Performance & Reliability Driven Memory solution

Macronix International Co., Ltd.
About Macronix
A Leading Non-Volatile Memory Solutions Provider

- Founded in 1989
- Headquarters Hsin-Chu, Taiwan
- Total 5280 Patents Granted (As of December 2013)
- Total 4,859 Employees (18% people working in R&D)
- 2013 Revenue US$ 740 Million

Complete In-house Wafer Manufacturing Flow and Sufficient Supply

150mm Fab: ~40K wafer/month
200mm Fab: ~48K wafer/month
300mm Fab: ~50K wafer/month (Capable Capacity)
Many Memory Technologies

- EE
- NOR
- SLC NAND
- PCM
- MLC NAND
- TLC NAND
- 3D NAND
- ROM
- RRAM
- Kilo
- Mega
- Giga
- Tera

High Cost → Low Cost

Code Storage

Data Storage
NVM Interface Evolution

- Parallel SLC NAND
- Parallel NOR Page Mode
- Parallel NOR AD-Mux
- SPI NOR Quad I/O
- SPI NOR Dual I/O
- SPI NOR Single I/O
- SPI NAND
- SPI NOR 8 I/O w/DTR

Timeline:
- 2000
- 2005
- 2010
- 2015
- 2020+
SPI Specification Evolution

Time

SPI  1IO  2IO  4IO  4IO DTR  SPI 8IO DTR
Flash Process Technology Pipeline

- **SLC NAND Flash**: 75 nm (2009-2010), 36 nm (2012-2014), 2x nm (2015+)
- **3D NAND Flash**: 75 nm (2009-2010), 36 nm (2012-2014), 2x nm (2015+)

Future Technology in Development:
- Equi. 1y nm (2D NAND)
- Equi. 1z nm (2D NAND)

Future Technology in Research:
- **VG 3D NAND**
- **PCM**
- **ReRAM**
# NOR Flash Memory Portfolio

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<th>512Kb</th>
<th>1Mb</th>
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*Multi I/O, RPMC Feature, Page Mode, ADMUX, Secure, Multi I/O, Secure, ADMUX, SRW*

**Legend**

- **1.8V**
- **2.5V**
- **3V**
- **5V**

**Note:** Roadmap information is subject to change without notice
## SLC NAND Flash Memory Portfolio

<table>
<thead>
<tr>
<th></th>
<th>512Mb</th>
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<td>MX30LxxS</td>
<td>* Secure</td>
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<td>MX35L</td>
<td>* Multi I/O</td>
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<td>MX35U</td>
<td>* Multi I/O</td>
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</table>

**Legend**

- 1.8V
- 3V

*Note: Roadmap information is subject to change without notice*
Automotive market

*Our Vision: To enable memory technology innovation for a safe, reliable and engaging in-vehicle experience.*
Automotive Capabilities

In late 2009, Macronix entered the automotive market

Macronix is an established player and part of the Automotive Eco-system

- TS16949 (since 2004) certified manufacturing flow and passed VDA 6.3 process audit
- Most products & technologies released as AEC-Q100 compliant
- Member of the Automotive Electronics Council (AEC)
- Passed all audits and product design reviews first time with automotive systems manufacturers

Established a best-in-class automotive quality management system

- Improved quality throughout the product lifecycle - design, manufacturing & testing
- Target “zero defects” by continuous improvement process

Global automotive team to support regional customer requirements

- Dedicated resources assigned for each region
- Priority escalation process for automotive customers
“Companies looking to intimately engage within the Automotive industry can only truly achieve the required quality, service and continuous product and technology alignment with their Customers, when the whole of their organisation is aligned and the company stakes its reputation on its automotive performance.

Macronix is well positioned to do this and our customers clearly see the benefits”

Quote from Miin Wu – Macronix Chairman & CEO
Macronix is an AEC Member

- A valued and influential member of the Automotive industry Eco-system
- Advanced insight to understand industry quality trends and support needs for future Flash specifications from OEM’s and Tier 1 suppliers alike
Ecosystem Engagement

- Macronix is committed to providing a “total solution” to our end-customers. This includes:
  - Complete family of embedded flash memories – including NOR & SLC NAND
  - An extensive list of technical documents to support flash design-in
  - Software drivers, simulation models, programmer support, etc.

- In addition to this, Macronix has also invested heavily in working with SoC companies to support their Reference Designs
  - Assigned dedicated resources to work on flash qualification
  - Develop software, hardware and system-level tools to support flash adoption
  - Co-develop future non-volatile memory technologies
  - Future memory interface & specification alignment

- Ultimately, Macronix Reference Design program leads to faster time-to-market and optimal solutions for our end-customer
### Flash Product Portfolio for Automotive

<table>
<thead>
<tr>
<th>1Mb</th>
<th>2Mb</th>
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**Serial**

<table>
<thead>
<tr>
<th>3V</th>
<th>Single I/O, Dual I/O</th>
<th>80 Mhz → 104 Mhz</th>
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<table>
<thead>
<tr>
<th>1.8V</th>
<th>Single I/O, Dual I/O, Quad I/O</th>
<th>80 Mhz → 133 Mhz</th>
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**Parallel**

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<table>
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<tr>
<th>80 Mhz → 104 Mhz</th>
<th>Page Mode</th>
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**NAND**

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**Note:** Further extensions determined by market demand.
Future Technology Development
The top NVM research topics in worldwide technology conferences are: **Floating Gate, Charge Trapping, PCM, ReRAM.**

(Source: IEDM/ VLSI/ ISSCC/ IRPS/ SSDM/ VLSITSA, 2008-2013)
3D NAND Update
Equivalent 1Xnm 3D VG NAND

- 8-layer 3D VG (WL ½ pitch = 38nm, BL ½ pitch = 75nm) already produces an equivalent 1Xnm node NAND technology
- Fully integrated test chip have been demonstrated (IEDM 2012, by Macronix)
On going to develop an equivalent 1Ynm node 3DVG NAND Flash, using 43nm half pitch and 4F² minimal cell size.

- Starting at 8-layer, plenty of headroom to scale into 0Znm node and below.
- Moderate aspect ratio of ~ 20 only.

43nm 4F² unit size
→ 8-layer is equivalent to 1Ynm (~15nm) node
Transition Metal Oxide ReRAM (TMO ReRAM)
1. Transition metals typically have several oxidation states with different resistivity.

   TMO (Transition Metal Oxide) Resistance levels ↔ Memory states

2. Most accepted operation mechanism: oxidation ↔ reduction of a conduction filament.

3. An initial forming process is needed to “activate” the cell.

4. Operates in bipolar or unipolar mode. Bipolar operation is more stable.
Very Simple CMOS Compatible Process

**Process flow**

1. Array Periphery
   - (a). W-plug CMP
2. Array Periphery
   - (b). Oxidation
3. Array Periphery
   - (c). Photolithography to define cell region
4. Array Periphery
   - (d). Remove WO_x on periphery contacts
5. Array Periphery
   - (e). TiN top electrode and M1 Deposition

- **Rapid Thermal Oxidation (RTO) (500°C)**
- WO_x cell formed on W-plug
- Fully CMOS compatible, simple process
- No new material introduced
Performance of 60nm WO$_x$ ReRAM

- Very good scaling ability
- Good endurance > 1M times
- MLC possibility > 10K times
- Thermal stability > 150°C/2000 hours
- NiTE~ low operation current

2010 IEDM, Macronix
Proposed 3D ReRAM Structure

Self-aligned process

2012 VLSI Symp., Macronix
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Kingtech, MXSMIO, Macronix vEE, Macronix MAP, Rich Au-dio, Rich Book, Rich TV, and FitCAM.
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