אוניברסיטת
אריאל
בשומרון
המחלקה להנדסת
חשמל ואלקטרוניקה

Reliability in Microelectronics

Final Project

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Project Background

An electric scooter company is developing a new motor control system. The task, as a reliability engineer, is to evaluate the reliability of two key components:

• A silicon controller chip (65nm node)

• A GaN power transistor module

Test data was provided from an accelerated life testing. The goal is to extract reliability models for each component and determine the maximum voltage and temperature that ensure long-term mission success.

Theory Section

Series System in Reliability:

In reliability engineering, a series system is one in which all components must operate successfully for the system to function. If any single component fails, the entire system is considered to have failed. This configuration is common in systems with no redundancy (parallel system) and represents a conservative reliability model. The reliability of the overall system is calculated as the product of the individual component reliability:

$$Rsystem = R1 \cdot R2 \cdot R3 \cdot \ldots \cdot Rn$$

As more components are added in series, the system reliability decreases—even if each component is highly reliable. For example, if three components each have a reliability of 0.99, the system reliability would be:

$$Rsystem = 0.99 \times 0.99 \times 0.99 \approx 0.9703$$

Thus, series systems are highly sensitive to individual component failures and are often used to model worst-case reliability scenarios.

In a series system, the entire system fails if just one component stops working. This makes the system unreliable, especially if it has a lot of parts. Redundancy helps solve this issue by adding backup components in **parallel**. That way, even if one component fails, the system can keep running because another component can take over.

For example, let's say a single component has a reliability of R=0.9R = 0.9R=0.9, meaning it has a 90% chance of working. If we add another identical component in parallel, the new reliability becomes:

$$Rparallel = 1 - (1 - R)2 = 1 - (0.1)2 = 0.99$$

So instead of a 10% chance of failure, it drops to just 1%. This shows how redundancy can make systems much more reliable by reducing the impact of individual failures. It's especially useful in systems where uptime is critical and failures can't be tolerated.

Weibull Analysis (Silicon)

Given data shows TTF (Time-to-Fail) samples for Silicon under 3 Voltages under 3 voltages (1.0 V, 1.2 V, 1.4 V) and 3 temperatures (100°C, 120°C, 140°C).

$k = 0.00008617$ (Boltzmann Constant)

$T[K] = T[C] + 273$

Using Weibull and Weibit analysis:

$x - axis: Weibull = \ln(TTf)$

$y - axis: Weibit = \ln\left(-\ln\left(1 - R(t)\right)\right)$

Where $F(t) = \frac{\#failures}{N+0.5}, N = 30$

The Weibull analysis was plotted for each different T and V to derive the shape parameter (β) and characteristic life (θ) using: $y = \beta \ln(t) - \ln(\theta)$. The plots for each condition can be viewed below with their linear equations. Each temperature will be combined to one graph each for simplicity and comparison between voltages. Each of the equations are listed top to bottom in order from V=1V until V=1.4V

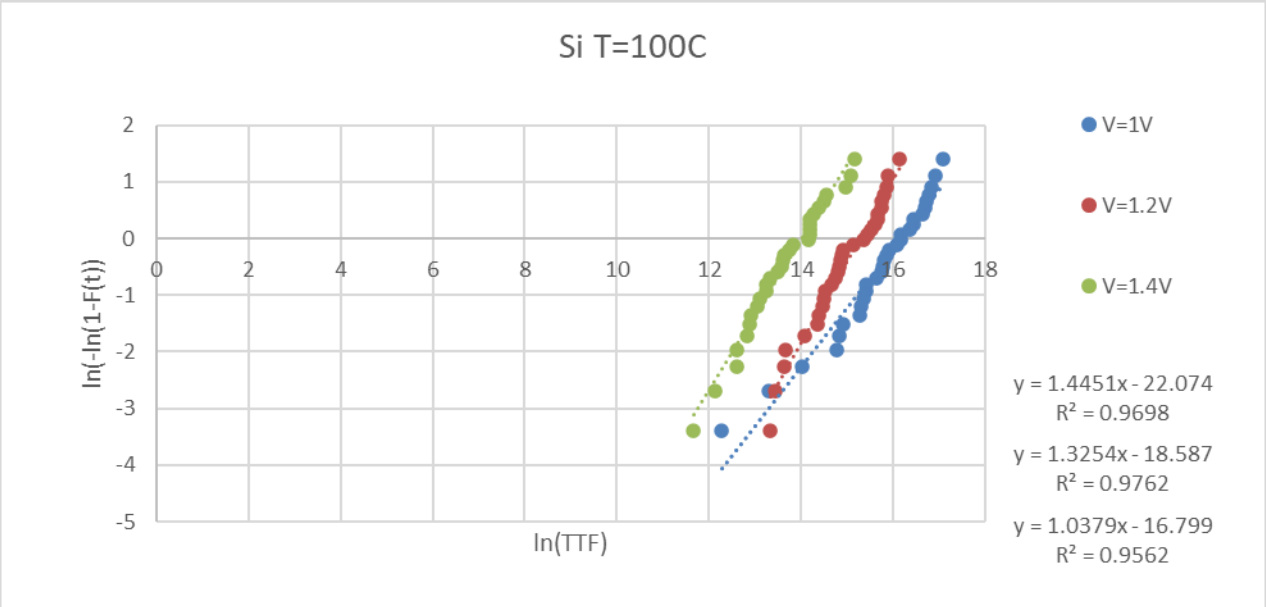

Image 1 – Si Weibull Graph T=100C

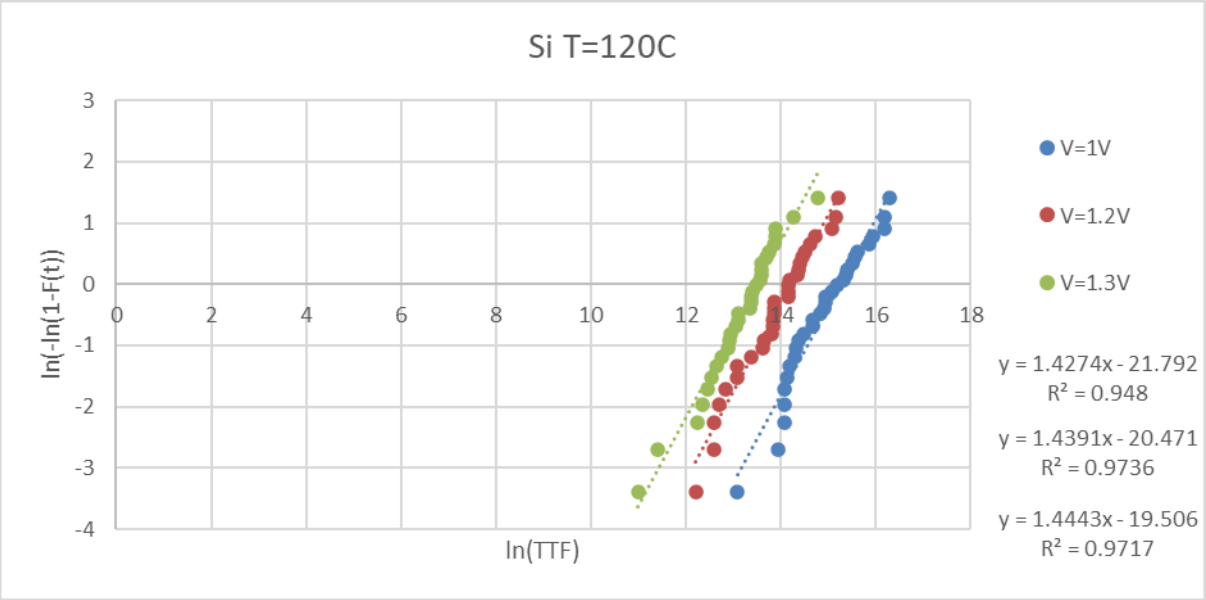

Image 2 – Si Weibull Graph T= 120C

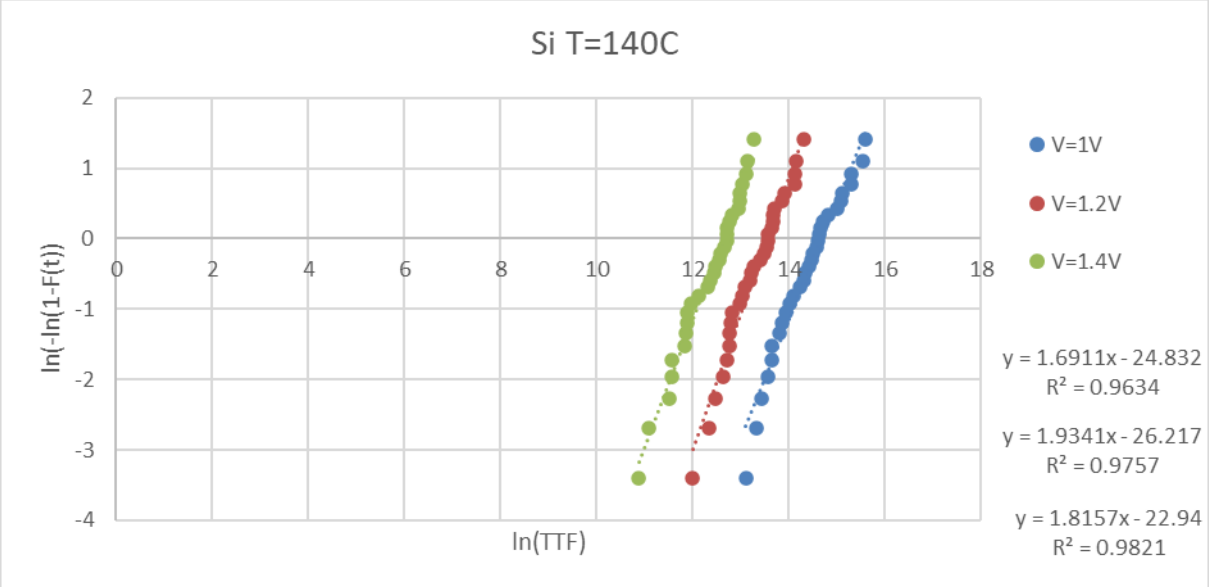

Image 3 – Si Weibull Graph T=140C

Using the linear equations from the graphs the, β is found from the slope, and $\theta = \exp\left(\frac{intercept}{\beta}\right)$.

$MTTF = \theta \cdot \Gamma\left(1 + \frac{1}{\beta}\right)$, $\Gamma(Z)$ is the Gamma function calculated in Excel.

Table 1 – Silicon $\beta, \theta, MTTF$ calculation and values

	β = slope	b- intercept	θ=exp(b/β)	(1+1/β)	Γ(1+1/β)	MTTF
T100C_V1_0	1.0379	16.779	10493822.74	1.963483958	0.985106906	10337537.25
T100C_V1_2	1.4451	22.074	4304052.029	1.691993634	0.907145945	3904403.345
T100C_V1_4	1.3254	18.587	1231435.304	1.754489211	0.920091209	1133032.798
T120C_V1_0	1.4274	21.792	4269122.555	1.700574471	0.908747718	3879555.378
T120C_V1_2	1.4391	20.471	1505841.99	1.694878744	0.907678254	1366820.028
T120C_V1_4	1.4443	19.506	733442.4372	1.69237693	0.907216299	665390.9334
T140C_V1_0	1.6911	24.832	2383149.605	1.591331086	0.892568402	2127124.034
T140C_V1_2	1.9341	26.217	770767.4043	1.517036348	0.886897729	683591.8608
T140C_V1_4	1.8157	22.94	306890.3343	1.550751776	0.888923518	272802.0356

Once MTTF was calculated, the TTF can be used to find the Ea and Gamma of the materials.

Using the equation: $TTF == A \cdot e^{\frac{Ea}{KT}} \cdot e^{-\gamma \cdot V}$ for silicon the Ea and γ can be found by using 2 graphs, one dependent on V and the other dependent on $\frac{1}{KT}$. The slopes of the graphs will be the Ea and γ values, which can be resubstituted into the equations until the graphs show no change. At this point the values can be confirmed. Afterwards the A can be found by solving for A in the equation $TTF == A \cdot e^{\frac{Ea}{KT}} \cdot e^{-\gamma \cdot V}$ using calculated Ea and gamma, and T and V values from the experiment data.

Table 2 – Silicon T' and V' for Ea and Gamma, A calculation

	T100C_V1_0	T100C_V1_2	T100C_V1_4	T120C_V1_0	T120C_V1_2	T120C_V1_4	T140C_V1_0	T140C_V1_2	T140C_V1_4
Voltage	1	1.2	1.4	1	1.2	1.4	1	1.2	1.4
Temp [K]	373	373	373	393	393	393	413	413	413
MTTF	10337537.25	3904403.345	1133032.798	3879555.378	1366820.028	665390.9334	2127124.034	683591.8608	272802.0356
1/KT	31.1125	31.1125	31.1125	29.5292	29.5292	29.5292	28.0992	28.0992	28.0992
Ln(TTF)	16.15129222	15.17761554	13.94040849	15.17123111	14.12799745	13.40813002	14.57028141	13.43511632	12.51650167
T'=exp(Ea/KT)	12566105.83	12566105.83	12566105.83	5469129.842	5469129.842	5469129.842	2580042.109	2580042.109	2580042.109
V'=exp(-V*Gamm	0.006584084	0.002410985	0.000882863	0.006584084	0.002410985	0.000882863	0.006584084	0.002410985	0.000882863
ln(TTF/V')	21.17439222	21.20533554	20.97274849	20.19433111	20.15571745	20.44047002	19.59338141	19.46283632	19.54884167
ln(TTF/T')	-0.195221513	-1.168898197	-2.406105247	-0.343398972	-1.386632631	-2.106500067	-0.193034872	-1.328199954	-2.246814611
A=TTF/(V'*T')	124.9456056	128.8722757	102.1287991	107.7378572	103.6569997	137.8050401	125.2191157	109.8944155	119.7642693

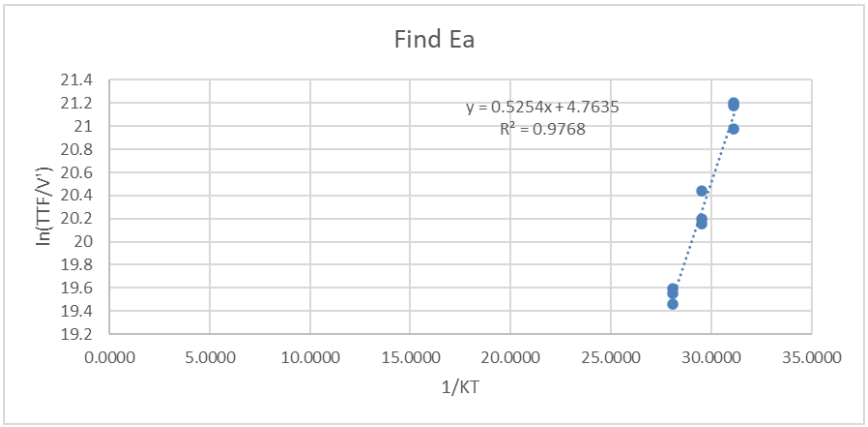

Image 4 – Si finding Ea

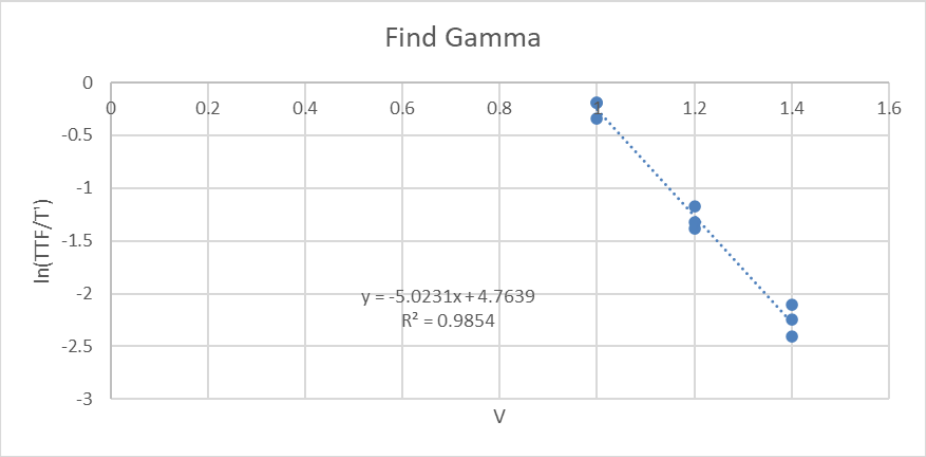

Image 5 – Si finding Gamma

Using the slope from the graphs in accordance with our equations the following parameters were found;

$Ea = 0.5254$

$\gamma = 5.0231$

The values from table 2 show the A constant for each condition. The average of these values is;

$A_{avg} = 117.78$

To get a more accurate A value, the *solver* will be used to minimize the sum of the error between the measured and calculated TTF values (based off of the each T/V individual calculated A values, or by a constant A value).

Table 3 – Finding the optimized A value using solver

	TTFmeas	Voltage	Temp [K]	1/KT	A=TTF/(V'*T')	TTF calc	Error=((mea-calc)^2
T100C_V1_0	10337537	1	373	31.11251187	124.9456056	10120752.89	46995456909
T100C_V1_2	3904403	1.2	373	31.11251187	128.8722757	3706055.33	39341934949
T100C_V1_4	1133033	1.4	373	31.11251187	102.1287991	1357097.269	50204887256
T120C_V1_0	3879555	1	393	29.52917793	107.7378572	4404842.073	2.75926E+11
T120C_V1_2	1366820	1.2	393	29.52917793	103.6569997	1612981.625	60595531456
T120C_V1_4	665390.9	1.4	393	29.52917793	137.8050401	590647.6732	5586554946
T140C_V1_0	2127124	1	413	28.09919353	125.2191157	2077968.225	2416293515
T140C_V1_2	683591.9	1.2	413	28.09919353	109.8944155	760918.2141	5979364921
T140C_V1_4	272802	1.4	413	28.09919353	119.7642693	278635.8913	34033873.25
						SUM	4.8708E+11

After using the solver, the optimized A value was found: $A_{solver} = 122.325$

Using all this information the lifetime model equation for Silicon can be built:

$$TTF(T,V) = 122.325 \cdot e^{\frac{0.5254}{KT}} \cdot e^{-5.0231 \cdot V}$$

GaN Analysis

The given information for GaN includes the time in hours and RDS values at different Temperatures and Voltages. The RDS vs time plot will be graphed for each condition as an exponential curve. Using the following the TTF can be calculated:

$$TTF = 20\%\ rise\ in\ RDS$$

$$TTF = 1.2\ RDS$$

$$e^{at} = 1.2 \rightarrow \frac{\ln(1.2)}{a} = t = TTF$$

The GaN degradation curves can be viewed below:

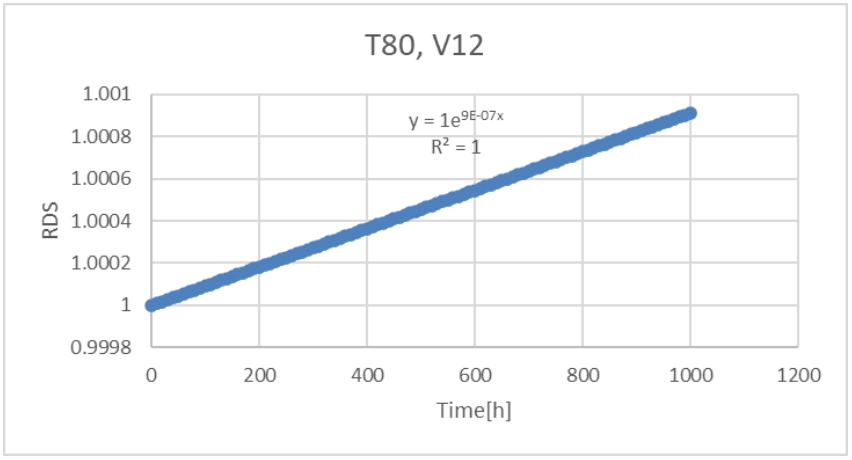

Image 6 – GaN Degradation Curve T80, V12

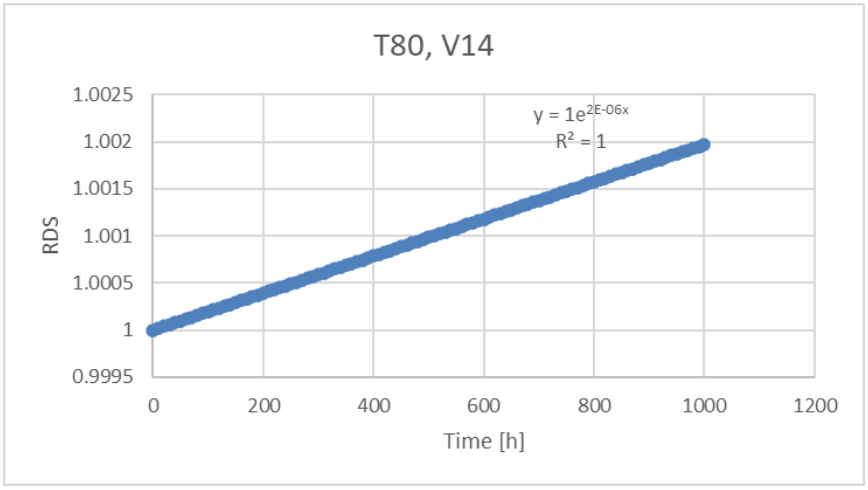

Image 7 – GaN Degradation Curve T80, V14

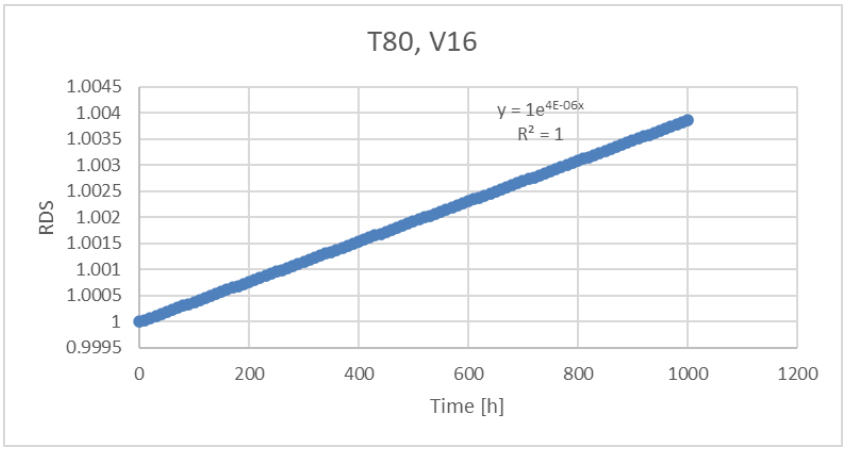

Image 8 – GaN Degradation Curve T80, V16

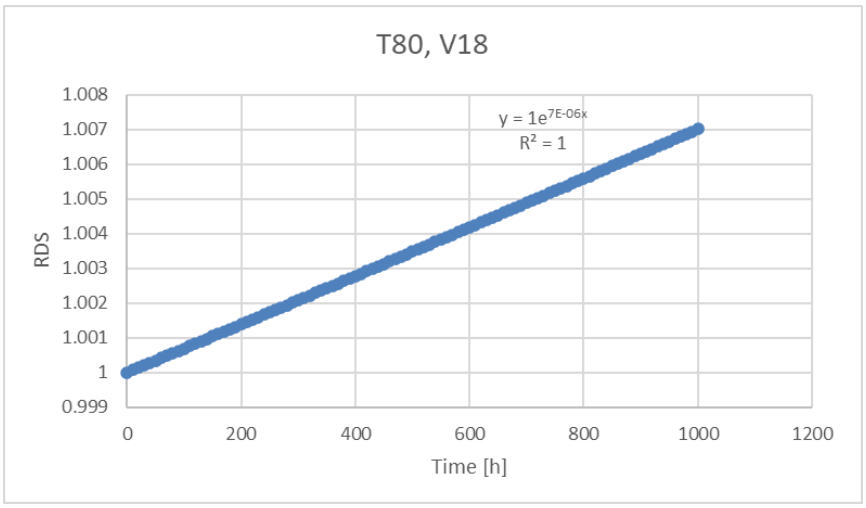

Image 9 – GaN Degradation Curve T80, V18

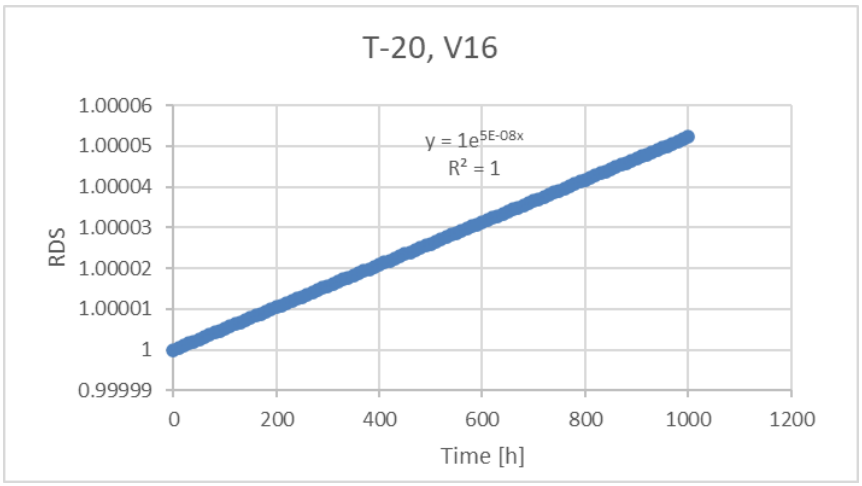

Image 10 – GaN Degradation Curve T -20, V16

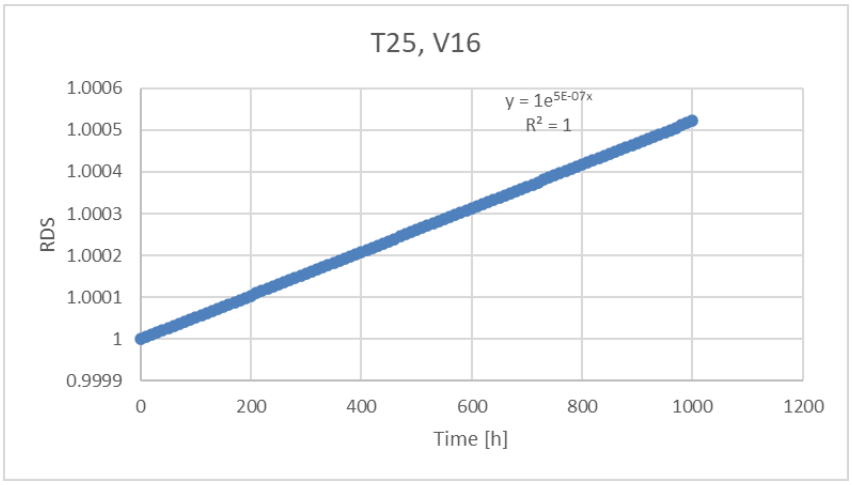

Image 11 – GaN Degradation Curve T25, V16

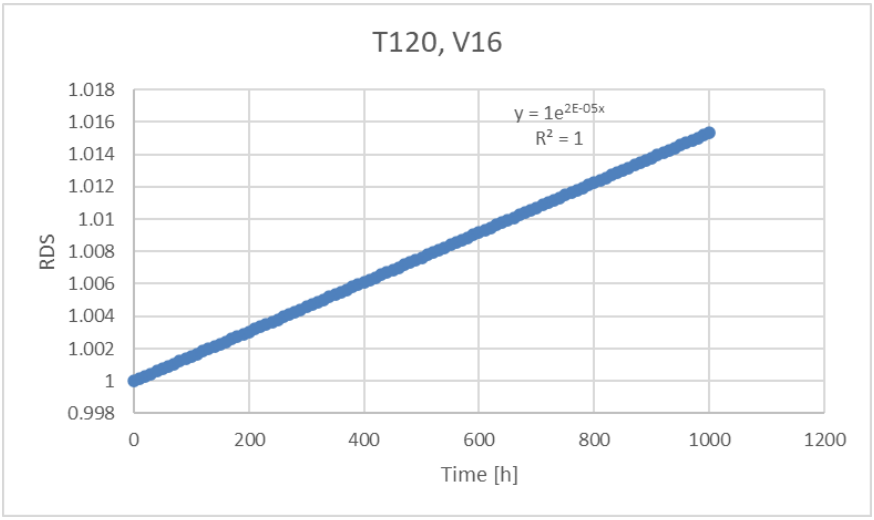

Image 12 – GaN Degradation Curve T120, V16

Using the exponential equation from the graphs, the a values of each condition can be obtained. This can be used to calculate the TTF for each condition using the equations above.

Table 4 – TTF of GaN Trials

	T80C_V12V	T80C_V14V	T80C_V16V	T80C_V18V	T-20C_V16V	T25C_V16V	T120C_V16V
a	9.00E-07	2.00E-06	4.00E-06	7.00E-06	5.00E-08	5.00E-07	2.00E-05
TTF	202579.51	91160.78	45580.39	26045.94	3646431.14	364643.11	9116.08

The equation $TTF(T,V) = -\gamma V * e^{\frac{Ea}{KT}}$ is used for GaN to find Ea and γ values.

Using the same method as with Silicon and Graphing Ln(TTF) vs 1/KT and ln(TTF) vs V.

At least 3 trials of the same T values and same V values are needed to obtain a usable model. In this case there are 4 of each T and V.

Afterwards the A constant values from the TTF equation will be found for each condition by solving for A using the found Ea and gamma values.

In the first graph T= 80C is constant. Using log laws the equation can be written as the following:

Constant T: $\ln(TTF) = -\gamma \ln(V) + \ln(C)$

Table 5 – Finding Ea for GaN T=80C

V	T(K)	TTF	1/KT	Ln(TTF)	LN(V)	A
12	353	202579.5	32.875260	12.21889	2.484907	439803.8
14	353	91160.78	32.875260	11.42038	2.639057	432899.5
16	353	45580.39	32.875260	10.72723	2.772589	426388.4
18	353	26045.94	32.875260	10.16762	2.890372	443087.2

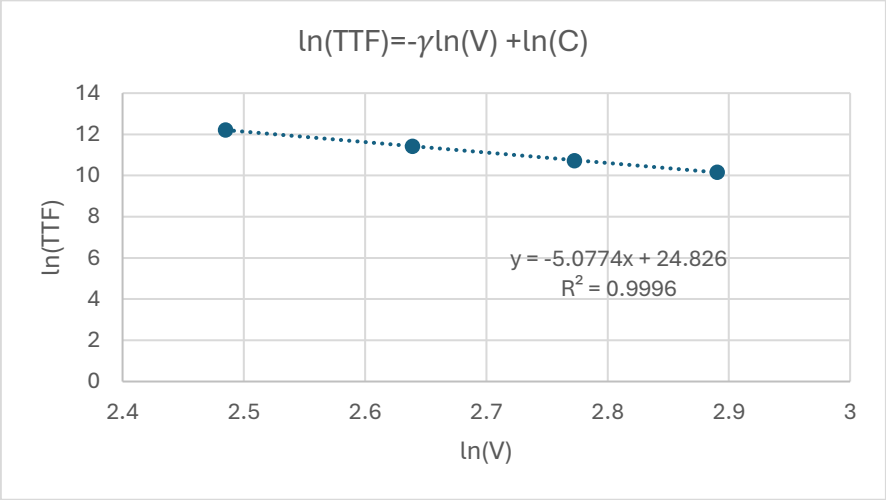

Image 13 – GaN deriving Gamma

In the second graph Voltage is constant at V=16V.

Constant V: $\ln(TTF) = \frac{Ea}{KT} + \ln(C)$

Table 6 – Finding Ea for GaN V=16V

V	T(K)	TTF	1/KT	Ln(TTF)	A
16	253	3646431.136	45.869434	15.10926	316358.4
16	298	364643.1136	38.942842	12.80667	383465.4
16	353	45580.3892	32.875260	10.72723	426388.4
16	393	9116.07784	29.529178	9.117795	284624.8

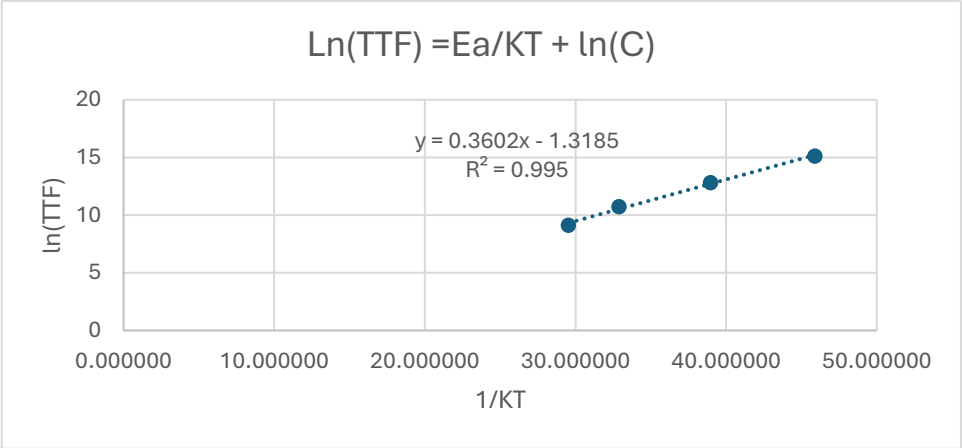

Image 14 – GaN deriving Ea

Using the outcomes of the slopes of each graph:

$Ea = 0.3602$

$\gamma = 5.0774$

A is calculated table 5 and 6 by solving the TTF equation for A. Then the average A value is found;
A_{avg} = 384480.3382

To get a more accurate A value , the *solver* will be used to minimize the sum of the error between the measured and calculated TTF values (based off of the each T/V individual calculated A values).

Table 7 – Optimizing A using solver

	V	T(K)	1/KT	A	ln(A)	TTFmeas	MODELindA	Error=((meas-calc)^2
T80C_V12V	12	353	32.87526041	439803.7753	12.99408394	202579.5075	146040.9506	3196608417
T80C_V14V	14	353	32.87526041	432899.5122	12.97826091	91160.7784	66766.56321	595077734.5
T80C_V16V	16	353	32.87526041	426388.4307	12.96310602	45580.3892	33893.05451	136593792.2
T80C_V18V	18	353	32.87526041	443087.1765	13.00152182	26045.93668	18637.55305	54884148.12
T-20C_V16V	16	253	45.86943449	316358.4393	12.66463115	3646431.136	3654489.219	64932705.59
T25C_V16V	16	298	38.94284203	383465.3951	12.85700466	364643.1136	301494.873	3987700289
T120C_V16V	16	393	29.52917793	284624.7764	12.55892702	9116.07784	10154.84773	1079042.89
							SUM	8036876129

A_{solver} =317057.546

With this the life time equation can be build for GaN:

$$TTF(T,V) = 317057.546 \cdot V^{-5.0774} \cdot e^{\frac{0.3602}{KT}}$$

Reliability Prediction

Using the fitted compact models, a safe operating region will be determined for the electric scooter.

Using the TZ: 342785**912**

The safe operating region will be:

$$R(t = 17yrs.) \geq 99.12\% \text{ where } R(t) = e^{\left(\frac{-t}{TTF(V,T)}\right)}.$$

$$t = 17yrs. \cdot 365days \cdot 24hours = 148920\ [hours]$$

$$TTF_{Si}(T,V) = 122.325 \cdot e^{\left(\frac{0.5254}{KT}\right)} \cdot e^{(-5.0231 \cdot V)}$$

$$TTF_{GaN}(T,V) = 317057.546 \cdot V^{(-5.0774)} \cdot e^{\left(\frac{0.3602}{KT}\right)}$$

A sweep of the reliability for each of the materials was done using Temperatures from 10°C to 200°C (jumps of 10°C) and Voltages of 0.1V to 2V (jumps of 0.1V) for the Si component and 1V to 20V (jumps of 1V) for the GaN component.

The reliability of the system was found by taking the minimum reliability at each given temperature:

$$TTFsys = min\,(TTFSi, TTFGaN).$$

$$R(t)_{sys} = e^{\left(\frac{-t}{TTF_{sys(T,V)}}\right)}$$

The calculated values were then filtered to give the highest Voltage for each material at the given temperature where the $R(t = 17\ yrs.)_{sys} \geq 99.12\%$. These values were graphed and plotted.

These values show the required parameters the electric scooter needs to last the required 17 years and the requested reliability of 99.12%.

Table 8 – TTF Si (T/V)

T | V	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2
10	1.68369E+11	1.0189E+11	61653948280	37308727146	22576674489	13661849920	8267211512	5002747548	3027318581	1831924898	1.109E+09	670821144	405934798	245643808	148646730	89950772.64	54432018.17	32938512	19932120.98	12061548.11
20	80707481250	4.8839E+10	29553768799	17883907309	10822110128	6548796390	3962880958	2398062874	1451142643	878131675.4	531384867	321557557	194584507	117749155	71253686.2	43117828.01	26091942.61	15789048.3	9554445.604	5781693.047
30	40611108973	2.4575E+10	14871128508	8998983704	5445565726	3295281673	1994077723	1206678627	730198874.7	441866114.7	267386968	161804194	97912765	59250068	35854064.2	21696412.58	13129175.99	7944873.9	4807691.004	2909283.783
40	21351806381	1.2921E+10	7818684705	4731329987	2863075349	1732536196	1048411691	634426615.4	383911333.3	232316722.3	140582095	85070610	51478880	31151475.9	18850729.7	11407164.5	6902831.04	4177118.37	2527704.612	1529592.902
50	11681885768	7069073446	4277716833	2588579882	1566430426	947895909.4	573601380.5	347104086.5	210043509.2	127103878.9	76914522	46543376	28164849	17043428.4	10313510.1	6241026.65	3776639.889	2285362.59	1382944.188	836862.6634
60	6627081609	4010253786	2426729650	1468489803	888628983.2	537737114.9	325401500.7	196910597.6	119156744.5	72105462.67	43633264	26403849	15977793	9668660.77	5850808.21	3540506.538	2142470.938	1296475.99	784538.0597	474748.4504
70	3885857063	2351453312	1422937743	861064011.1	521056690.4	315307655.6	190802497.1	115460542.3	69868775.48	42279775.31	25584811	15482167	9368742.2	5669318.1	3430681.22	2076012.21	1256259.741	760201.953	460021.9132	278373.6081
80	2348477912	1421137236	859974467.9	520397373.9	314908682.6	190561066.1	115314444.9	69780367.36	42226276.8	25552437.17	15462577	9356887.5	5662144.5	3426340.22	2073385.34	1254670.139	759240.0352	459439.827	278021.3695	168239.4024
90	1459270301	883049975	534361083.1	323358558.6	195674349.7	118408652.2	71652768.74	43359325.28	26238080.14	15877480.68	9607958.8	5814075.5	3518278.5	2129020.03	1288336.43	779612.5575	471767.8753	285481.456	172753.7336	104538.6725
100	930176742.1	562878960	340615615.2	206117132.9	124727906.1	75476746.34	45673333.4	27638358.63	16724832.87	10120718.03	6124362.2	3706042.6	2242642	1357092.59	821219.058	496945.2665	300717.081	181973.285	110117.7109	66635.66151
110	607026646.1	367330757	222283298.6	134510557.2	81396533.67	49255581.35	29806088.6	18036593.89	10914505.54	6604707.737	3996714.7	2418536.7	1463532	885628.858	535921.646	324302.9037	196245.8024	118754.456	71862.02544	43485.95303
120	404839609.5	244981075	148245689.7	89708090.74	54285163.78	32849645.81	19878345.29	12029006.76	7279127.184	4404826.902	2665498.1	1612976.1	976062.13	590645.639	357418.099	216284.8398	130880.7027	79199.9955	47926.38758	29001.75199
130	275479316.3	166701127	100876051.3	61043245.08	36939171.59	22353044.9	13526524.68	8185321.988	4953193.642	2997331.967	1813779.1	1097574.3	664176.43	401913.876	243210.623	147174.3337	89059.77983	53892.8506	32612.24488	19734.68658
140	190981613.2	115568931	69934364.86	42319465.49	25608828.55	15496700.92	9377537.081	5674640.182	3433901.771	2077961.068	1257439.1	760915.59	460453.76	278634.932	168610.688	102031.5864	61742.49541	37362.3098	22609.09901	13681.47101
150	134715155.2	81520342.3	49330501.83	29851425.32	18064028.55	10931107.11	6614753.864	4002793.883	2422215.429	1465758.107	886975.95	536736.81	324796.19	196544.303	118935.088	71971.33157	43552.09758	26354.7327	15948.07077	9650.675057
160	96570062.79	58437557.1	35362388.52	21398884.28	12949132.33	7835923.866	4741761.941	2869388.05	1736356.208	1050723.3	635825.44	384757.81	232828.95	140892.06	85258.1799	51592.38392	31220.16072	18892.293	11432.31578	6918.050866
170	70274151.72	42525081.1	25733252.98	15571994.02	9423099.288	5702211.294	3450585.911	2088057.162	1263548.517	764612.6188	462690.94	279988.72	169429.91	102527.323	62042.4808	37543.8403	22718.94879	13747.9445	8319.310051	5034.273999
180	51861311.6	31382897.2	18990769.99	11491907.26	6954111.524	4208149.788	2546482.693	1540956.105	932480.6027	564273.0976	341459.25	206627.64	125036.83	75663.6871	45786.4571	27706.81328	16766.25692	10145.785	6139.530969	3715.221687
190	38778522.29	23466093.4	14200065.03	8592902.262	5199833.179	3146581.244	1904094.455	1152226.945	697248.4637	421926.7932	255321.06	154502.74	93494.426	56576.3935	34236.1404	20717.35641	12536.71856	7586.35943	4590.742717	2778.001608
200	29354681.75	17763433.5	10749207.68	6504680.847	3936185.267	2381908.478	1441367.114	872216.1983	527805.2268	319391.4054	193273.7	116955.95	70773.69	42827.3676	25916.1759	15682.6864	9490.0827	5742.74505	3475.114149	2102.899963

This table shows all the TTF values for Silicon under 20 different voltages for each of the 20 different temperatures. As Temperature and Voltages grows, the TTF becomes smaller.

Table 9 – R(t=17 yrs.) Si (T/V)

T | V	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2
10	0.999999116	0.999998538	0.999997585	0.999996008	0.999993404	0.9999891	0.999981987	0.999970233	0.999950809	0.999918712	0.999865672	0.999778028	0.99963321	0.99939394	0.998998663	0.998345797	0.997267849	0.995489054	0.992556484	0.987729234
20	0.999998155	0.999996951	0.999994961	0.999991673	0.999986239	0.99997726	0.999962422	0.999937902	0.999897383	0.999830427	0.99971979	0.999536986	0.99923497	0.998736077	0.997912185	0.996552166	0.994308748	0.990612486	0.984534379	0.974571725
30	0.999996333	0.99999394	0.999989986	0.999983452	0.999972653	0.999954809	0.999925322	0.999876594	0.999796076	0.999663032	0.999443209	0.999080052	0.99848021	0.997489741	0.99585511	0.993159695	0.988721409	0.981430418	0.969499453	0.950100172
40	0.999993025	0.999988474	0.999980953	0.999968525	0.999947987	0.999914049	0.999857967	0.999765296	0.999612173	0.999359184	0.998941251	0.998250986	0.997111343	0.995230897	0.992131163	0.987029893	0.978657292	0.964976653	0.942786797	0.907230036
50	0.999987252	0.999978934	0.999965188	0.999942472	0.999904935	0.999842906	0.999740411	0.999571056	0.999291255	0.998829046	0.998065698	0.996805517	0.994726512	0.991300384	0.985664434	0.976420975	0.961335441	0.936915178	0.897911916	0.836983983
60	0.999977529	0.999962866	0.999938635	0.999898595	0.99983243	0.9997231	0.999542455	0.999244004	0.998750998	0.997936823	0.996592825	0.994375789	0.990722864	0.984715669	0.9748683	0.958810545	0.932852178	0.89148629	0.82710907	0.730751437
70	0.999961677	0.999936671	0.999895349	0.999827066	0.999714237	0.999527811	0.999219812	0.99871104	0.997870846	0.996483944	0.994196266	0.990427304	0.984230255	0.974074286	0.957520366	0.930778746	0.888214186	0.822098293	0.723450097	0.585690078
80	0.999936591	0.999895216	0.999826847	0.999713875	0.999527213	0.999218824	0.998709408	0.997868151	0.996479498	0.994188934	0.990415234	0.984210434	0.974041869	0.957467707	0.930694158	0.888080798	0.821894282	0.723153442	0.585293248	0.412645175
90	0.999897954	0.999831371	0.999721351	0.999539565	0.999239229	0.998743112	0.997923802	0.996571336	0.994340356	0.990664527	0.984619851	0.974711546	0.958555783	0.932442609	0.890839569	0.826117751	0.729304663	0.593543312	0.422301248	0.240618019
100	0.999839914	0.999735467	0.999562887	0.999277759	0.998806754	0.998028887	0.996744764	0.994626326	0.991135399	0.985393356	0.975977251	0.960613607	0.935752909	0.89607193	0.834151561	0.741062117	0.609439072	0.441153725	0.258626327	0.107009317
110	0.999754703	0.999594671	0.999330269	0.998893488	0.998172111	0.996981152	0.995016166	0.991777444	0.986448433	0.977704743	0.963425031	0.940282965	0.903251869	0.845225602	0.757390398	0.631788667	0.468207242	0.285356472	0.125895319	0.032563797
120	0.999632218	0.999392301	0.998995956	0.998341326	0.997260468	0.995476878	0.992536423	0.987696243	0.979749358	0.96675675	0.945662554	0.911807642	0.858496861	0.777143025	0.659248391	0.502310678	0.325013758	0.152543857	0.044723094	0.005887863
130	0.999459561	0.999107064	0.998524822	0.997563391	0.995976623	0.993359964	0.989050903	0.981970861	0.970382019	0.951528883	0.921175398	0.873121095	0.799141278	0.690370311	0.542097838	0.363541721	0.187845534	0.063085724	0.010395492	0.000528164
140	0.999220543	0.998712248	0.99787284	0.996487236	0.994201693	0.990436239	0.984244928	0.974098283	0.957559348	0.930841368	0.888312941	0.822249346	0.723669778	0.585984008	0.413450272	0.232341265	0.089640052	0.018576927	0.001378542	1.8741E-05
150	0.998895167	0.998174884	0.99698573	0.995023716	0.99178988	0.986468874	0.977738224	0.963479552	0.940370901	0.903391467	0.845441483	0.757710102	0.632229435	0.468747158	0.28590046	0.126292174	0.032733603	0.003515414	8.80323E-05	1.98784E-07
160	0.998459096	0.997454883	0.995797601	0.993064918	0.988565492	0.981174673	0.969082	0.949424215	0.917809146	0.867854731	0.791191512	0.67905804	0.527497484	0.347503909	0.174349291	0.055772601	0.008480425	0.000377259	2.20181E-06	4.4797E-10
170	0.997883115	0.996504191	0.994229648	0.990482261	0.984320506	0.974221894	0.957760159	0.931163978	0.888821765	0.823027807	0.72480233	0.587500275	0.415219688	0.233986731	0.09069157	0.018938417	0.001423153	1.97538E-05	1.68229E-08	1.42245E-13
180	0.997132614	0.995265981	0.992188962	0.987124918	0.978812997	0.965230376	0.943196477	0.907881606	0.852396867	0.768039003	0.646534851	0.48640351	0.303914441	0.139710447	0.038677775	0.004631608	0.000138849	4.22103E-07	2.92271E-11	3.90706E-18
190	0.996167094	0.993673917	0.989567524	0.982818728	0.97176684	0.953774932	0.924769829	0.878758317	0.807685604	0.702610761	0.558072929	0.381415324	0.2033509	0.071920551	0.012909531	0.000755466	6.93655E-06	2.9841E-09	8.16275E-15	5.23939E-24
200	0.994939721	0.991651529	0.986241481	0.977365803	0.962873164	0.939393059	0.901839622	0.843042856	0.754160902	0.627343047	0.462775363	0.279906417	0.121946635	0.030893304	0.00319484	7.51652E-05	1.53101E-07	5.46941E-12	2.44941E-19	1.75707E-31

This table shows the reliability of Silicon under the different temperatures and voltage conditions Iin a time of 17 years. Marked in red on the table shows at which Temperatures and Voltages the reliability of below the desired reliability of 92.12%.

Table 10 – TTF GaN

T | V	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
10	8.24087E+11	2.4408E+10	3114853699	722892488.3	232821354.7	92254583.66	42176673.49	21410362.08	11773408	6895616.686	4250166	2732362.1	1819856.5	1249173.1	880009.485	634124.1775	466113.5826	348700.439	264990.0569	204231.8221
20	4.97779E+11	1.4743E+10	1881487358	436653919.9	140632748	55725195.98	25476277.74	12932654.14	7111575.839	4165208.665	2567258.2	1650448.2	1099260.9	754546.962	531558.423	383034.5622	281549.921	210628.02	160063.8393	123363.6082
30	3.10851E+11	9206656896	1174941381	272679355.4	87821602.72	34798978.83	15909292.63	8076116.193	4440999.673	2601067.715	1603187.9	1030663.3	686460.7	471195.539	331944.823	239195.4194	175820.8216	131531.884	99955.82893	77037.4606
40	2.00047E+11	5924926878	756131335	175482290.7	56517428.67	22394817.94	10238395.61	5197369.517	2857997.058	1673912.278	1031728.6	663281.43	441770.51	303237.011	213622.472	153933.7661	113149.1619	84647.0988	64326.38732	49577.31412
50	1.32302E+11	3918470653	500070044.4	116055813.1	37377994.74	14810889.43	6771197.95	3437298.105	1890146.129	1107047.61	682337.25	438663.44	292166.44	200546.834	141279.952	101804.6227	74831.58519	55981.6483	42542.47625	32788.12624
60	89698394717	2656653846	339038651.6	78683790.03	25341619.79	10041521.26	4590752.532	2330427.362	1281485.668	750558.7128	462612.59	297406.06	198083.68	135967.209	95785.3106	69021.73482	50734.49214	37954.5681	28843.04698	22229.77008
70	62207756270	1842446294	235130560.2	54568892.21	17574955.63	6964009.881	3183785.122	1616201.247	888737.7342	520528.5292	320831.73	206257.47	137375.27	94296.169	66429.1627	47868.05016	35185.45601	26322.3052	20003.27032	15416.82126
80	44046307928	1304547241	166484594.2	38637597.2	12443977.31	4930879.074	2254284.486	1144354.049	629272.2685	368561.1129	227165.46	146040.95	97268.795	66766.5633	47035.282	33893.05456	24913.12214	18637.5531	14163.34966	10915.90659
90	31785962516	941424870	120143397.3	27882773.25	8980180.519	3558362.659	1626801.554	825821.6551	454113.5382	265971.6619	163933.66	105390.27	70193.903	48182.0061	33942.9519	24458.88004	17978.52314	13449.7666	10220.96341	7877.450211
100	23343054931	691365959	88231209.62	20476621	6594887.508	2613199.301	1194694.608	606468.9798	333493.04	195324.9366	120390.02	77396.769	51549.175	35384.0226	24927.1102	17962.17371	13203.11295	9877.27339	7506.09676	5785.061657
110	17421336215	515978686	65848517.77	15282065.7	4921881.601	1950277.02	891621.7909	452618.5639	248891.775	145774.467	89849.206	57762.583	38472.064	26407.7241	18603.5448	13405.48905	9853.71754	7371.58444	5601.933239	4317.494195
120	13196908826	390861160	49881184.47	11576381.12	3728394.995	1477362.454	675416.1298	342864.9701	188539.0432	110426.2226	68062.045	43755.974	29143.133	20004.2249	14092.4485	10154.84775	7464.330541	5584.07958	4243.543738	3270.562978
130	10135578481	300191811	38310082.05	8890969.918	2863506.945	1134653.827	518737.6287	263329.4553	144803.0213	84810.28855	52273.469	33605.757	22382.705	15363.779	10823.3769	7799.194316	5732.805235	4288.72227	3259.15494	2511.879727
140	7884527071	233521004	29801641.77	6916338.632	2227539.165	882653.9924	403529.1014	204845.557	112643.1356	65974.43029	40663.844	26142.119	17411.64	11951.5755	8419.56957	6067.039866	4459.583451	3336.22269	2535.316105	1954.006251
150	6206687322	183827367	23459805.57	5444530.903	1753515.331	694823.8359	317657.4745	161254.1006	88672.49934	51934.96786	32010.514	20579.035	13706.415	9408.26147	6627.87194	4775.96425	3510.577086	2626.26926	1995.796854	1538.19065
160	4940192715	146316799	18672756.43	4333556.777	1395704.86	553042.7867	252838.4403	128349.6802	70578.58928	41337.46982	25478.665	16379.817	10909.577	7488.47532	5275.43325	3801.41331	2794.232486	2090.37053	1588.548056	1224.317877
170	3972854652	117666538	15016448.04	3485003.965	1122412.195	444751.5987	203330.2001	103217.5572	56758.61103	33243.18883	20489.693	13172.488	8773.3751	6022.15859	4242.45181	3057.059395	2247.094429	1681.05553	1277.494806	984.5844592
180	3225818158	95541087.9	12192827.33	2829700.57	911359.2003	361122.6457	165096.9666	83809.02384	46085.99462	26992.29938	16636.91	10695.597	7123.6718	4889.78083	3444.72156	2482.224639	1824.561593	1364.95793	1037.280823	799.4479298
190	2642924568	78277161.4	9989627.845	2318383.985	746679.9126	295869.0991	135264.5461	68665.03852	37758.42327	22114.88921	13630.681	8762.9414	5836.4503	4006.21525	2822.27292	2033.695689	1494.86996	1118.315	849.8479566	654.990601
200	2183682479	64675499.2	8253801.703	1915534.99	616934.6876	244458.043	111760.5939	56733.60616	31197.41226	18272.14317	11262.175	7240.2678	4822.2921	3310.08389	2331.86675	1680.314943	1235.117104	923.993406	702.1759589	541.1775715

This table shows all the TTF values for GaN under 20 different voltages for each of the 20 different temperatures. As Temperature and Voltages grows, the TTF becomes smaller.

Table 11 – R(t=17 yrs.) GaN

T | V	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
10	0.999999819	0.999993899	0.999952192	0.999794015	0.999360572	0.998387073	0.996475364	0.993068623	0.987430816	0.978635203	0.965568114	0.946956337	0.921428008	0.887617064	0.844318531	0.79069451	0.72651733	0.65241694	0.570077279	0.482308474
20	0.999999701	0.999988899	0.999920853	0.99965901	0.998941632	0.997331168	0.994171613	0.988551007	0.979277223	0.964878289	0.943642954	0.913720974	0.87330288	0.820892217	0.755664827	0.677876622	0.589235532	0.493107322	0.394404288	0.299044426
30	0.999999521	0.999983825	0.999873261	0.999454013	0.998305727	0.995729708	0.990683107	0.981729412	0.967023008	0.944354729	0.91129381	0.865464017	0.804979187	0.729025087	0.638503082	0.536554481	0.428699677	0.322324343	0.225404641	0.14470103
40	0.999999256	0.999974866	0.999803069	0.999151727	0.997368529	0.993372308	0.985560023	0.971753647	0.949227843	0.914877378	0.865593151	0.798899533	0.713838806	0.611952262	0.498018691	0.380058888	0.268168764	0.172164607	0.098759408	0.049598573
50	0.999998874	0.999961996	0.999702246	0.998717647	0.996023764	0.989995616	0.978246932	0.957600381	0.924236249	0.874135431	0.803924558	0.712136423	0.600670064	0.475889455	0.34851383	0.231586472	0.136686026	0.069937208	0.030182245	0.010653273
60	0.99999834	0.999943946	0.999560854	0.998109151	0.994140734	0.985279007	0.968081379	0.938096514	0.89028925	0.820031772	0.724762821	0.606088331	0.471515415	0.334451273	0.211247064	0.115604403	0.053115782	0.019769036	0.005723836	0.00123199
70	0.999997606	0.999919176	0.99936685	0.997274693	0.991562377	0.97884279	0.954302556	0.911975648	0.845722917	0.751192129	0.628657586	0.485774757	0.338227037	0.206123571	0.106268486	0.044554053	0.014517063	0.003491027	0.000584483	6.38114E-05
80	0.999996619	0.999885852	0.999105903	0.996153141	0.988104088	0.970249998	0.936073881	0.877977291	0.789264075	0.667605519	0.519152597	0.36069809	0.216315958	0.107479218	0.042166303	0.012353442	0.002534972	0.000338726	2.71411E-05	1.18891E-06
90	0.999995315	0.999841827	0.998761249	0.994673305	0.983553559	0.959012942	0.912523364	0.834995041	0.720409406	0.57126089	0.403162239	0.243403748	0.119845509	0.045466459	0.012433492	0.002268614	0.000252723	1.55366E-05	4.70225E-07	6.16367E-09
100	0.99999362	0.999784624	0.998313585	0.992753698	0.977671917	0.944605767	0.882804857	0.78227218	0.639834295	0.466535178	0.290259581	0.146005452	0.055637823	0.01486599	0.002543489	0.000250825	1.26335E-05	2.83222E-07	2.41916E-09	6.61181E-12
110	0.999991452	0.999711425	0.997741001	0.99030257	0.970196431	0.926484111	0.846181427	0.719629514	0.549727627	0.360026342	0.190626564	0.075915108	0.020804424	0.003555501	0.000333814	1.49787E-05	2.73196E-07	1.68433E-09	2.85006E-12	1.04765E-15
120	0.999998716	0.999619068	0.997018958	0.987218265	0.960845051	0.904112696	0.802128632	0.647691948	0.453907011	0.259605341	0.112140403	0.033259296	0.006036375	0.000584691	5.57426E-05	4.27669E-07	2.16491E-09	2.61783E-12	5.74344E-16	1.67915E-20
130	0.999985307	0.99950404	0.996120318	0.983389916	0.949323019	0.877001059	0.750450531	0.568060521	0.357567337	0.172748408	0.057910073	0.011898016	0.001289693	6.17184E-05	1.05802E-06	5.0987E-09	5.22895E-12	8.31227E-16	1.43172E-20	1.78771E-26
140	0.999981113	0.999362488	0.995015424	0.978698527	0.935331709	0.844746721	0.691394978	0.483363306	0.266587898	0.104639085	0.025675413	0.003357515	0.000192985	3.87765E-06	2.08197E-08	2.18736E-11	3.14409E-15	4.11399E-20	3.09248E-26	7.96646E-34
150	0.999976007	0.99919022	0.993672227	0.973018466	0.918579755	0.807083854	0.625748435	0.397122136	0.186478674	0.056844704	0.009540385	0.000719833	1.9116E-05	1.3357E-07	1.7456E-10	2.87213E-14	3.77629E-19	2.36462E-25	3.92943E-33	8.98999E-43
160	0.999969856	0.998982726	0.992056463	0.966219368	0.898796371	0.763933969	0.55488593	0.313402243	0.121239381	0.027254335	0.002894653	0.000112599	1.17953E-06	2.30875E-09	5.49943E-13	9.69517E-18	7.14597E-24	1.14933E-31	1.9348E-41	1.49471E-53
170	0.999962516	0.99873519	0.990131887	0.958168472	0.875746573	0.715453555	0.480751522	0.236270534	0.072530882	0.011336648	0.000697475	1.23065E-05	4.24863E-08	1.82168E-11	5.69175E-16	6.9824E-22	1.65321E-29	1.36565E-39	2.36301E-51	2.05236E-66
180	0.999953836	0.998442513	0.987860547	0.948733372	0.849247779	0.662072194	0.4057511	0.16916225	0.039504114	0.004017365	0.000129584	8.97649E-07	8.33865E-10	5.93483E-14	1.67826E-19	8.80419E-27	3.57318E-36	4.14666E-48	4.46015E-63	1.25966E-81
190	0.999943655	0.998099338	0.985203104	0.937785159	0.819187003	0.60451385	0.332553782	0.113415937	0.019370178	0.001189854	1.79961E-05	4.16363E-08	8.29383E-12	7.18291E-17	1.21346E-23	1.57843E-32	5.43597E-44	1.47007E-58	7.90668E-77	1.811E-99
200	0.999931806	0.997700077	0.982119198	0.925201901	0.785537582	0.543794265	0.263819234	0.072447056	0.00845098	0.000288703	1.80848E-06	1.16762E-09	3.87525E-14	2.89188E-20	1.8393E-28	3.23677E-39	4.32948E-53	1.01104E-70	7.82107E-93	3.1034E-120

This table shows the reliability of GaN under the different temperatures and voltage conditions Iin a time of 17 years. Marked in red on the table shows at which Temperatures and Voltages the reliability of below the desired reliability of 92.12%.

Table 12 – TTF System = Min(TTF Si, TFF GaN)

T | V	0.1 | 1	0.2 | 2	0.3 | 3	0.4 | 4	0.5 | 5	0.6 | 6	0.7 | 7	0.8 | 8	0.9 | 9	1 | 10	1.1 | 11	1.32 | 12	1.3 | 13	1.4 | 14	1.5 | 15	1.6 | 16	1.7 | 17	1.8 | 18	1.9 | 19	2 | 20
10	1.68369E+11	2.4408E+10	3114853699	722892488.3	232821354.7	92254583.66	42176673.49	21410362.08	11773408	6895616.686	4250166	2732362.1	1819856.5	1249173.1	880009.485	634124.1775	466113.5826	348700.439	264990.0569	204231.8221
20	80707481250	1.4743E+10	1881487358	436653919.9	140632748	55725195.98	25476277.74	12932654.14	7111575.839	4165208.665	2567258.2	1650448.2	1099260.9	754546.962	531558.423	383034.5622	281549.921	210628.02	160063.8393	123363.6082
30	40611108973	9206656896	1174941381	272679355.4	87821602.72	34798978.83	15909292.63	8076116.193	4440999.673	2601067.715	1603187.9	1030663.3	686460.7	471195.539	331944.823	239195.4194	175820.8216	131531.884	99955.82893	77037.4606
40	21351806381	5924926878	756131335	175482290.7	56517428.67	22394817.94	10238395.61	5197369.517	2857997.058	1673912.278	1031728.6	663281.43	441770.51	303237.011	213622.472	153933.7661	113149.1619	84647.0988	64326.38732	49577.31412
50	11681885768	3918470653	500070044.4	116055813.1	37377994.74	14810889.43	6771197.95	3437298.105	1890146.129	1107047.61	682337.25	438663.44	292166.44	200546.834	141279.952	101804.6227	74831.58519	55981.6483	42542.47625	32788.12624
60	6627081609	2656653846	339038651.6	78683790.03	25341619.79	10041521.26	4590752.532	2330427.362	1281485.668	750558.7128	462612.59	297406.06	198083.68	135967.209	95785.3106	69021.73482	50734.49214	37954.5681	28843.04698	22229.77008
70	3885857063	1842446294	235130560.2	54568892.21	17574955.63	6964009.881	3183785.122	1616201.247	888737.7342	520528.5292	320831.73	206257.47	137375.27	94296.169	66429.1627	47868.05016	35185.45601	26322.3052	20003.27032	15416.82126
80	2348477912	1304547241	166484594.2	38637597.2	12443977.31	4930879.074	2254284.486	1144354.049	629272.2685	368561.1129	227165.46	146040.95	97268.795	66766.5633	47035.282	33893.05456	24913.12214	18637.5531	14163.34966	10915.90659
90	1459270301	883049975	120143397.3	27882773.25	8980180.519	3558362.659	1626801.554	825821.6551	454113.5382	265971.6619	163933.66	105390.27	70193.903	48182.0061	33942.9519	24458.88004	17978.52314	13449.7666	10220.96341	7877.450211
100	930176742.1	562878960	88231209.62	20476621	6594887.508	2613199.301	1194694.608	606468.9798	333493.04	195324.9366	120390.02	77396.769	51549.175	35384.0226	24927.1102	17962.17371	13203.11295	9877.27339	7506.09676	5785.061657
110	607026646.1	367330757	65848517.77	15282065.7	4921881.601	1950277.02	891621.7909	452618.5639	248891.775	145774.467	89849.206	57762.583	38472.064	26407.7241	18603.5448	13405.48905	9853.71754	7371.58444	5601.933239	4317.494195
120	404839609.5	244981075	49881184.47	11576381.12	3728394.995	1477362.454	675416.1298	342864.9701	188539.0432	110426.2226	68062.045	43755.974	29143.133	20004.2249	14092.4485	10154.84775	7464.330541	5584.07958	4243.543738	3270.562978
130	275479316.3	166701127	38310082.05	8890969.918	2863506.945	1134653.827	518737.6287	263329.4553	144803.0213	84810.28855	52273.469	33605.757	22382.705	15363.779	10823.3769	7799.194316	5732.805235	4288.72227	3259.15494	2511.879727
140	190981613.2	115568931	29801641.77	6916338.632	2227539.165	882653.9924	403529.1014	204845.557	112643.1356	65974.43029	40663.844	26142.119	17411.64	11951.5755	8419.56957	6067.039866	4459.583451	3336.22269	2535.316105	1954.006251
150	134715155.2	81520342.3	23459805.57	5444530.903	1753515.331	694823.8359	317657.4745	161254.1006	88672.49934	51934.96786	32010.514	20579.035	13706.415	9408.26147	6627.87194	4775.96425	3510.577086	2626.26926	1995.796854	1538.19065
160	96570062.79	58437557.1	18672736.43	4333556.777	1395704.86	553042.7867	252838.4403	128349.6802	70578.58928	41337.46982	25478.665	16379.817	10909.577	7488.47532	5275.43325	3801.41331	2794.232486	2090.37053	1588.548056	1224.317877
170	70274151.72	42525081.1	15016448.04	3485003.965	1122412.195	444751.5987	203330.2001	103217.5572	56758.61103	33243.18883	20489.693	13172.488	8773.3751	6022.15859	4242.45181	3057.059395	2247.094429	1681.05553	1277.494806	984.5844592
180	51861311.6	31382897.2	12192827.33	2829700.57	911359.2003	361122.6457	165096.9666	83809.02384	46085.99462	26992.29938	16636.91	10695.597	7123.6718	4889.78083	3444.72156	2482.224639	1824.561593	1364.95793	1037.280823	799.4479298
190	38778522.29	23466093.4	9989627.845	2318383.985	746679.9126	295869.0991	135264.5461	68665.03852	37758.42327	22114.88921	13630.681	8762.9414	5836.4503	4006.21525	2822.27292	2033.695689	1494.86996	1118.315	849.8479566	654.990601
200	29354681.75	17763433.5	8253801.703	1915534.99	616934.6876	244458.043	111760.5939	56733.60616	31197.41226	18272.14317	11262.175	7240.2678	4822.2921	3310.08389	2331.86675	1680.314943	1235.117104	923.993406	702.1759589	541.1775715

To find the TTF of the system, the minimum TTF for each condition was taken.

Table 13– R(t) System

T | V	0.1 | 1	0.2 | 2	0.3 | 3	0.4 | 4	0.5 | 5	0.6 | 6	0.7 | 7	0.8 | 8	0.9 | 9	1 | 10	1.1 | 11	1.32 | 12	1.3 | 13	1.4 | 14	1.5 | 15	1.6 | 16	1.7 | 17	1.8 | 18	1.9 | 19	2 | 20
10	0.999999116	0.999993899	0.999952192	0.999794015	0.999360572	0.998387073	0.996475364	0.993068623	0.987430816	0.978635203	0.965568114	0.946956337	0.921428008	0.887617064	0.844318531	0.79069451	0.72651733	0.65241694	0.570077279	0.482308474
20	0.999998155	0.999989899	0.999920853	0.99965901	0.998941632	0.997331168	0.994171613	0.988551007	0.979277223	0.96487289	0.943642954	0.913720974	0.87330288	0.820892217	0.75664827	0.677876622	0.589235532	0.493107322	0.394404288	0.299044426
30	0.999996333	0.999983825	0.999873261	0.999454013	0.998305727	0.995729708	0.990683107	0.981729412	0.967023008	0.944354729	0.91129381	0.865464017	0.804979187	0.729025087	0.638503082	0.536554481	0.428699677	0.322324343	0.225404641	0.14470103
40	0.999993025	0.999974866	0.999803069	0.999151727	0.997368529	0.993372308	0.985560023	0.971753647	0.949227843	0.914877378	0.865593151	0.798899533	0.713838806	0.611952262	0.498018691	0.380058888	0.268168764	0.172164607	0.098759408	0.049598573
50	0.999987252	0.999961996	0.999702246	0.998717647	0.996023764	0.989995616	0.978246932	0.957600381	0.924236249	0.874135431	0.803924558	0.712136423	0.600670064	0.475889455	0.34851383	0.231586472	0.136686026	0.069937208	0.030182245	0.010653273
60	0.999977529	0.999943946	0.999560854	0.998109151	0.994140734	0.985279007	0.968081379	0.938096514	0.89028925	0.820031772	0.724762821	0.606088331	0.471515415	0.334451273	0.211247064	0.115604403	0.053115782	0.019769036	0.005723836	0.00123199
70	0.999961677	0.999919176	0.99936685	0.997274693	0.991562377	0.97884279	0.954302556	0.911975648	0.845722917	0.751192129	0.628657586	0.485774757	0.338227037	0.206128571	0.106268486	0.044554053	0.014517063	0.003491027	0.000584483	6.38114E-05
80	0.999936591	0.999885852	0.999105903	0.996153141	0.988104088	0.970249998	0.936073881	0.877977291	0.789264075	0.667605519	0.519152597	0.36069809	0.216315958	0.107479218	0.042166303	0.012353442	0.002534972	0.000338726	2.71411E-05	1.18891E-06
90	0.999897954	0.999831371	0.998761249	0.994673305	0.983553559	0.959012942	0.912523364	0.834995041	0.720409406	0.57126089	0.403162239	0.243403748	0.119845509	0.045466459	0.012433492	0.002268614	0.000252723	1.55366E-05	4.70225E-07	6.16367E-09
100	0.999839914	0.999735467	0.998313585	0.992753698	0.977671917	0.944605767	0.882804857	0.78227218	0.639834295	0.466535178	0.290259581	0.146005452	0.055637823	0.01486599	0.002543489	0.000250825	1.26335E-05	2.83222E-07	2.4191E-09	6.61181E-12
110	0.999754703	0.999594671	0.997741001	0.99030257	0.970196431	0.926484111	0.846181427	0.719629514	0.549727627	0.360026342	0.190625654	0.075915108	0.020840424	0.003555501	0.000333814	1.49787E-05	2.73196E-07	1.68433E-09	2.85006E-12	1.04765E-15
120	0.999632218	0.999392301	0.997018958	0.987218265	0.960845051	0.904112696	0.801228632	0.647691948	0.453907011	0.259605341	0.112140403	0.033259296	0.006036375	0.000584691	2.57426E-05	4.27669E-07	2.16491E-09	2.61783E-12	5.7434E-16	1.6791E-20
130	0.999459561	0.999107064	0.996120318	0.983389916	0.949323019	0.877001059	0.750450531	0.568060521	0.357567337	0.172748408	0.057910073	0.011898016	0.001289693	6.17184E-05	1.05802E-06	5.0987E-09	5.22895E-12	8.31227E-16	1.43172E-20	1.78771E-26
140	0.999220543	0.998712248	0.995015424	0.978698527	0.935331709	0.844746721	0.691394978	0.483363306	0.266587898	0.104639085	0.025675413	0.003357515	0.000192985	3.87765E-06	2.08197E-08	2.18736E-11	3.14409E-15	4.11399E-20	3.09248E-26	7.96646E-34
150	0.998895167	0.998174884	0.993672227	0.973018466	0.918579755	0.807083854	0.625748435	0.397122136	0.186478674	0.056844704	0.009540385	0.000719833	1.9116E-05	1.3357E-07	1.7456E-10	2.87213E-14	3.77629E-19	2.36462E-25	3.92943E-33	8.98999E-43
160	0.998459096	0.997454883	0.992056463	0.966219368	0.898796371	0.763933969	0.55488593	0.313402243	0.121239381	0.027254335	0.002894653	0.000112599	1.17953E-06	2.30875E-09	5.49443E-13	9.69517E-18	7.14597E-24	1.14933E-31	1.9348E-41	1.49471E-53
170	0.997883115	0.996504191	0.990133887	0.958168472	0.875746573	0.715453555	0.480751522	0.236270534	0.072530882	0.011336648	0.000697475	1.23065E-05	4.24863E-08	1.82168E-11	5.69175E-16	6.9824E-22	1.65321E-29	3.36565E-39	2.36301E-51	2.05236E-66
180	0.997132614	0.995265981	0.987860547	0.948733272	0.849247779	0.662072194	0.4057511	0.16916225	0.039504114	0.004017365	0.000129584	8.97649E-07	8.33865E-10	5.93483E-14	1.67826E-19	8.80419E-27	3.57318E-36	4.14466E-48	4.46015E-63	1.25966E-81
190	0.996167094	0.993673917	0.985203104	0.937785159	0.819187003	0.60451385	0.332553782	0.114315937	0.019370178	0.001189854	1.79961E-05	4.16363E-08	8.29383E-12	7.18291E-17	1.21346E-23	1.57843E-32	5.43597E-44	1.47007E-58	7.90668E-77	1.811E-99
200	0.994939721	0.991651529	0.982119198	0.925201901	0.785537582	0.543794265	0.263819234	0.072447056	0.00845098	0.000288703	1.80848E-06	1.16762E-09	3.87525E-14	2.89188E-20	1.8393E-28	3.23677E-39	4.32948E-53	1.01104E-70	7.82107E-93	3.1034E-120

Using the TTF of the system, the R(t) of the system at each condition was calculated. Marked in green shows at which conditions the system reliability meets the desired threshold after 17 years. Marked in red on the table shows at which Temperatures and Voltages the reliability of below the requested amount of 92.12%.

Using the following equation: =IF(ABS(R(t)system-0.9921)<0.001,1,"0"), the R(t) can be checked for when it equals exactly R(t)=99.12% ± 0.1%

Table 15 – When R(t)=0.9921

T | V	0.1 | 1	0.2 | 2	0.3 | 3	0.4 | 4	0.5 | 5	0.6 | 6	0.7 | 7	0.8 | 8	0.9 | 9	1 | 10	1.1 | 11	1.32 | 12	1.3 | 13	1.4 | 14	1.5 | 15	1.6 | 16	1.7 | 17	1.8 | 18	1.9 | 19	2 | 20
10	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
110	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
140	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
160	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
170	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
190	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
200	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Marked in green with a 1 show at which Temperature and Voltage conditions the model will have a Reliability of exactly 99.21% with an error of ± 0.1%.

**It should be noted that by increasing the error percentage, the amount of conditions at which the system is exactly at our desired Reliability percentage grows drastically. For the sake of this specific project the error was kept low.*

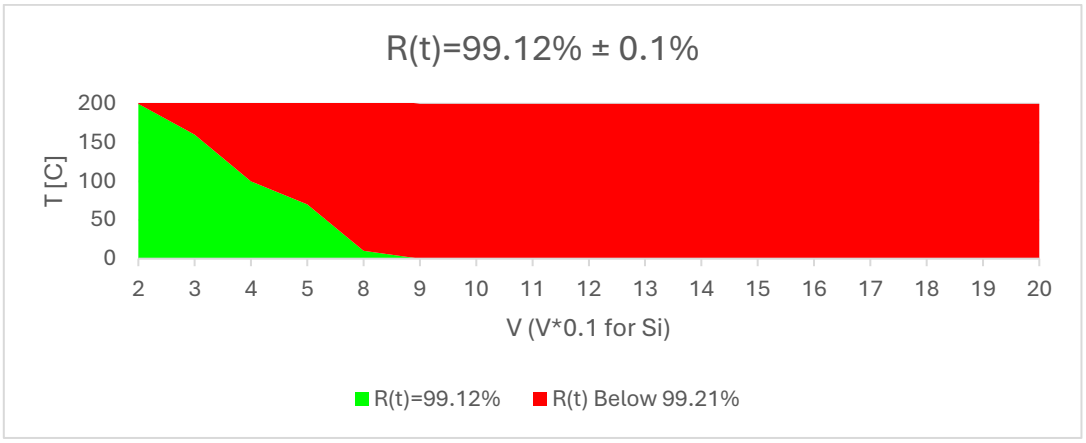

Image 15 – Boundary curve in the (Voltage, Temperature) plane where reliability is exactly 99.21%.

This graph shows where the system has a reliability of exactly 99.21% and marked in red above that is where the Reliability is lower than that.

To test which Material is the limiting factor the following logic was used in an excel equation:

IF(TTFSi<=TTFGan), if true then paste "Si", if false then paste "GaN") . If The TTF or Si was lower than it is the limiting factor, if the TTf of GaN is lower than it is the limiting factor.

Table 16 – Limiting Factor per T/V

T | V	0.1 | 1	0.2 | 2	0.3 | 3	0.4 | 4	0.5 | 5	0.6 | 6	0.7 | 7	0.8 | 8	0.9 | 9	1 | 10	1.1 | 11	1.32| 12	1.3| 13	1.4 | 14	1.5 | 15	1.6 | 16	1.7 | 17	1.8 | 18	1.9 | 19	2 | 20
10	Si	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN
20	Si	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN
30	Si	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN
40	Si	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN
50	Si	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN
60	Si	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN
70	Si	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN
80	Si	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN
90	Si	Si	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN
100	Si	Si	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN
110	Si	Si	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN
120	Si	Si	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN
130	Si	Si	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN
140	Si	Si	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN
150	Si	Si	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN
160	Si	Si	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN
170	Si	Si	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN
180	Si	Si	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN
190	Si	Si	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN
200	Si	Si	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN	GaN

Based on the results, it can be clearly seen that GaN is the limiting factor at almost every condition, except for the lowest voltages. Since the system is in series, one does rely upon the other and the GaN failing first will cause the whole system to fail. These results assume of both components being at the same temperatures and Silicon have voltage 10% that of GaN at any given moment.

According to the data, the system is more sensitive to changes in Voltage rather than changes in temperature. This can be seen in Table 13 when looking at the change in system Reliability and how it changes based on T and V. For example, as V=0.1V, as the temperature is raised the R(t) stays stable and high. When the temperature stays stable, for example at 100C, as the voltage rises, the Reliability quickly drops and becomes unreliable even at relatively low voltages. From this it can be concluded that the system is more sensitive to Voltage.