Between Fuses and Flash

An Overview of CMOS NVM in Consumer Applications
Agenda

- Definition of CMOS NVM
- Market Landscape
- Technologies
- Applications
- Summary / Conclusions
**What Is CMOS NVM?**

- **CMOS NVM** = nonvolatile memory manufactured in a standard CMOS process
  - No additional masks or processing steps
- Includes several different technologies
  - **MTP** = Multiple Time Programmable
    - Up to 1M cycle endurance
  - **FTP** = Few Time Programmable
    - ~100 cycle endurance
  - **OTP** = One Time Programmable
    - Either floating gate or antifuse based technologies
Embedded NVM Landscape

Traditional Fuses and Flash Leave Significant Applications Unserviced
Embedded NVM Landscape

CMOS NVM Fills the Gap

Embedded Flash

Bit Count

>128k

1k – 64k

256 – 1k

<128

Write Cycle Endurance

1

2 – 100

100 – 1k

1k → 1M

CMOS OTP

Fuse

CMOS FTP

CMOS MTP
## Embedded Flash Overview

*Includes Other Mask Adder Solutions (SONOS, FRAM, MRAM, etc.)*

### Basic Technology
- Floating gate / charge storage
- Process / mask adders to standard CMOS process
- Available from foundries – technology from 3rd parties
- Available down to 90nm?

### Advantages
- High endurance (20k $\rightarrow$ 100k write-erase cycles)
- High density (>1Mb)
- Production proven for high reliability applications (i.e. automotive)

### Target Applications
- Microcontrollers
- Embedded code storage

### Limitations
- Process cost / complexity
- 25% $\rightarrow$ 100% wafer adder
- Advanced process node support
- Long test times for large arrays (several seconds)
# Fuse Overview

*Includes Other Mask Adder Solutions (SONOS, FRAM, MRAM, etc.)*

## Basic Technology
- Overstress of poly, metal, oxide to create an open/short
- Developed and available from foundries
- Available down to 40nm

## Advantages
- ~Free from the foundry
- Available early in process life – foundries develop fuse technology along with advanced nodes

## Target Applications
- Trim
- Device ID

## Limitations
- One time programmable only
- Limited bit count
- Long-term reliability concerns
# OTP Overview

## CMOS Based OTP Technology

### Basic Technology
- Floating Gate – typically hot carrier injection
- Antifuse – overstress of gate oxide causing a short
- Available down to 55nm

### Advantages
- High density (1Mb or more)
- Low cost CMOS process

### Target Applications
- Code storage
- Encryption keys
- Trim / configuration data

### Limitations
- One time programmable only
- Long test time for large arrays
- No electrical testing capability

---

*Image credit: [VIRAGE Logic]*
# MTP / FTP Overview

*Reprogrammable NVM in Standard CMOS*

<table>
<thead>
<tr>
<th>Basic Technology</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Floating Gate – combination of FN-FN and hot carrier-FN</td>
<td>• High endurance (MTP) up to 1M cycles</td>
</tr>
<tr>
<td>• Single poly standard CMOS process</td>
<td>• Minimal area (FTP)</td>
</tr>
<tr>
<td>• Supports up to ~16k bits</td>
<td>• High temperature (150°C operation)</td>
</tr>
<tr>
<td>• Available down to 65nm</td>
<td>• Qualified to meet automotive standards</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Target Applications</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Encryption keys</td>
<td>• Currently limited to ~16kbit</td>
</tr>
<tr>
<td>• Datalogging</td>
<td>• Currently requires 50A gate oxide (solutions already in development)</td>
</tr>
<tr>
<td>• Trim / configuration settings</td>
<td></td>
</tr>
</tbody>
</table>
Key Applications
CMOS NVM in Smartphones

Baseband Processor
- OTP

Flash / DRAM
- MTP

System Power Management
- MTP

RF FE Power Amps

Digital Media Controller
- OTP / MTP

BlueTooth/WiFi/GPS/RFID
- FTP

MEMS / Gyro
- FTP

Battery Fuel Gage
- MTP

Display Controller
- FTP

Configuration / Performance settings
- Encryption Keys

Real-time datalogging
- Performance Trimming / Calibration

Code Storage

Performance Trimming / Device mating
Code Storage Applications

Using OTP to Store Boot / Firmware Code

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>★★★★★</td>
</tr>
<tr>
<td>Area</td>
<td>★★★</td>
</tr>
<tr>
<td>Flexibility (i.e. reprogrammability)</td>
<td>★★</td>
</tr>
<tr>
<td>Power</td>
<td>★</td>
</tr>
</tbody>
</table>

- **CMOS NVM Advantages**
  - Post-fab programming (ROM)
  - Advanced process node support (eFlash)
  - Available at power-up (external)

- **Competing Solutions**
  - Mask ROM
  - Embedded Flash
  - External NVM

- **End Products**
  - Consumer electronics
  - Automotive
  - Energy monitoring
  - Medical
# Storing Encryption Keys

**OTP or MTP to Store AES, HDMI, etc. Keys**

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Importance</th>
<th>CMOS NVM Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>★</td>
<td>• Secure – both floating gate and antifuse</td>
</tr>
<tr>
<td>Area</td>
<td>★ ★ ★</td>
<td>• Advanced process support</td>
</tr>
<tr>
<td>Flexibility (i.e. reprogrammability)</td>
<td>★ ★ ★</td>
<td>• Ability to tightly integrate with crypto engine</td>
</tr>
<tr>
<td>Power</td>
<td>★ ★</td>
<td>• MTP allows proactive / reactive key updates</td>
</tr>
</tbody>
</table>

- **Competing Solutions**
  - Software implementation (no NVM needed)
  - External Storage

- **End Products**
  - HDMI Tx/Rx
  - Digital media controllers
  - Secure Flash Drives
  - Encrypted HDD

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>★</td>
</tr>
<tr>
<td>Area</td>
<td>★ ★ ★</td>
</tr>
<tr>
<td>Flexibility (i.e. reprogrammability)</td>
<td>★ ★ ★</td>
</tr>
<tr>
<td>Power</td>
<td>★ ★</td>
</tr>
</tbody>
</table>
Real-time Datalogging

**OTP or MTP to Store AES, HDMI, etc. Keys**

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>⭐⭐</td>
</tr>
<tr>
<td>Area</td>
<td>⭐⭐</td>
</tr>
<tr>
<td>Flexibility (i.e. reprogrammability)</td>
<td>⭐⭐⭐⭐⭐</td>
</tr>
<tr>
<td>Power</td>
<td>⭐⭐⭐⭐</td>
</tr>
</tbody>
</table>

- Competing Solutions
  - Embedded Flash

- CMOS NVM Advantages
  - Up to 1M cycle endurance
  - Support for BCD processes
  - High temperature operation (150°C)

- End Products
  - Portable Devices
  - Notebook
  - Server / Telecom Power Management
## Performance Trim

Overcoming the Limitations of Fuses

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>★</td>
</tr>
<tr>
<td>Area</td>
<td>★★★★★</td>
</tr>
<tr>
<td>Flexibility (i.e. reprogrannability)</td>
<td>★★★</td>
</tr>
<tr>
<td>Power</td>
<td>★★★</td>
</tr>
</tbody>
</table>

### Competing Solutions
- Fuses

### CMOS NVM Advantages
- Reprogrammable up to 100 times
- Allows post-package / in-field calibration
- Fully integrated high voltage circuitry

### End Products
- MEMS devices
- Silicon clocks
- Precision analog

### Attribute Importance

- Density: ★
- Area: ★★★★★
- Flexibility (i.e. reprogrannability): ★★★
- Power: ★★★
Example FTP Specification
Targeted at MEMS, Si Clocks, Precision Analog

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retention</td>
<td>10</td>
<td></td>
<td></td>
<td>Years</td>
</tr>
<tr>
<td>Endurance</td>
<td>100</td>
<td></td>
<td></td>
<td>Cycles</td>
</tr>
<tr>
<td>Temperature Range</td>
<td>-40</td>
<td>+25</td>
<td>+85</td>
<td>°C</td>
</tr>
<tr>
<td>Bit Counts</td>
<td>64</td>
<td></td>
<td>1k</td>
<td>bits</td>
</tr>
<tr>
<td><strong>Program</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input</td>
<td></td>
<td>16</td>
<td></td>
<td>Bits</td>
</tr>
<tr>
<td>Power Supply</td>
<td>1.55</td>
<td>1.8</td>
<td>2.0</td>
<td>V</td>
</tr>
<tr>
<td>Current</td>
<td>200</td>
<td>400</td>
<td></td>
<td>µA</td>
</tr>
<tr>
<td>Time</td>
<td>4</td>
<td>8</td>
<td></td>
<td>ms</td>
</tr>
<tr>
<td><strong>Erase</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input</td>
<td></td>
<td>16</td>
<td></td>
<td>Bits</td>
</tr>
<tr>
<td>Power Supply</td>
<td>1.55</td>
<td>1.8</td>
<td>2.0</td>
<td>V</td>
</tr>
<tr>
<td>Current</td>
<td>200</td>
<td>400</td>
<td></td>
<td>µA</td>
</tr>
<tr>
<td>Time</td>
<td>4</td>
<td>8</td>
<td></td>
<td>ms</td>
</tr>
<tr>
<td><strong>Read</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output</td>
<td></td>
<td>16</td>
<td></td>
<td>Bits</td>
</tr>
<tr>
<td>Power Supply</td>
<td>1.55</td>
<td>1.8</td>
<td>2.0</td>
<td>V</td>
</tr>
<tr>
<td>Current</td>
<td>100</td>
<td>200</td>
<td></td>
<td>µA/MHz</td>
</tr>
<tr>
<td>Time</td>
<td>50</td>
<td>120</td>
<td></td>
<td>ns</td>
</tr>
</tbody>
</table>

- Targets bit counts from 64 bits → 1k bits
- 100 write-erase cycle endurance
- Ideal for trim / OTP replacement applications
<table>
<thead>
<tr>
<th>Technology</th>
<th>Process Node</th>
<th>Process Adders</th>
<th>Bit Counts</th>
<th>Endurance</th>
<th>Key Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Embedded Flash</td>
<td>180nm</td>
<td>Yes</td>
<td>&gt;1Mb</td>
<td>20k → 100k</td>
<td>Code storage</td>
</tr>
<tr>
<td></td>
<td>90nm?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuses</td>
<td>→ 40nm</td>
<td>No</td>
<td>&lt;1kb</td>
<td>1</td>
<td>Factory Trim</td>
</tr>
<tr>
<td>FG OTP</td>
<td>→ 110nm</td>
<td>No</td>
<td>&lt;256kb</td>
<td>1</td>
<td>Trim / config Code storage</td>
</tr>
<tr>
<td>Antifuse OTP</td>
<td>→ 55nm</td>
<td>No</td>
<td>&gt;1Mb</td>
<td>1</td>
<td>Code storage Keys</td>
</tr>
<tr>
<td>MTP</td>
<td>→ 65nm</td>
<td>No</td>
<td>&lt;16kb</td>
<td>1M</td>
<td>Datalogging Keys</td>
</tr>
<tr>
<td>FTP</td>
<td>→ 65nm</td>
<td>No</td>
<td>&lt;16kb</td>
<td>100</td>
<td>Precision trim Config</td>
</tr>
</tbody>
</table>
Conclusions

- Traditional embedded NVM technologies are not sufficient to cover the breadth of new applications and technologies today
- Emerging applications are driving high volumes and new requirements for embedded NVM
  - Firmware / Boot code for SoC
  - Encryption keys for securing data / media
  - Real-time datalogging
  - Precision trim for MEMS, analog
  - Wireless / RFID
- CMOS based NVM fills the gaps with a variety of enabling technologies
  - OTP → code storage
  - MTP → encryption keys, datalogging, RFID
  - FTP → precision trim, wireless
- Visit us at www.viragelogic.com for additional information on CMOS based NVM