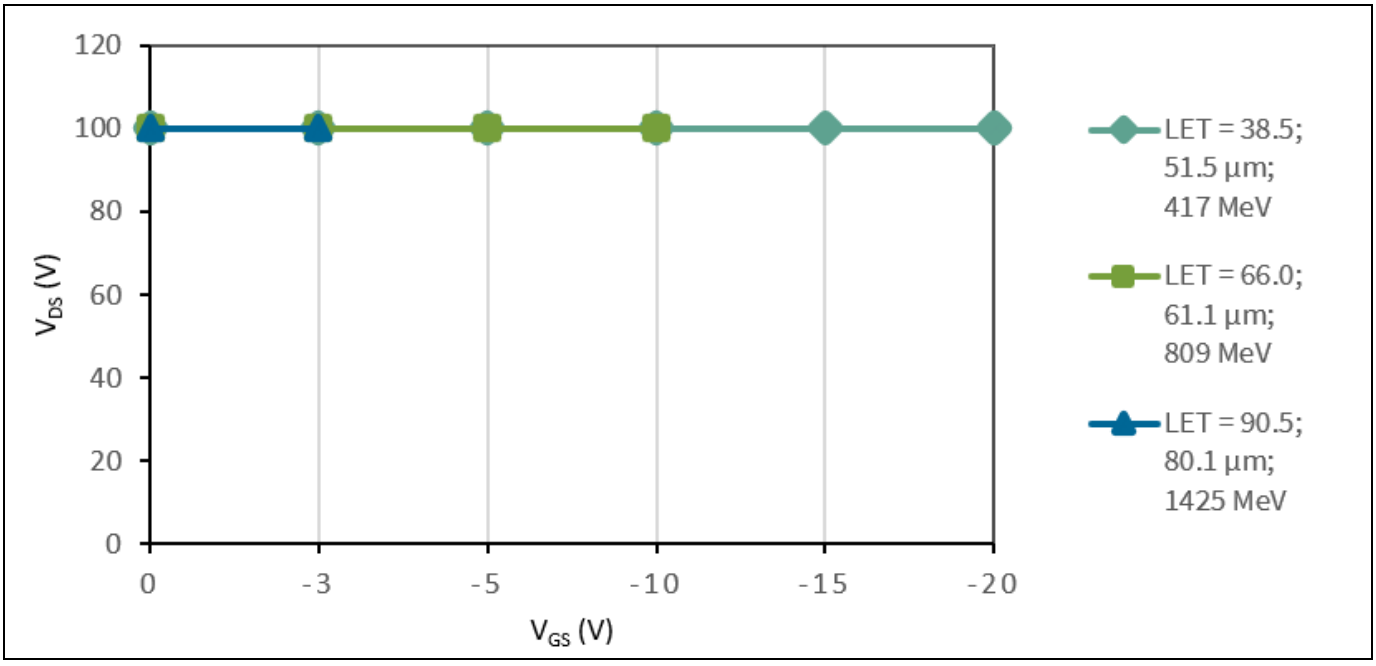

Figure 2 **SEE-SOA of IRHC9Ax160 – Worst-Case Beam Conditions (TAMU)**

4.2 ^{197}Au – SEE Run Results

Heavy-ion irradiation using ^{197}Au ion species was conducted in May 2023 at the K500 Cyclotron facility at Texas A&M University (TAMU). All tests were performed at a normal incidence with a 1.5 cm air gap between the beam window and the die surface. The beam parameters and degrader configuration were carefully selected to position the Bragg peak in close proximity to the epitaxial-substrate interface, as follows: LET = 90.5 MeV·cm^2/mg, Energy = 1425 MeV, Range = 80.1 µm, Degrader = 2 mil aluminum foil, and Degrader Angle = 14.113°.

Table 5 SEE run data of IRHC9Ax160 - ^{197}Au ion species

Run No.	Wafer Lot	SEE ID	DUT Serial #	Eff. Fluence	Avg. Flux	VGS	VDS	Pass/Fail (subject to Post-SEE Electricals)
				ions/cm^2	ions/cm2/s	*Volts*	*Volts*	*Blank=Pass*
513	VE304281.1	63A	1	3.03E+05	1.48E+04	-5	100	
514				3.01E+05	1.50E+04	-6	100	
515				3.01E+05	1.52E+04	-7	100	Failed – Gate Stress
516			2	3.03E+05	1.47E+04	-5	100	
517				3.06E+05	1.44E+04	-6	100	Failed – Gate Stress
518			3	3.00E+05	1.44E+04	-3	100	← Worst-Case Kr curve spec point
519			4	3.01E+05	1.42E+04	-3	100	← Worst-Case Kr curve spec point
520			5	3.01E+05	1.42E+04	-3	100	← Worst-Case Kr curve spec point
521	VE308539.1	64A	1	3.08E+05	1.46E+04	-5	100	
522				3.04E+05	1.54E+04	-6	100	
523				6.63E+04	1.39E+04	-7	100	Failed
524			2	2.98E+05	1.52E+04	-5	100	
525				3.08E+05	1.49E+04	-6	100	
526				1.86E+05	1.45E+04	-7	100	Failed
527			3	3.04E+05	1.45E+04	-5	100	← Worst-Case Kr curve spec point
528			4	2.94E+05	1.44E+04	-5	100	← Worst-Case Kr curve spec point
529			5	3.01E+05	1.39E+04	-5	100	← Worst-Case Kr curve spec point
530	VE308540.1	65A	1	2.98E+05	1.43E+04	-5	100	
531				3.01E+05	1.40E+04	-6	100	Failed – Gate Stress
532			2	3.01E+05	1.39E+04	-5	100	
533				3.00E+05	1.32E+04	-6	100	Failed
534			3	2.95E+05	1.33E+04	-3	100	← Worst-Case Kr curve spec point
535			4	2.97E+05	1.33E+04	-3	100	← Worst-Case Kr curve spec point
536			5	2.97E+05	1.44E+04	-3	100	← Worst-Case Kr curve spec point

4.3 ^{129}Xe – SEE Run Results

Heavy-ion irradiation using ^{129}Xe ion species was conducted in May 2023 at the K500 Cyclotron facility at Texas A&M University (TAMU). All tests were performed at a normal incidence with a 1.5 cm air gap between the beam window and the die surface. The beam parameters and degrader configuration were carefully selected to position the Bragg peak in close proximity to the epitaxial-substrate interface, as follows: LET = 66.0 MeV·cm^2/mg, Energy = 809 MeV, Range = 61.1 µm, Degrader = 2 mil aluminum foil, and Degrader Angle = 27.838 °.

Table 6 SEE run data of IRHC9Ax160 - ^{129}Xe ion species

Run No.	Wafer Lot	SEE ID	DUT Serial #	Eff. Fluence	Avg. Flux	VGS	VDS	Pass/Fail (subject to Post-SEE Electricals)
				ions/cm^2	ions/cm2/s	*Volts*	*Volts*	*Blank=Pass*
1087	VE304281.1	63A	7	2.95E+05	2.25E+04	-10	100	
1088				3.02E+05	2.27E+04	-12	100	
1089				3.07E+05	2.20E+04	-14	100	
1090				3.10E+05	2.28E+04	-15	100	Failed
1091			8	2.94E+05	2.29E+04	-12	100	Failed
1092				2.95E+05	2.06E+04	-14	100	
1093				3.04E+05	2.17E+04	-15	100	Failed
1094			9	3.04E+05	2.22E+04	-10	100	← Worst-Case Xe curve spec point
1095			10	3.05E+05	2.22E+04	-10	100	← Worst-Case Xe curve spec point
1096			11	3.12E+05	2.25E+04	-10	100	← Worst-Case Xe curve spec point
1097	VE308539.1	64A	7	2.97E+05	2.08E+04	-12	100	
1098				2.97E+05	2.10E+04	-14	100	
1099				3.02E+05	2.19E+04	-15	100	Failed
1100			8	2.99E+05	2.26E+04	12	100	
1101				3.02E+05	2.21E+04	-14	100	
1102				3.04E+05	2.13E+04	-15	100	Failed
1103			9	3.12E+05	2.21E+04	-10	100	← Worst-Case Xe curve spec point
1104			10	2.90E+05	2.10E+04	-10	100	← Worst-Case Xe curve spec point
1105			11	3.06E+05	2.20E+04	-10	100	← Worst-Case Xe curve spec point
1106	VE308540.1	65A	7	2.91E+05	2.22E+04	-12	100	
1107				2.92E+05	2.12E+04	-14	100	
1108				2.26E+05	2.22E+04	-15	100	Failed
1109			8	3.03E+05	2.26E+04	-12	100	
1110				3.04E+05	2.28E+04	-14	100	
1111				3.12E+05	2.27E+04	-15	100	Failed
1112			9	3.06E+05	2.23E+04	-10	100	← Worst-Case Xe curve spec point
1113			10	3.02E+05	2.24E+04	-10	100	← Worst-Case Xe curve spec point
1114			11	2.93E+05	2.26E+04	-10	100	← Worst-Case Xe curve spec point

4.4 ^{84}Kr – SEE Run Results

Heavy-ion irradiation using ^{84}Kr ion species was conducted in July 2023 at the K500 Cyclotron facility at Texas A&M University (TAMU). All tests were performed at a normal incidence with a 1.5 cm air gap between the beam window and the die surface. The beam parameters and degrader configuration were carefully selected to position the Bragg peak in close proximity to the epitaxial-substrate interface, as follows: LET = 38.5 MeV·cm^2/mg, Energy = 417 MeV, Range = 51.5 µm, Degrader = 2 mil aluminum foil, and Degrader Angle = 49.188°.

Table 7 SEE run data of IRHC9Ax160 - ^{84}Kr ion species

Run No.	Wafer Lot	SEE ID	DUT Serial #	Eff. Fluence	Avg. Flux	VGS	VDS	Pass/Fail (subject to Post-SEE Electricals)
				ions/cm^2	ions/cm2/s	*Volts*	*Volts*	*Blank=Pass*
1118	VE304281.1	63A	6	3.06E+05	2.35E+04	-15	100	
1119				2.99E+05	2.16E+04	-20	100	
1120				2.21E+05	2.22E+04	-24	100	Failed
1121			12	2.96E+05	2.23E+04	-15	100	
1122				3.06E+05	2.34E+04	-20	100	
1123				3.04E+05	2.40E+04	-22	100	
1124				3.02E+05	2.26E+04	-24	100	
1125				1.26E+05	2.24E+04	-26	100	Failed
1126			13	2.94E+05	2.32E+04	-20	100	← Worst-Case Kr curve spec point
1127			14	3.01E+05	2.31E+04	-20	100	← Worst-Case Kr curve spec point
1128			15	2.99E+05	2.42E+04	-20	100	← Worst-Case Kr curve spec point
1129	VE308539.1	64A	6	3.10E+05	2.15E+04	-15	100	
1130				3.11E+05	2.30E+04	-20	100	
1131				2.94E+05	2.23E+04	-22	100	
1132				3.04E+05	2.16E+04	-24	100	Failed
1133			12	3.05E+05	2.33E+04	-20	100	
1134				3.06E+05	2.38E+04	-22	100	
1135				2.97E+05	2.21E+04	-24	100	
1136				2.32E+05	2.27E+04	-26	100	Failed
1137			13	2.96E+05	2.34E+04	-20	100	← Worst-Case Kr curve spec point
1138			14	2.91E+05	2.37E+04	-20	100	← Worst-Case Kr curve spec point
1139			15	2.93E+05	2.28E+04	-20	100	← Worst-Case Kr curve spec point
1140	VE308540.1	65A	6	2.92E+05	2.39E+04	-20	100	
1141				3.06E+05	2.32E+04	-22	100	
1142				2.11E+05	2.31E+04	-24	100	Failed
1143			12	2.92E+05	2.35E+04	-20	100	
1144				2.95E+05	2.38E+04	-22	100	
1145				2.95E+05	2.37E+04	-24	100	
1146				1.07E+05	2.22E+04	-26	100	Failed
1147			13	2.99E+05	2.40E+04	-20	100	← Worst-Case Kr curve spec point
1148			14	3.01E+05	2.38E+04	-20	100	← Worst-Case Kr curve spec point
1149			15	2.90E+05	2.37E+04	-20	100	← Worst-Case Kr curve spec point

5 Conclusion

As a guardband against the possibility of fluctuating beam conditions, IR HiRel is publishing the following typical worst case SEE response specifications for final datasheet use: Typical SEE-SOA of IRHC9Ax160 – Worst-Case Beam Conditions.

Table 8 Typical SEE-SOA of IRHC9Ax160 – Worst-Case Beam Conditions

	V_{DS} (V)		
V_{GS} (V)	LET = 37 ± 5%; 50 µm ± 7.5%; 417 MeV ± 7.5%	LET = 63 ± 7.5%; 60 µm ± 7.5%; 753 MeV ± 7.5%	LET = 90 ± 5%; 82 µm ± 7.5%; 1515 MeV ± 7.5%
0	100	100	100
-3	100	100	100
-5	100	100	
-10	100	100	
-15	100		

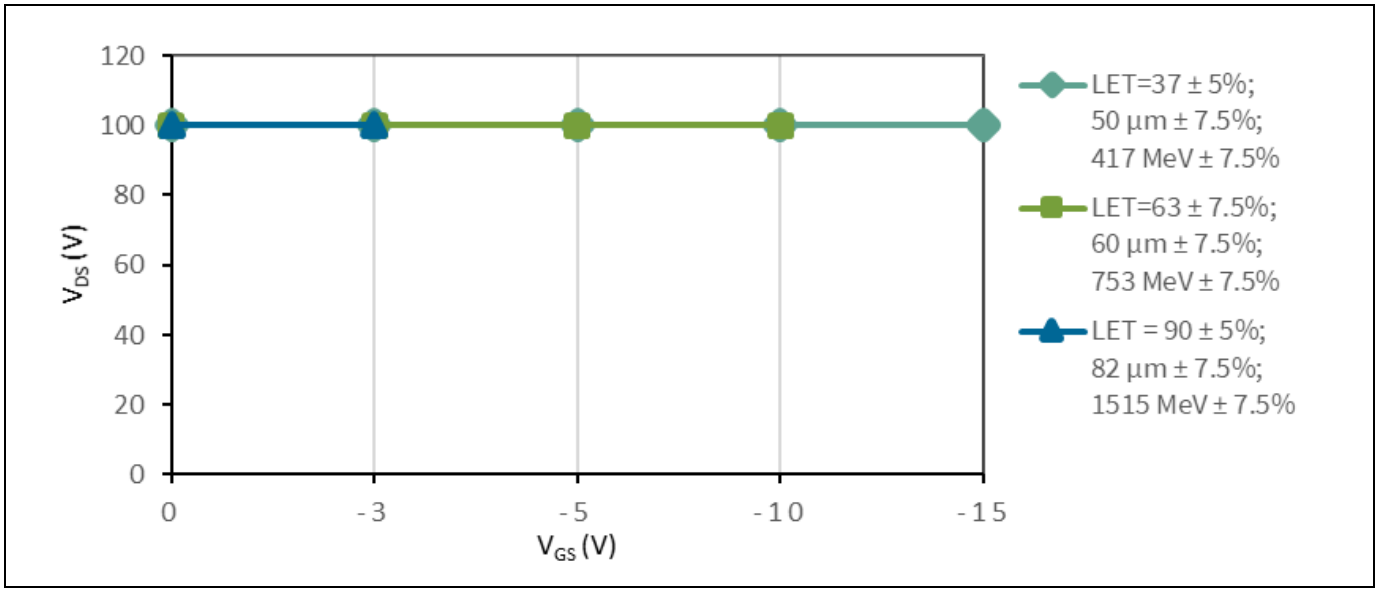

Figure 3 **Typical SEE-SOA of IRHC9Ax160 – Worst-Case Beam Conditions**

Revision History

Document version	Date of release	Description of changes
Rev A	2026/09/02	Initial released

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