Radtest Ltd

Total dose radiation and electrical testing of BFR391 bipolar transistors

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Date of issue: June 2021

Title	Total dose radiation and electrical testing of BFR391 bipolar transistors
Customer	Die Devices Ltd
Customer reference	SP264
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File reference	C180/54
Report number	REP214
Report status	Issue 1

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Radtest Ltd is certificated by BSi to BS EN ISO9001 (2015) under certificate number FS613540.

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1 Introduction

Die Devices has contracted Radtest Ltd to carry out total dose radiation testing of the BFR391 bipolar transistor. This report describes the samples and the test procedure and summarises the results.

2 Reference documents

[RD1]: ESCC basic specification no. 22900, issue 5, “Total dose steady-state irradiation test method”, June 2016;
[RD2]: Mil-Std-883, method 1019.9, “Ionizing Radiation (Total Dose) Test Procedure”;
[RD3]: “Die requirements RF transistor BFR391 Ft=16 GHz”, Microsemi drawing number 121200074, rev. D, dated 29 January 2021.
[RD4]: “TID radiation test plan for BFR391 NPN transistors”, Test plan DIE0120, issue 2, dated 02 February 2021.

3 Description of the samples

3.1 IDENTIFICATION OF THE SAMPLES

Device type number: BFR391

Manufacturer: Die Devices Ltd

Quantity: 15 devices in TO-46 packages were supplied for testing and 12 were given serial numbers 1 to 12. Samples 1 and 2 were kept unirradiated as control devices.

Datasheet reference: 121200074, rev. D, dated 29 January 2021 [RD3]

Sample size: five biased, five unbiased and two control samples

Wafer number: 1Z113767 WF5

Lot code: 201492

Date code: 921A

3.2 PICTURES OF THE SAMPLES

Figs. 1 and 2 show the package and the labelling on the outside of the package.

Fig. 1: sample package

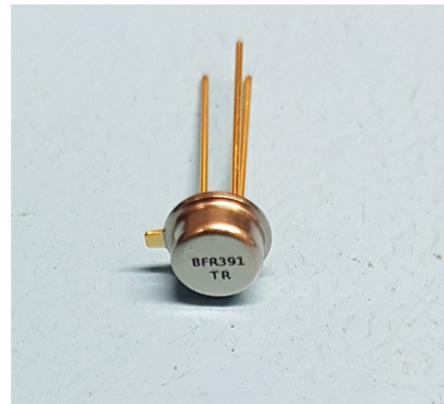


Fig. 2: example package markings

3.3 DISPOSITION OF THE SAMPLES

Each sample was labelled with its origin on the wafer, indicated by one of TR, TL, LR and LL. Table 1 shows the label for each test sample.

Sample number	Label	Status
1	TR	Control
2	LL	Control
3	TL	Biased
4	TR	Biased
5	LL	Biased
6	LR	Biased
7	TL	Biased
8	TL	Unbiased
9	TR	Unbiased
10	LL	Unbiased
11	LR	Unbiased
12	LR	Unbiased

Table 1: disposition of the samples

4 Radiation environment

4.1 RADIATION SOURCE

MRC Cell 2 at Harwell was used for the irradiation. This facility is fitted with two cobalt-60 sources emitting gamma radiation with a mean energy of 1.25MeV/photon. Source C was used for this work.

4.2 DOSIMETRY

The dose rate was determined by measurements with a TN31010-1 ionisation chamber, manufactured by PTW and allocated the reference number DS07 in Radtest's calibration register, in conjunction with a Unidos E reader, reference number DS01. These measurements were made on 16 March 2021.

4.3 RADIATION DOSE STEPS

Table 2 lists the start and end times for each irradiation and both annealing stages. All irradiations were carried out between 16 March and 8 June 2021.

Level	Dose step (krad[Si])	Start date/time	End date/time
1	100	16/03/21 16:35	13/04/21 11:17
2	150	13/04/21 12:09	27/04/21 10:00
3	200	27/04/21 10:50	11/05/21 08:07
4	250	11/05/21 08:56	25/05/21 08:05
5	300	25/05/21 08:50	08/06/21 08:01

Table 2: radiation test levels and times

4.4 RADIATION DOSE RATE

The measured dose rate was 1.65 Gy[H_2O]/hr, with an uncertainty of ± 5%. This dose rate was converted to silicon as a reference material by multiplying by a factor of 0.916, giving a dose rate of 1.51 Gy[Si]/hr or 151 rad[Si]/hr.

The irradiation sequence covered a period of approximately three months and so a correction for the decay of the radioisotope was applied.

5 Test conditions and parameters measured

5.1 TEST CONDITIONS

Electrical testing was undertaken before irradiation and after each of five dose steps, as listed in table 2. This test was carried out with electrical measurements conducted in the not in-flux manner. Electrical bias was removed from the samples and the samples were transported on the bias board between the irradiation facility and the measurement facility and back again for the next irradiation.

5.2 POST-IRRADIATION PROCEDURE

In accordance with RD2, the time between the end of an irradiation and the start of the electrical measurements was no more than one hour. The time to perform the electrical measurements and to return the devices for the subsequent irradiation, if any, was no more than two hours from the end of the previous irradiation.

The sequence of electrical measurements was the same for each set of measurements made.

No post-irradiation annealing stages were applied.

5.3 PARAMETERS MEASURED

Tables 3 lists the measurements made on these samples (taken from RD4).

Pre-Irradiation:

Parameter	Pre-Irradiation Specification		Measurement Precision/Resolution
	MIN	MAX	
I_{CBO} (A)		1.00E^{-06}	±1.40E^{-12}
I_{EBO} (A)		1.00E^{-06}	±4.66E^{-12}
h_{FE}	6.00E^{+01}	1.50E^{+02}	±1.28E^{+00}

Interim and Post-Irradiation:

Parameter	Test Conditions	Post-Irradiation Specification	
		MIN	MAX
I_{CBO} (A)	V_{CB}=5V, I_E=0mA		1.00E^{-06}
I_{EBO} (A)	V_{EB}=1V, I_C=0mA		1.00E^{-06}
h_{FE}	V_{CE}=5V, I_C=50mA	[h_{FE}]=[60]	1.50E^{+02}

Table 3: parameters measured and specification limits

For these measurements, each test sample was plugged into a socket in an Agilent 16442B test fixture, connected to an Agilent B1500A Semiconductor Parameter Analyser (ET01) via leads of length 1m, as shown in overview in fig. 3.

Fig. 3: overview of the B1500A test equipment

5.4 BIAS CONDITIONS DURING IRRADIATION

The bias board comprised three sockets, each accommodating up to four test samples, as shown in fig. 4. Samples 3 to 7 were irradiated under the electrical bias condition shown in fig. 5 (‘biased on’). Samples 8 to 12 were irradiated with their leads electrically shorted together (‘biased off’).

The supply voltage and current were monitored at intervals of one minute during irradiation. No deviations were observed.

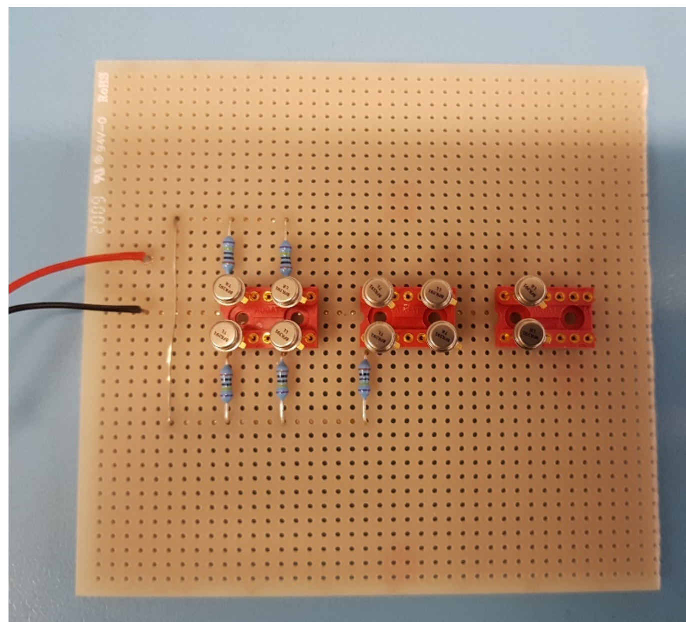


Fig. 4: bias board used during irradiation

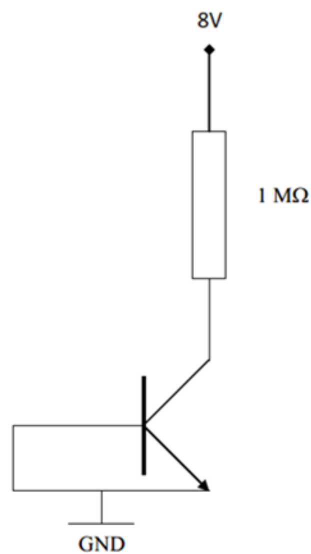


Fig. 5: bias arrangement

6 Results

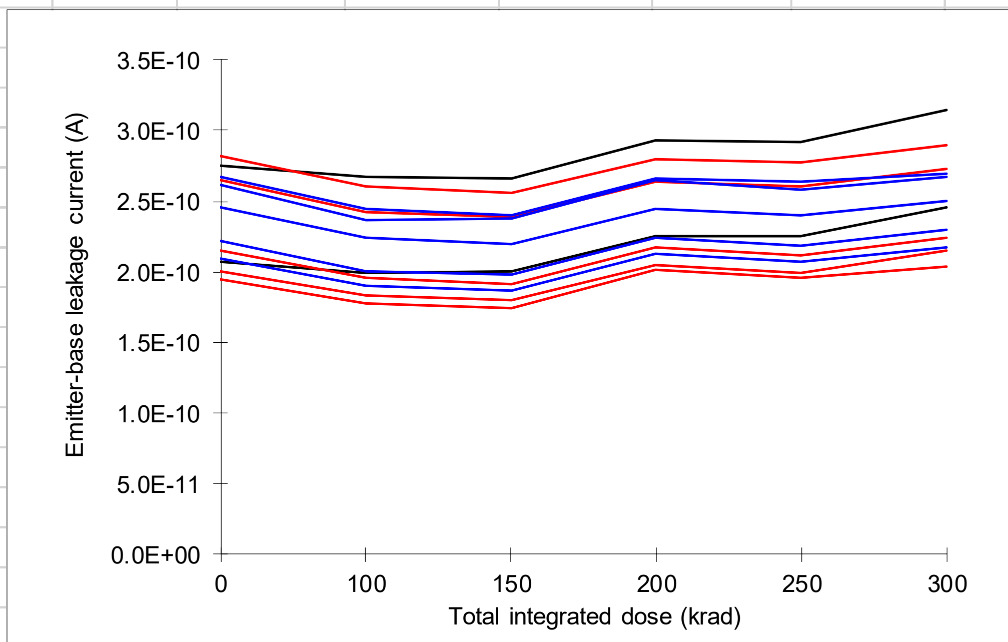
The results are presented firstly as graphs of each parameter, with data for each test sample at each dose step. Data for the control samples are indicated by a black line. Data for the irradiated samples are shown as red (‘biased on’) or blue (‘biased off’) lines.

Secondly, the results are presented in tabular format, with the measured data from each dose step shown as an individual table page.

At no point during the work did any of the test samples show a measurement result that fell outside of the specification limits.

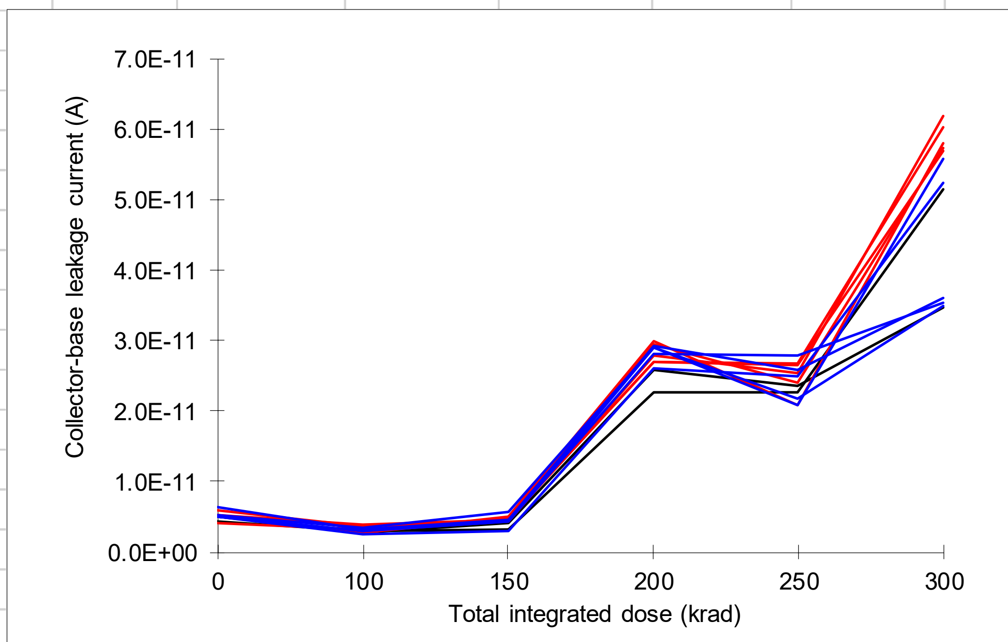
6.1 I_{EBO}

	Type number:	BFR391	Test dates:	12/03/2021 - 08/06/2021
	Category:	NPN bipolar transistor	Samples:	2/10
	Manufacturer:	Die Devices	Spec.	Max 1E-6A
	Parameter:	Emitter-base leakage current		
	Test equipment:	B1500A		
	Ambient temperature during irradiation:	20°C		
	Radiation source:	MRC cell 2, Harwell, UK		
	Radiation type:	Gamma		
	Energy:	1.25 MeV/photon		
	Electrical conditions during irradiation:	Devices 3 - 7 biased, 8 - 12 unbiased		



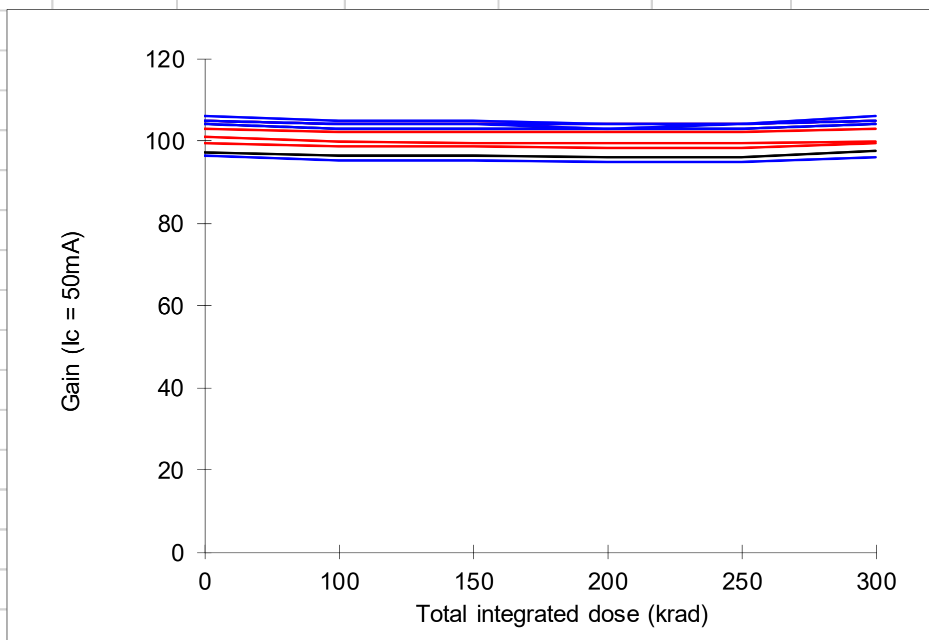
6.2 I_{CBO}

Type number:	BFR391	Test dates:	12/03/2021 - 08/06/2021
Category:	NPN bipolar transistor	Samples:	2/10
Manufacturer:	Die Devices	Spec.	Max 1E-6A
Parameter:	Collector-base leakage current		
Test equipment:	B1500A		
Ambient temperature during irradiation:	20°C		
Radiation source:	MRC cell 2, Harwell, UK		
Radiation type:	Gamma		
Energy:	1.25 MeV/photon		
Electrical conditions during irradiation:	Devices 3 - 7 biased, 8 - 12 unbiased		



6.3 h_{FE}

Type number:	BFR391	Test dates:	12/03/2021 - 08/06/2021
Category:	NPN bipolar transistor	Samples:	2/10
Manufacturer:	Die Devices	Spec.	Min 60, max 150
Parameter:	Gain (Ic = 50mA)		
Test equipment:	B1500A		
Ambient temperature during irradiation:	20°C		
Radiation source:	MRC cell 2, Harwell, UK		
Radiation type:	Gamma		
Energy:	1.25 MeV/photon		
Electrical conditions during irradiation:	Devices 3 - 7 biased, 8 - 12 unbiased		



6.4 TABULATED DATA

Type number:	BFR391	Test number:	1
Category:	NPN bipolar transistor	Date:	12/03/2021
Manufacturer:	Die Devices	Time:	13:22
Date code:	201492	Total integrated dose:	0 krad
Test equipment:	B1500A	Time since irradiation:	-
Test program:	STS ver. 3.00		
Parameters tested:	Emitter-base and collector-base leakage currents and gain		

DUT		I_{EBO}	I_{CBO}	h_{FE}
		V ± 1%	V ± 1%	A ± 1%
1	Control	2.07E-10	4.95E-12	97.2
2		2.75E-10	4.40E-12	104.0
3		2.01E-10	5.20E-12	105.0
4		2.15E-10	4.15E-12	101.0
5		2.82E-10	5.30E-12	99.6
6		2.65E-10	6.00E-12	103.0
7		1.94E-10	5.30E-12	105.0
8		2.09E-10	5.00E-12	105.0
9		2.21E-10	5.05E-12	96.2
10		2.67E-10	4.90E-12	104.0
11		2.61E-10	5.20E-12	106.0
12		2.61E-10	5.20E-12	106.0

Tested by: RES

Type number:	BFR391	Test number:	2
Category:	NPN bipolar transistor	Date:	13/04/2021
Manufacturer:	Die Devices	Time:	11:28
Date code:	201492	Total integrated dose:	100 krad
Test equipment:	B1500A	Time since irradiation:	00h 11m
Test program:	STS ver. 3.00		
Parameters tested:	Emitter-base and collector-base leakage currents and gain		

DUT		I_{EBO} V ± 1%	I_{CBO} V ± 1%	h_{FE} A ± 1%
1	Control	2.00E-10	2.80E-12	96.2
2		2.67E-10	2.85E-12	103.0
3		1.83E-10	2.80E-12	104.0
4		1.96E-10	3.15E-12	99.7
5		2.61E-10	3.80E-12	98.8
6		2.43E-10	3.70E-12	102.0
7		1.77E-10	2.80E-12	104.0
8		1.90E-10	2.95E-12	104.0
9		2.01E-10	2.45E-12	95.3
10		2.45E-10	3.00E-12	103.0
11		2.37E-10	3.40E-12	105.0
12		2.37E-10	3.40E-12	105.0

Tested by: RES

Type number:	BFR391	Test number:	3
Category:	NPN bipolar transistor	Date:	27/04/2021
Manufacturer:	Die Devices	Time:	10:07
Date code:	201492	Total integrated dose:	150 krad
Test equipment:	B1500A	Time since irradiation:	00h 15m
Test program:	STS ver. 3.00		
Parameters tested:	Emitter-base and collector-base leakage currents and gain		

DUT		I_{EBO} V ± 1%	I_{CBO} V ± 1%	h_{FE} A ± 1%
1	Control	2.00E-10	4.15E-12	96.2
2		2.67E-10	3.25E-12	103.0
3		1.80E-10	4.90E-12	104.0
4		1.91E-10	4.60E-12	99.6
5		2.56E-10	4.50E-12	98.6
6		2.39E-10	4.40E-12	102.0
7		1.75E-10	4.85E-12	104.0
8		1.87E-10	4.35E-12	104.0
9		1.98E-10	2.85E-12	95.1
10		2.40E-10	4.20E-12	103.0
11		2.38E-10	5.65E-12	105.0
12		2.38E-10	5.65E-12	105.0

Tested by: RES

Type number:	BFR391	Test number:	4
Category:	NPN bipolar transistor	Date:	11/05/2021
Manufacturer:	Die Devices	Time:	08:17
Date code:	201492	Total integrated dose:	200 krad
Test equipment:	B1500A	Time since irradiation:	00h 10m
Test program:	STS ver. 3.00		
Parameters tested:	Emitter-base and collector-base leakage currents and gain		

DUT		I_{EBO} V ± 1%	I_{CBO} V ± 1%	h_{FE} A ± 1%
1	Control	2.25E-10	2.58E-11	95.9
2		2.94E-10	2.26E-11	103.0
3		2.04E-10	3.00E-11	104.0
4		2.17E-10	2.94E-11	99.3
5		2.80E-10	2.71E-11	98.1
6		2.64E-10	2.79E-11	102.0
7		2.01E-10	2.69E-11	104.0
8		2.13E-10	2.90E-11	103.0
9		2.25E-10	2.60E-11	94.8
10		2.66E-10	2.80E-11	103.0
11		2.64E-10	2.90E-11	104.0
12		2.64E-10	2.90E-11	104.0

Tested by: RES

Type number:	BFR391	Test number:	5
Category:	NPN bipolar transistor	Date:	25/05/2021
Manufacturer:	Die Devices	Time:	08:15
Date code:	201492	Total integrated dose:	250 krad
Test equipment:	B1500A	Time since irradiation:	00h 10m
Test program:	STS ver. 3.00		
Parameters tested:	Emitter-base and collector-base leakage currents and gain		

DUT		I_{EBO} V ± 1%	I_{CBO} V ± 1%	h_{FE} A ± 1%
1	Control	2.26E-10	2.37E-11	96.1
2		2.92E-10	2.26E-11	103.0
3		1.99E-10	2.09E-11	104.0
4		2.12E-10	2.41E-11	99.3
5		2.77E-10	2.65E-11	98.3
6		2.61E-10	2.55E-11	102.0
7		1.96E-10	2.68E-11	104.0
8		2.07E-10	2.09E-11	104.0
9		2.18E-10	2.50E-11	94.9
10		2.64E-10	2.79E-11	103.0
11		2.58E-10	2.18E-11	104.0
12		2.58E-10	2.18E-11	104.0

Tested by: RES

Type number:	BFR391	Test number:	6	
Category:	NPN bipolar transistor	Date:	08/06/2021	
Manufacturer:	Die Devices	Time:	08:37	
Date code:	201492	Total integrated dose:		300 krad
Test equipment:	B1500A	Time since irradiation:		00h 26m
Test program:	STS ver. 3.00			
Parameters tested:	Emitter-base and collector-base leakage currents and gain			

DUT		I_{EBO}	I_{CBO}	h_{FE}
		A ± 1%	A ± 1%	A ± 1%
1	Control	2.45E-10	3.46E-11	97.3
2		3.15E-10	5.15E-11	104.0
3		2.15E-10	5.80E-11	105.0
4		2.24E-10	5.74E-11	100.0
5		2.90E-10	5.69E-11	99.4
6		2.73E-10	6.20E-11	103.0
7		2.04E-10	6.04E-11	105.0
8		2.17E-10	5.57E-11	105.0
9		2.30E-10	5.24E-11	96.0
10		2.70E-10	3.55E-11	104.0
11		2.67E-10	3.49E-11	106.0
12		2.67E-10	3.49E-11	106.0

Tested by: RES

7 Calibration details

This section lists the test instruments used during the work and provides details of their calibration status.

Code	Manufacturer	Description	Serial no	Date last calibrated	Date next calibration due
DS01	PTW	Unidos E dosemeter	1250	17/08/20	17/08/22
DS07	PTW	TN31010 ion chamber	6561	12/03/20	12/03/22
ET01	Agilent	B1500A parameter analyser	JP49320110	17/03/20	17/03/21
ET02	Tektronix	DMM4050	2129207	22/05/20	22/05/21
ET15	Lufft	Opus 20 barometer	148.0414.0802.022	01/03/21	01/03/22
ET16	Keysight	E3633A power supply	MY55506488	17/02/21	17/02/22
ET34	Lufft	Opus 20 barometer	169.0314.0802.022	23/06/20	23/06/21

Table 4: list of calibrated instruments used for the work.