Accelerated Life Testing and Temperature Dependence of Device Characteristics in GaAs CHFET Devices

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ABSTRACT

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INTRODUCTION

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CHFET STRUCTURE

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SYNCHRONOUS RECTIFIER CHFET

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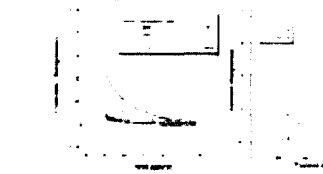
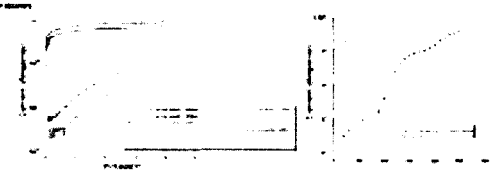
SINGLE CHFET DEVICE CHARACTERISTICS





SINGLE CHFET DEVICE TEMPERATURE DEPENDENCE RESULTS

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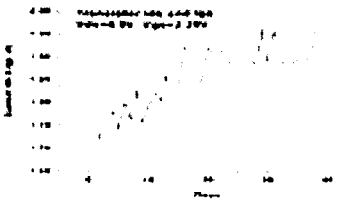

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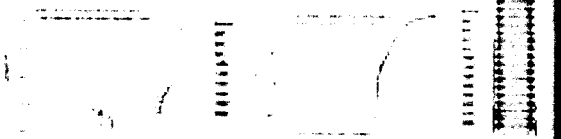
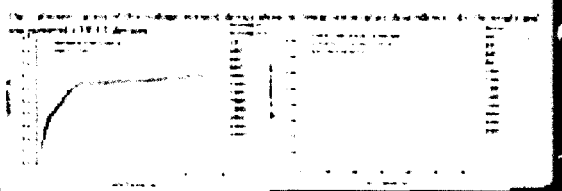
LOW POWERED THERMALLY STRESSED GaAs SYNCHRONOUS RECTIFIER



ELECTRICALLY STRESSED CHFET SYNCHRONOUS RECTIFIER



SUMMARY OF RESULTS/CONCLUSION

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REFERENCES

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ACKNOWLEDGEMENTS:

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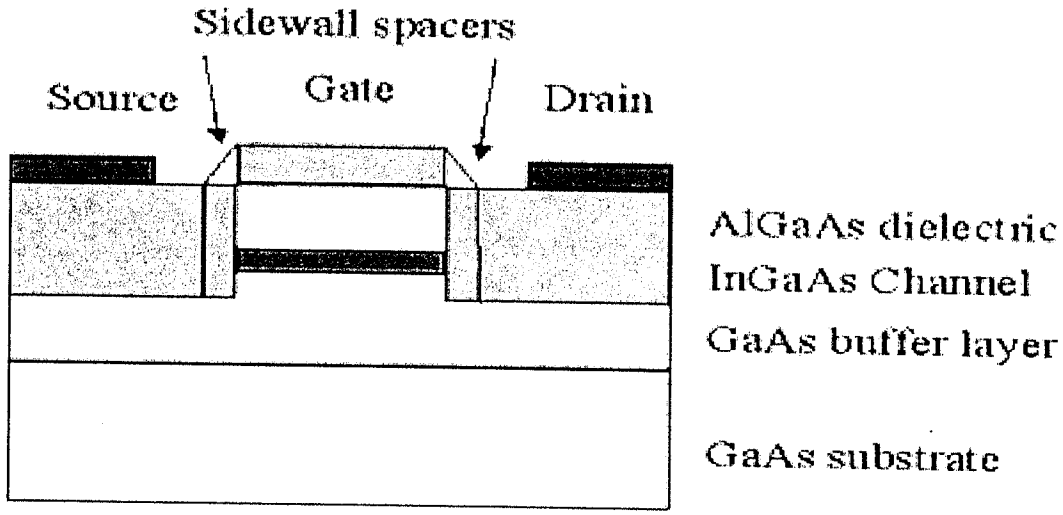
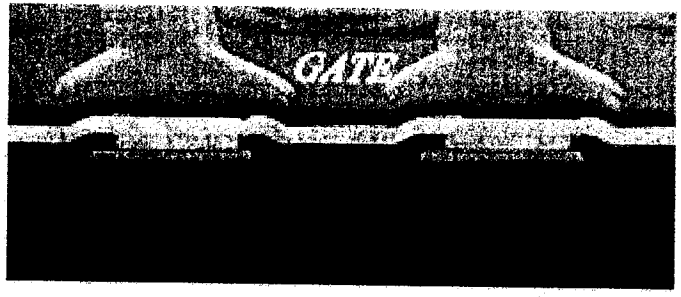
ABSTRACT:

Accelerated life testing of GaAs complementary heterojunction field effect transistors (CHFET) was carried out. Temperature dependence of single and synchronous rectifier CHFET device characteristics were also obtained. Plots of the gate current (Igs) vs. gate voltage (Vgs) show a linear dependence with temperature for low drain voltage (Vds) biased devices. An exponential increase of Igs with temperature is also observed in single and synchronous rectifier devices yielding a change in threshold voltage (Vth), which is not observed in the electrically stressed devices. This temperature dependence is also observed in the forward and reverse gate current vs. gate voltage log plots yielding a dependence in drain leakage in all devices and a small change in slope for both these characteristics for the electrically stressed devices. Extreme ESD sensitivity was observed in single devices once the device was powered. Synchronous rectifier devices exhibited a significantly lower ESD sensitivity even when thermally and electrically stressed. Data analysis of our ~1000 hour life test yields an mean time to failure MTTF of 3.7 x 10^5 hours at operational temperature of 100°C using an assumed 0.7eV activation energy.

CHFET STRUCTURE:

* Molecular Beam Epitaxy is used to grow:
  - GaAs buffer layer
  - InGaAs channel layer
  - High Al mole fraction AlGaAs dielectric layer
* WSi gate is deposited.
* Source and drain implants are made.
* Ohmic contacts are added for source and drain.
* Channel length is 0.7 micrometers





INTRODUCTION:

GaAs complementary heterojunction field effect transistors have exhibited good operation at high temperature (>500K) and cryogenic (4K) digital application in both experimental and simulation device tests [1,2,3]. This heterojunction III-V material technology has also demonstrated superior tolerance and performance under high dose rate radiation exposure [4]. These characteristics make the GaAs CHFET an attractive candidate for space applications, high temperature applications such as jet engine control systems, and automotive technology. Due to high electron velocity in the n-channel, CHFET devices are 2-3 times faster than similar silicon-on-insulator (SOI) technology [5]. Such highly reliable and radiation-hard devices might be of interest for deep space and outer planet exploration. Some of the requirements for these projects include a long life (>10 years), total ionizing dose of 4 Mrad, average power consumption below 150W, and reduction in cost [6]. Here we report on both the temperature dependence and on the life expectancy of CHFET synchronous rectifier devices tested under thermal stress and voltage stress.

SYNCHRONOUS RECTIFIER CHFET:

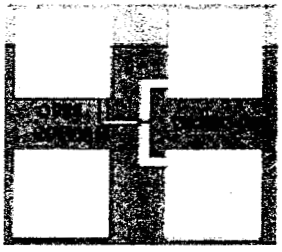
Life and temperature dependence, from room temperature (~300 K) to 513 K, test were performed on these devices using different stress procedures in order to obtain results in a reasonable time frame. Step-voltage stressing was also performed at 473 K using the real time LabView program for >1000 hours. Table-1 shows the parameters used.

Voltage stressing was performed on the CHFET synchronous rectifier at 513 K using non-stepped voltage stressing using the following parameters: Gate Current Vgs = 0 - 5V; Drain Leakage Vgs = 0 - 4V; Transistor Curve Vgs = 0-5V and Vds = 2.25V; and Transistor On Curve Vgs = 4V and Vds = 2.25V

TABLE-1

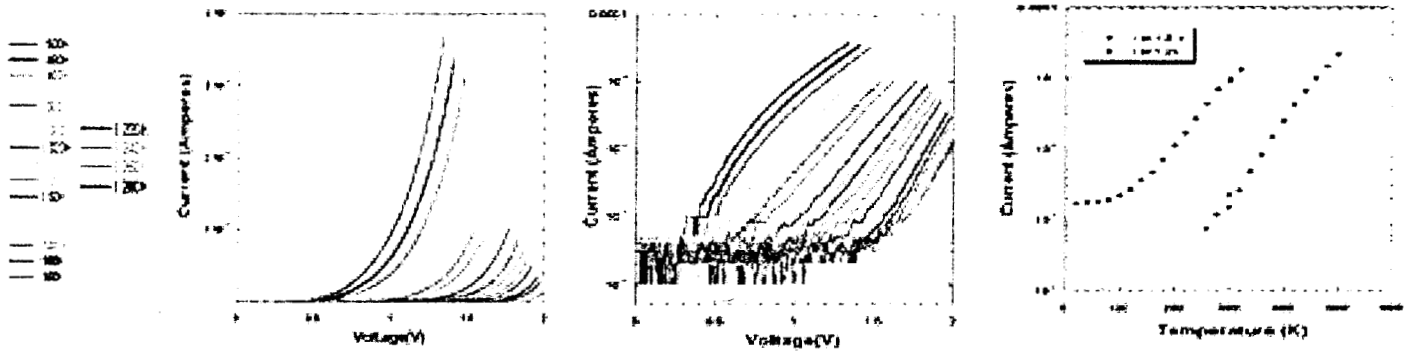
Days	Gate Current	Drain Leakage	Transistor Curve		Transistor On Curve	
	Vgs (V)	Vgs (-V)	Vgs (V)	Vds (V)	Vgs (V)	Vds (V)
0 - 11	0 - 1.5	0 - 4.5	0 - 2	1	0.5	1
12.-17	0 - 1.5	0 - 5	0 - 2.5	1.25	1.25	1
17 - 24	0 - 5.3	0 - 6	0 - 5	2	3	2
24 - 32	0 - 5.3	0 - 6	0 - 5	2.25	4	2.25

SINGLE CHFET DEVICE CHARACTERISTICS:

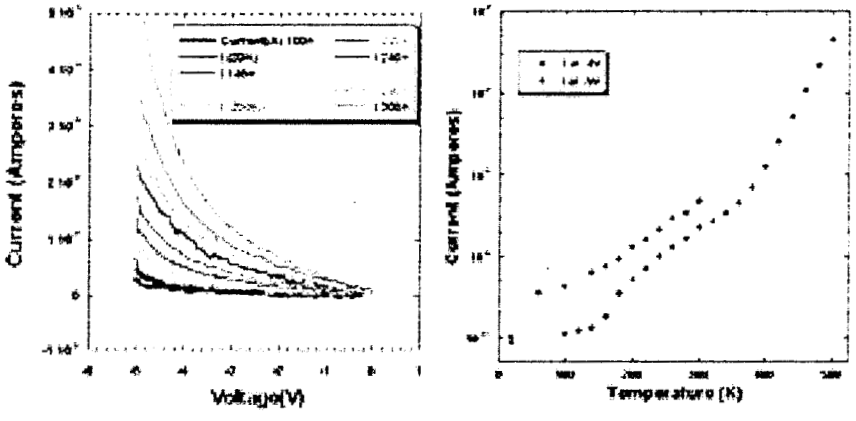


Temperature dependent I-V measurements were performed from 20K to 500K. Graph shows linear measurements of gate current.

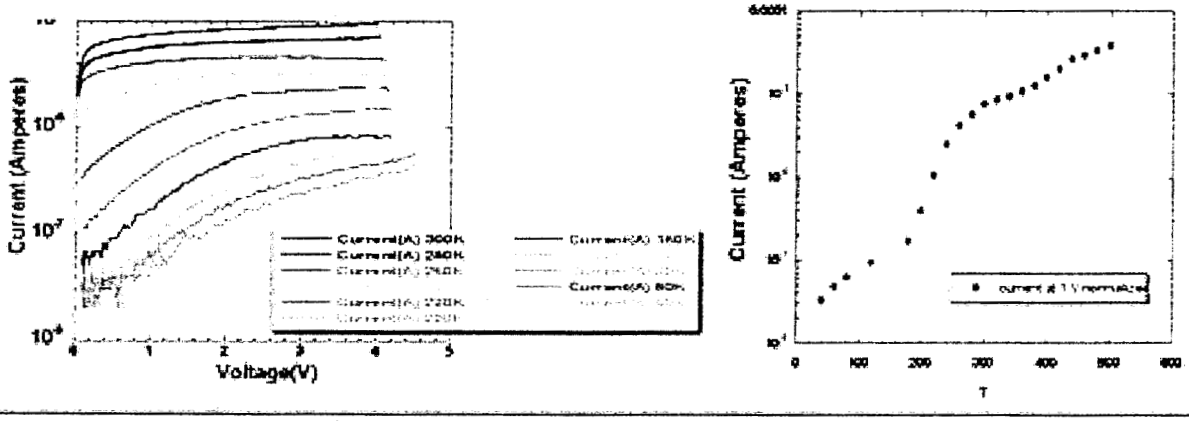
Log I-V curves show decrease in slope with increasing temperature.
Gate current at 1.2 V and at 1.8 V show exponential increase with temperature.



Gate body leakage (2-terminal measurement at reverse bias) also shows an exponential increase with temperature. Curve on the right shows measured values at –4V and –5V. The cause(s) for the change in slope above room temperature are still under investigation.



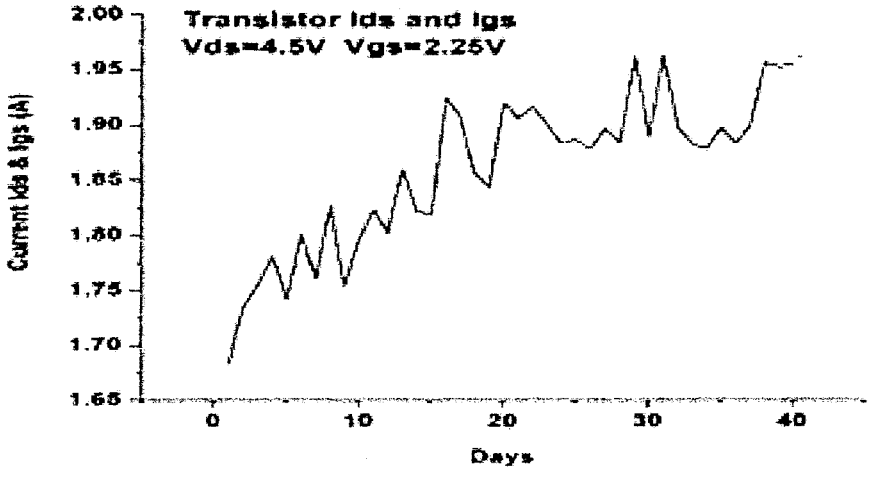
Log of I-V curves with gate biased at 600mV show current decreases exponentially with decreasing temperature. Furthermore, voltage threshold change strongly, and curves become sub-threshold at the lowest temperatures.



SINGLE CHFET DEVICE TEMPERATURE DEPENDENCE RESULTS:

* Device to device variations were observed in power CHFETS
* For 2-terminal measurements (I-V gate - source, drain open)
  - Exponential increase in forward current with temperature (Linear from ~ 100K to 500K)
  - Log of forward I-V curves show:
    a) Decrease in slope with temperature
    b) Non linear behavior ("bump" for low voltage values) at high temperatures > 400K
  - Reverse current also shows exponential increase with temperature with a steeper slope above 300K
* For 3-terminal measurements (connecting all 3 terminals and varying gate voltage)
  - Strong increase (exponential) in forward current values
  - Large changes in threshold voltage with decreasing temperature (mainly below room temperature)

MEAN TIME TO FAILURE ESTIMATION:



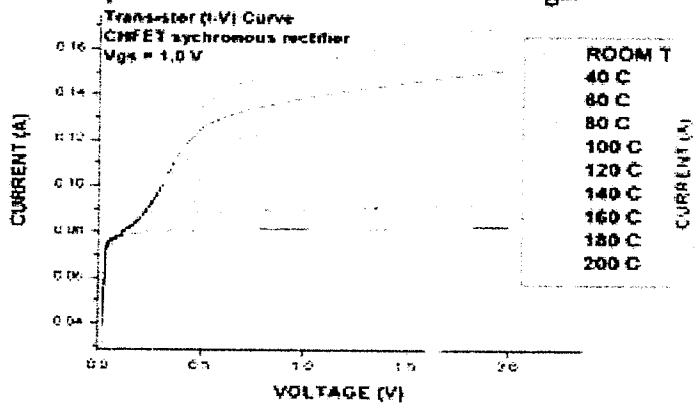
An estimated mean time to failure (MTTF) can be extrapolated from the results of our life test. The synchronous CHFET was tested using the experimental setup described in the experimental portion of the presentation. Even though no real failure was recorded, the transistor showed degradation of <20% after ~1000 hrs. Assuming a low activation energy Ea value for GaAs devices of 0.7eV and using the following equation:

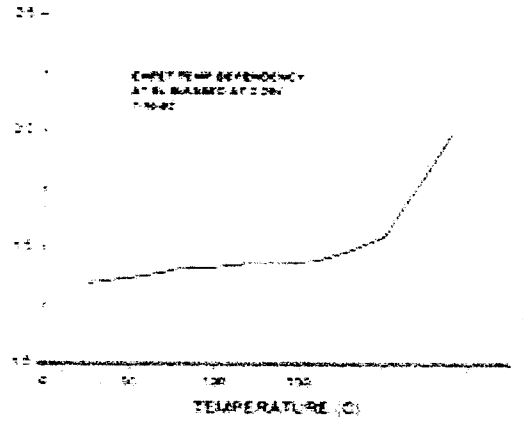
MTTF = A exp [Ea/kT] (where T is in Kelvin, and K is Boltzmann's constant)

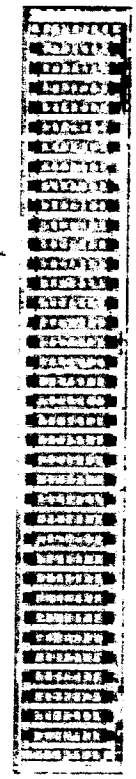
We obtain a MTTF of 3.7 x 10^5 hours (about 42 years). Further work is in progress to determine experimentally the value of Ea for these devices.

LOW POWERED THERMALLY STRESSED CHFET SYNCHRONOUS RECTIFIER:

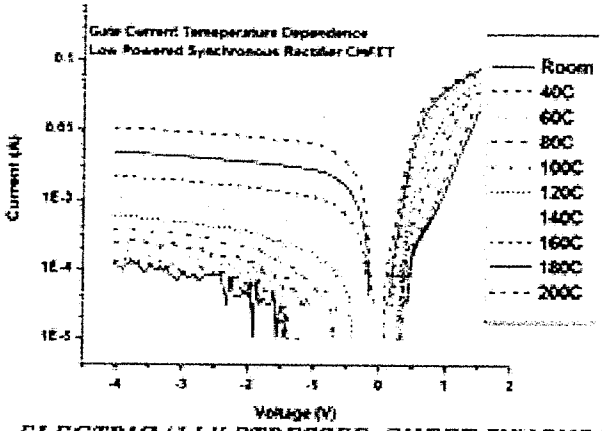
Behavior of these devices was very similar to those observed of the single CHFET's temperature dependence plots of the Igs vs. Vgs which show linear temperature dependence. Exponential increase of gate current with temperature is observed at a constant Vgs.

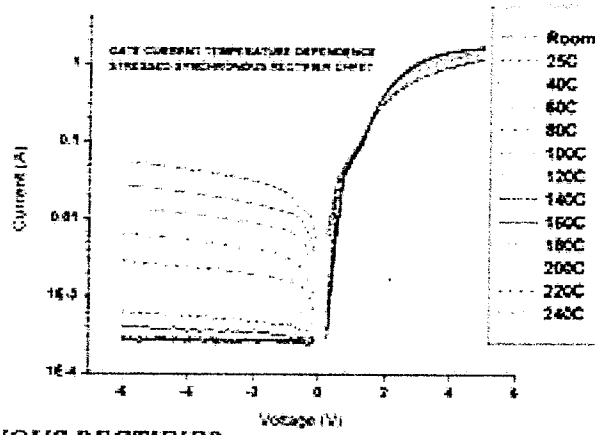






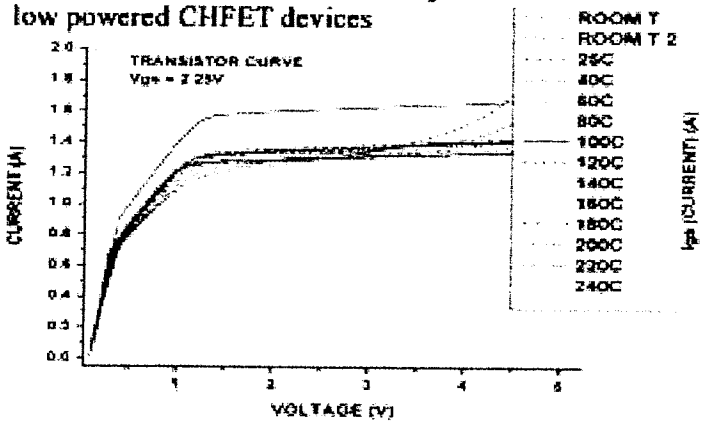
Both voltage and thermally stressed CHFET synchronous rectifier's forward and reverse gate current vs. gate voltage log plots show an increase in drain leakage and a smaller slope change as a function of temperature.

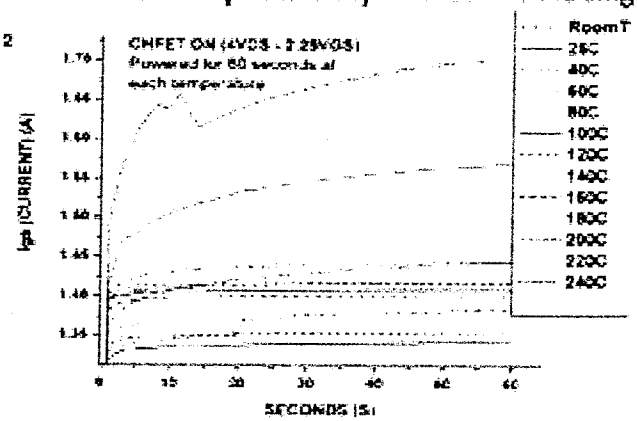




ELECTRICALLY STRESSED CHFET SYNCHRONOUS RECTIFIER:

The transistor curves of this voltage stressed device show no linear temperature dependence like the single and low powered CHFET devices





EXPERIMENTAL:

Single CHFET device characteristics, which included gate current (Igs), drain leakage (Igss), and transistor curves of biased devices, were analyzed from 20 K-500 K. A Techtronics 370A curve tracer was used to make measurements at 20 K intervals. Extreme ESD sensitivity was observed in these devices when powered.

Accelerated life tests were performed on CHFET synchronous rectifier devices using both thermal and electrical stresses (at 200 C and 240 C). Electrical and thermal stresses were applied simultaneously to determine worst-case scenario mean time to failure (MTTF) prediction. Device characteristics with temperature dependence were also monitored at the beginning and end of the life test. The test consisted of powering devices at a constant gate voltage bias and taking device characteristic curves each 30 minutes. This was accomplished using a real time automated LabVIEW controlled experimental setup using an interfaced HP6629A power supply and a Delta-Designs 900 furnace.

SUMMARY OF RESULTS/CONCLUSION:

Single and synchronous rectifier CHFET's temperature dependence and accelerated life testing has been performed. Single and low powered synchronous rectifier devices exhibit similar temperature dependence. The plots of Igs vs. Vgs yield a linear dependence on temperature, while constant Vgs biased plots of Igs vs. Temperature shows an exponential dependence. A log of the I-V curves for single devices with gate biased at 600 mV exponentially decrease with temperature yielding a large change in threshold voltage below room temperature. Extreme ESD sensitivity was observed only in single CHFET powered devices. Steped voltage stressing of the synchronous rectifier CHFET device yielded a useful life >1000 hrs. before the 20% degradation was reached. A linear temperature dependence was not observed for the voltage stressed synchronous rectifier CHFET device. Forward and reverse gare current vs. gate voltage log plots of synchronous rectifiers CHFET temperature dependence yields an increase in drain leakage and a smaller change of both these properties with increasing temperature. Taking the results of our thermally and voltage stressed synchronous rectifier CHFET to determine a "worst-case scenario" mean time to failure (MTTF) and assuming a low value for the activation energy of GaAs devices, 0.7 eV, we derive a MTTF of 3.7 x 10^5 hours (about 42 years) at an operating temperature of 100 C (~373 K). This MTTF estimate can be considered a very pesimistic estimation being that the device was thermally and voltage stressed, a low value of activation energy was used, and the failure criteria used was device degradation < 20%. These observations suggest that this III-V technology is a good canditate for use in space applications and other high reliabilty applications.

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