Reinventing Memory for Things (TM)

Application specific memory solutions for integrated, connected, and high-temperature applications

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Adesto Technologies
Corporate Overview

100+ Employees

Revenue $50M+
Profitable

Licensing
Discrete Products

Business Highlights

Global Footprint

Consumer
Industrial
Mobile
Security
IoT
Growth Markets

Proprietary Technologies

Low Power
Reliable

Value Added
Code & Data Storage Solutions
00100111
10010001
11011011
00110101
00101101

Business Focus

Founded in 2007
Privately Held

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Differentiated Solutions To Address The New Requirements
Memory for LED lamps
LED driver overview

• Consumer LED lamps for home use mainly come in 2 categories:
  – LED lamps for 12 V halogen systems.
  – LED lamps for direct connection to 120V (or 240V) AC mains power.

• Each of these LED drivers come in 3 flavors:
  – Constant output LED lamps.
  – Dimmable LED lamps.
  – Remotely controlled LED lamps.
Constant output LED lamps

- Constant output LED lamps are not made to be connected to a lamp dimmer.
  - If connected to a dimmer, they may dim a bit, but will typically start flickering or turn off completely before any significant dimming is achieved.

- LED driver/controller is either a simple analog circuit or a small microcontroller.
  - The analog solution is most common for constant output lamps, as there is really no reason not to make the driver dimmable if an MCU is used.
  - The memory requirements for the MCU in this setup is in the 1 - 2 kByte range.
  - This memory is always embedded in the MCU.
Dimmable LED lamps

- Dimmable LED lamps are designed to be connected to a lamp dimmer.
  - Some may require “LED dimmers”, others may work with any dimmer.
- **LED driver/controller is either a slightly more complex analog circuit or a small microcontroller**
  - MCUs are becoming more popular for this application as it is usually easier to adapt a complex control algorithm in firmware than in hardware. And it is much easier to update the firmware of an MCU than to change the layout of an analog driver.
  - The memory requirements for the MCU in this setup is still only in the 1 – 2 (4?) kByte range.
  - This memory is always embedded in the MCU.
  - A lot of the “stand alone” LED drivers sold in the market may actually have full MCUs under the hood.
    - The programming interface is usually not available to the general user.
Remotely controlled LED lamps

• In this case, the LED driver/controller always contain a small or mid-size microcontroller.

• Typical remote control interfaces are
  – Wireless interfaces like Wi-Fi, Zigbee and Bluetooth.
  – (Less common) Wired interfaces like DALI or X10.

• The wireless interfaces require a lot more memory.
  – Typical memory requirements are 128 – 256 kBytes or more.
  – This may be embedded memory, or it may be external.

• For over-the-air updates, additional memory is required.
  – 3 memory images are stored at once:
    • The currently running firmware.
    • The new firmware being transferred.
    • The factory default.
  – This additional memory is usually external memory.
Temperature requirements for LED lamps

- LED lamps usually have the same form factor as the traditional incandescent lamps.
  - All the control circuitry is inside the lamp.
- Depending on the wattage of the lamp, the internal components have to withstand temperatures as high as 105°C or 125°C.
  - These are usually considered automotive grade temperatures.
  - 90% of electronic components do not meet this temperature spec.
  - Adesto offers discrete Flash Memory up to 125°C.
Embedded vs. Discrete Flash Memory
Advantages of Embedded Flash Memory

• No extra I/O pins for memory interface
  • On-chip memory bus can be 32 or 64 bits wide
  • No pinout restrictions
• System-on chip can be implemented as a single die
• Potentially lower power, faster
Disadvantages of Embedded Flash Memory (1/3)

- Device process is a compromise between what is needed for memory and what is needed for logic
  - More complex process
    - Requires on-chip high voltage circuitry
      - 10V or more required for programming
    - Longer development time
  - The most advanced logic processes may not offer embedded flash, or flash may be on an older/larger technology node
    - Valuable high density die area used for low density memory
Disadvantages of Embedded Flash Memory (2/3)

• A much higher number of masks needed for flash compared to standard logic
  – Typical 10 or more extra masks, 20-30 additional processing steps
    • Increases mask cost
    • Increases production time and time to market

• Limited number of foundry processes available
  – Pure logic processes offer more options than processes including flash
Disadvantages of Embedded Flash Memory (3/3)

- **A product family of multiple memory densities requires**
  - Individual mask sets for each
    - Increased development time
    - High mask set cost
    - Lower profit margin
  
  or

  - Build only the largest device, use the same die for all family members
    - Wasted silicon area for the smaller densities
    - Lower profit margin
Adesto Solutions

• **Discrete Serial Flash**
  – DataFlash offers code storage and data storage in one device.
  – Standard Flash optimized for code storage

• **Embedded or Discrete CBRAM**
  – Scalable at least down to 20nm
  – Compatible with standard logic processes
  – Requires only 2 additional mask layers
Benefits of External Serial Flash

- Modern serial devices only require a 4-pin interface between the CPU and the memory device
  - If DataFlash is already used for storing data, or SPI is already used in the system, no additional pins are required
  - High-speed dual or quad interfaces allow Execute-in-Place
    - Bandwidths above 400 Mbit/s may be achieved

- CPU may be built in a much more advanced logic process
  - Smaller die size, lower cost
- Flash is built in a more efficient process
  - Optimized for Flash memory
Product Families

- **Same CPU may be used for multiple memory sizes**
  - Shorter development time
  - Lower mask cost
  - Lower die cost
  - Smaller inventory
  - Wider product offering

- **For single chip solutions:**
  - Flash is offered in wafer form
  - Stacked die is a low cost, standard offering from most assembly vendors
Introducing
Adesto Technologies Corporation
CBRAM®
Conductive Bridging RAM (CBRAM): Next Generation Storage Technology

What is CBRAM?
Foundation of a New Revolutionary Technology For Storage of Digital Information

CBRAM Advantage Over Today’s Solutions
- Faster Storage
- Low Power Consumption

Bringing Value To Markets
- Enhanced User Experience
- Enabling Longer Battery Life
- Secure Storage
Adesto Technologies: Leading CBRAM Commercialization

Adesto: Pioneer in CBRAM

From Research To Market Place
Securing an Enormous Intellectual Property Position

Adesto’s Business Model
Discrete End to End Solution
Licensing Technology Solutions

What Markets Can CBRAM Impact?
Mobile
Consumer
Computing
Industrial
Embedded
Automotive

INVESTING IN TOMORROW’S DISRUPTIVE TECHNOLOGIES TODAY
Adesto’s CBRAM targets 70 billion dollar market
CBRAM Basics

- Present offering: EEPROM-compatible products
- Conductive Bridge Memory based on nanotechnology
- Integrated on industry standard CMOS Technology
  - Embedded Memory Solution
- Porting to 40 nm to enable higher density products
  - Release 64Mb Ultra low Power in 2015

Storage element scalable to <10 nanometers
Physical Principles for CBRAM Operation

- CBRAM technology operating principle:
  Electrically induced reversible nano-scale conductive link

**Simple Implementation:**
Access transistor and programmable resistor (1T1R)

Special Reprogrammable CBRAM Stack

Cell in High Resistance =>
Low Read Current (less than ~200nA) = DATA 0

Cell in Low Resistance =>
High Read Current (more than ~10uA) = DATA 1
CBRAM: Ideal Solution for Low Power Applications

2013: Adesto Demonstrates World’s Lowest Energy Flash Memory Technology

- Battery Operated Wearable Electronics
- Ultra Low Power Embedded Devices
- Energy Harvesting Body Sensors

Emerging Growth Markets

<table>
<thead>
<tr>
<th>Year</th>
<th>World Population</th>
<th>Connected Devices</th>
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<tbody>
<tr>
<td>2003</td>
<td>6.3 Billion</td>
<td>500 Million</td>
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<tr>
<td>2010</td>
<td>6.8 Billion</td>
<td>12.5 Billion</td>
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<tr>
<td>2015</td>
<td>7.2 Billion</td>
<td>25 Billion</td>
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<tr>
<td>2020</td>
<td>7.6 Billion</td>
<td>50 Billion</td>
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- SENSOR CHIP with CBRAM OPERATING by ENERGY HARVESTING

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Adesto’s CBRAM</th>
<th>Today’s Flash</th>
<th>Improvements</th>
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<tbody>
<tr>
<td>Core Read Voltage (V)</td>
<td>0.35</td>
<td>1</td>
<td>60% Lower</td>
</tr>
<tr>
<td>Read Energy Per Bit (fJ)</td>
<td>50</td>
<td>500</td>
<td>10x Lower</td>
</tr>
<tr>
<td>Core Write Voltage (V)</td>
<td>0.6</td>
<td>10</td>
<td>17x Lower</td>
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<tr>
<td>Write Energy Per Bit (pJ)</td>
<td>1</td>
<td>100</td>
<td>100x Lower</td>
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Source: Cisco I250, April 2011
Long Term Resistance vs. Time and Temperature
Product and Technology Qualified for 10yr/85°C

- **Long term 110°C retention study**
  - >8000hr (11.5 month) read point – no failures
  - 240 product/technology qualification units remain on long term retention bake.
  - Adding ~300 units per month starting this month – collecting large long term statistical retention database

- **Long term 200°C retention study**
  - 800hr 200°C retention bake indicated no resistance shift for either Program (Set) or Erase (Reset) bits, after initial read point
Conductive Bridging RAM (CBRAM) is a disruptive memory technology platform that is highly scalable, low power, high performance.

- 10x Lower Power Than Flash Memory
- Less than 1μA Write Capable
- Less than 0.6V Write Capable
- Scalable to 1Xnm and Lower Multi Level Cell Capable
- Sub 50ns Write Capable
- Large Dynamic Range Allowing Fast Access
- Bit Accessible for Read and Write
- 10x – 100x Faster Than Flash Memory

CBRAM: Adesto’s Proprietary Memory Technology
Memory For Medical Asset Tagging

Application
Electronic storage of code and data in medical equipment and health care industries.

Problem
Today’s Flash Memories are not compatible with medical sterilization processes used in health care industry.

Solution
CBRAM is the only memory technology proven to maintain the integrity of the data content after the sterilization processes.

Market Opportunity

![Chart showing Value of Intelligent Medical Devices from 2015 to 2020]
- Embedded Flash will reach its limits around 55-45 nm.
- CBRAM has been shown to work with a cell size of 20nm.
Embedded Memory Power Consumption

- On-chip voltage and current requirements for Flash remain \( \approx \) unchanged as the devices shrink.
  - Pumping this power from an ever lower external voltage makes overall power consumption go up significantly for low supply voltages.
Summary of Adesto IP Portfolio

<table>
<thead>
<tr>
<th></th>
<th>USA</th>
<th>Rest of World</th>
<th>Total</th>
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<tbody>
<tr>
<td>Patents (including patents transferred to Adesto)</td>
<td>70</td>
<td>43</td>
<td>103</td>
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<tr>
<td>Patents licensed</td>
<td>57</td>
<td>42</td>
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<tr>
<td>Adesto applications</td>
<td>63</td>
<td>28</td>
<td>91</td>
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<tr>
<td>New Adesto disclosures waiting to be filed</td>
<td>5</td>
<td>0</td>
<td>5</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td>195</td>
<td>113</td>
<td>308</td>
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</table>

- Comprehensive set of broad and critical manufacturing and functional know-how on CBRAM® and RRAM technologies. Focus on “commercialization” and fundamental understanding of CBRAM
CBRAM: NV Memory for Today and Tomorrow

• CBRAM is a new disruptive memory technology that delivers significant advantages in power consumption, operating speed, and cost

• Boot memory products are available today and can be integrated in applications that require fast, low cost NVM solutions

• Adesto Technologies is committed to the CBRAM Technology Roadmap, a roadmap that includes enhanced products from 32 Kbit to 256 Mbit densities

• With a comprehensive portfolio of memory technologies at its disposal, Adesto offers innovative solutions to its customers in a variety of markets, including class-leading products for wearable, mobile, and other energy conscious applications.

• Our hybrid business model of both discrete products and IP licensing allows us to address a variety of customer requirements.