A Radiation Hardened SONOS 1Mb EEPROM for Space Applications

Dennis Adams¹, Michael Fitzpatrick¹, Erica Folk¹, William Hand¹, Randall D. Lewis¹, Patrick Shea¹, Joseph Smith¹, Phillip Peyton¹, James Sheehy², Jeffrey Dame², Gary Grant², James Murray³, Marvin White⁴, Gan Wang⁴

¹ Northrop Grumman Corporation, Baltimore, MD
² Amtec Corporation, Huntsville, AL
³ Sandia National Labs, Albuquerque, NM
⁴ Lehigh University, Bethlehem, PA

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Outline

- 1Mb EEPROM Overview
- SONOS stack endurance cycling
- Memory retention study
- Qualification testing results
- Summary
The NGC EEPROM Team

- **Northrop Grumman** (Baltimore, MD) – wafer fabrication; device screening & test; product sales

- **Amtec** (Huntsville, AL) – device radiation effects analysis & radiation test; program management

- **Sandia** (Albuquerque, NM) – EEPROM design

- **Lehigh University** (Bethlehem, PA) – SONOS “stack” analysis and characterization
# Proven Rad Hard NVM Technology

<table>
<thead>
<tr>
<th>Part Number:</th>
<th>W28C64</th>
<th>W28C256</th>
<th>W28C0108</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organization:</td>
<td>8k x 8</td>
<td>32k x 8</td>
<td>128k x 8</td>
</tr>
<tr>
<td>Process:</td>
<td>1.25µm CMOS/SONOS</td>
<td>1.25µm CMOS/SONOS</td>
<td>0.8µm CMOS/SONOS</td>
</tr>
<tr>
<td>Memory Cell:</td>
<td>4T</td>
<td>4T</td>
<td>2T</td>
</tr>
<tr>
<td>Die Size:</td>
<td>6.5mm x 6.5 mm</td>
<td>8mm x 10.2 mm</td>
<td>8.3mm x 10.6 mm</td>
</tr>
<tr>
<td>Write Voltage:</td>
<td>10V</td>
<td>10V</td>
<td>7.5V</td>
</tr>
<tr>
<td>Write Time:</td>
<td>10 msec per page</td>
<td>10 msec per page</td>
<td>100 msec per page</td>
</tr>
<tr>
<td>Read Access:</td>
<td>250 nsec</td>
<td>250 nsec</td>
<td>250 nsec</td>
</tr>
<tr>
<td>Retention:</td>
<td>10 years @ 1E4 cycles</td>
<td>10 years @ 1E4 cycles</td>
<td>10 years @ 1E4 cycles</td>
</tr>
<tr>
<td>Production:</td>
<td>2Q93</td>
<td>2Q00</td>
<td>2Q08</td>
</tr>
</tbody>
</table>
Commercial Compatibility

The inner 32 pins are JEDEC compatible with commercial parts such as the Renesas HN58C1001.
# Rad Hard 1Mb EEPROM Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organization</td>
<td>128Kb x 8</td>
</tr>
<tr>
<td>Power Supplies</td>
<td>+3.3 V (Vdd), -4.2 V (Vwr)</td>
</tr>
<tr>
<td>Program Time (page)</td>
<td>100 ms</td>
</tr>
<tr>
<td>Endurance</td>
<td></td>
</tr>
<tr>
<td>Write</td>
<td>1E4 cycles (min)</td>
</tr>
<tr>
<td>Read</td>
<td>Infinite cycles</td>
</tr>
<tr>
<td>Read Access Time</td>
<td>250 ns</td>
</tr>
<tr>
<td>Retention</td>
<td>&gt;10 yrs @ +125° C</td>
</tr>
<tr>
<td>Temperature</td>
<td>-55 to +125C</td>
</tr>
<tr>
<td>Power Dissipation</td>
<td></td>
</tr>
<tr>
<td>Standby</td>
<td>1 mW</td>
</tr>
<tr>
<td>Read</td>
<td>60 mW</td>
</tr>
<tr>
<td>Write</td>
<td>40 mW</td>
</tr>
<tr>
<td>Radiation</td>
<td></td>
</tr>
<tr>
<td>Total Dose</td>
<td>300 krad(Si)</td>
</tr>
<tr>
<td>Prompt Dose Upset (logic)</td>
<td>&gt;1E8 rad(Si)/s</td>
</tr>
<tr>
<td>Prompt Dose Upset (memory)</td>
<td>&gt;1E12 rad(Si)/s</td>
</tr>
<tr>
<td>Prompt Dose Survivability</td>
<td>&gt;1E12 rad(Si)/s</td>
</tr>
<tr>
<td>SEU (logic)</td>
<td>40 MeV-cm2/mg</td>
</tr>
<tr>
<td>SEU (memory)</td>
<td>&gt;94 MeV-cm2/mg</td>
</tr>
<tr>
<td>Latch-up</td>
<td>None</td>
</tr>
</tbody>
</table>

- NGC 1Mb EEPROM has been successfully characterized in all radiation environments and has successfully passed life testing (1000 hour @ +150° C).
## Summary of 1M EEPROM Radiation Test Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>TID [krad(Si)]</td>
<td>300</td>
<td>&gt;500</td>
</tr>
<tr>
<td>Prompt Dose - Transient [rad(Si)/s]</td>
<td>&gt;1E8</td>
<td>2.9E8&lt;br&gt;Data recovered in one read cycle (1600 nsec)</td>
</tr>
<tr>
<td>Prompt Dose – Memory [rad(Si)/s]</td>
<td>&gt;1E12</td>
<td>&gt;6E12</td>
</tr>
<tr>
<td>Prompt Dose – Survivability [rad(Si)/s]</td>
<td>&gt;1E12</td>
<td>&gt;6E12</td>
</tr>
<tr>
<td>SEU – Logic (MeV-cm2/mg)</td>
<td>40</td>
<td>&gt;122&lt;br&gt;(Au, 45 degree Angle)</td>
</tr>
<tr>
<td>SEU – Memory (MeV-cm2/mg)</td>
<td>&gt;94</td>
<td>&gt;122&lt;br&gt;(Au, 45 degree Angle)</td>
</tr>
<tr>
<td>Latch-up</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>
SONOS Stack Endurance Cycling

2004 Process:
NGC Lot # 64017-1 Array
1000 NSONOS 5.0 x 0.8μm Transistors

2007 process:
NSONOS 1000 x 5 um x 0.8 um Transistor Array
Package 65512-7-10

"Optimized Process" has minimal degradation after 10 million cycles
1Mb EEPROM Activation Energy Study

- 1M EEPROM parts (59) characterized @ +225/+250/+300°C for memory retention

- Parts programmed once at each temperature (+7.5 V / 25 msec, -7.5 V / 75 msec, topological checkerboard)

- Arrhenius equation calculations used to determine the 1M EEPROM retention activation energy
  - \[ MTF = k e^{E_a/kT} \]
  - \( E_a = 1.68 \text{ eV} \) for NGC 1M EEPROM retention

- NGC uses an aggressive screen to guarantee >10 year memory retention on all EEPROM products (2 days @ +250°C – all die)
  - NSONOS transistor data taken at +250°C to quantify SONOS transistor level retention acceleration effects

- **Key finding** – Based on this data, NGC 1Mb EEPROM product will have >>100 year memory retention at +125°C
1Mb EEPROM Activation Energy Study

Arrhenius/Lognormal

- 125°C
- 225°C
- 250°C
- 300°C

Fail = 34 | Suspend = 25
Fail = 38 | Suspend = 8
Fail = 58 | Suspend = 0

CL: 95% 1-sided
Ea = 1.68 eV; sigma = 0.68

- 0.1% failures at 1.6E5 days (440 years)
- 0.1% failures at 9.3E4 days (250 years) at 95% LL confidence

Time (days)

Cumulative 1Mb EEPROM failures (%)
1Mb EEPROM Activation Energy Study

Arrhenius/Lognormal
- Median life
- Fail = 130 | Suspend = 33
- CL: 95% 1-sided
- $E_a = 1.68$; $\sigma = 0.68$

For 125°C operating temp:
- Median life = 3500 years
- 95% LL confidence
- Median life = 2100 years
SONOS Memory Retention Screen Acceleration Effects

SONOS transistor array - 1000 x 4 um x 0.8 um (7 parts)

2 days @ +250°C retention screen is equivalent to 2600 years @ +125°C

Lehigh University Data

+7.5 V / 25 msec

Time (s)

Threshold Voltage (V)

+250 C

+250 C

-7.5 V / 75 msec

1.73E3 sec

+125 C

10 years

+250 C

+125 C

2600 years @ +125°C

8E10 sec

Calculated $E_a = 1.86$ eV

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1Mb Qualification Testing Results

- **Life Test**
  - 10 device sample (1Mbit EEPROM)
  - 1000 hr burn-in at 150°C
  - All devices passed post 1,000 hr electrical testing
  - Tests were performed at 25°C, -55°C, and +125°C

- **Total Dose Radiation**
  - 6 device sample (1Mbit EEPROM)
  - 3 devices 300 Krad
  - 3 devices 1Mrad
  - All devices passed post radiation testing
Negligible change with 1000 hour @ 150° C life test or 1 Mrad(Si) total ionizing dose for NGC 1Mb EEPROM

Part specification = < 2 mA
Minimal change in NGC 1Mb EEPROM access time with life test and with 300 krad
Summary

- A 1Mb (128k x 8) SONOS EEPROM has completed qualification testing
- Recent process optimization has resulted in significant improvements in SONOS retention and endurance
- Extensive 1Mb activation energy characterization indicates >>100 year memory retention at +125° C
- Device has been fully characterized in all radiation environments
- Device has passed 1000 hour @ +150° C life tests; – no reliability issues seen with this part
- Engineering parts are available NOW; - Production parts available 2Q ‘08
Acknowledgements

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for their past and continued support of these programs.
“You can be sure if it’s ...........

Northrop Grumman’s Rad-Hard EEPROM Technology

2Kb BORAM device programmed in December 1976

No dropped bits as of October 18, 2007 – 31 years of retention!!