RRRAM Comes of Age

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Historical Tale of RRAM....

Where did it come from?

Why is it still here?

Where is it going?
Hype Cycle for RRAM

Trough of disillusionment

2007/8
STT-MRAM R&D – IBM, TDK, Samsung, others

2010
1st commercial RRAM – Adesto EEPROM w/ CBRAM

2012/3
1st 3D NAND – Samsung 32-layer V-NAND

2014/15
1st commercial eRRAM – Panasonic MCU w/ TaOx RRAM

2016
Adesto “Gen4” CBRAM – World’s lowest power S/A NVM chip

Dec 2018
Intel 22nm eSTT-MRAM @ IEDM
Feb 2019
Intel 22nm eRRAM @ ISSCC

~2000
NAND
Visionary scaling concerns

RRAM
Back to the future!
CBRAM by M. Kozicki
Oxide RRAM by IBM Zurich
Others...

2006
Adesto formed

Technology trigger

Today
CBRAM licensing to fabs
STT-MRAM coexisting as eNVM

2018
Adesto MRAM @ IEDM

2019
Adesto MRAM @ ISSCC

2014/15
3D NAND
Undisputed king of density

STT-MRAM
Going to major foundries
A “universal” memory?

RRAM
No high density chips
Adesto only company with
commercially available RRAM
High BERs fundamental?
“What is RRAM good for?”

This hype cycle was created by Adesto, and is not related to the research firm Gartner, Inc. or its affiliates.
# CBRAM vs. STT-MRAM as eNVM w/ Solder Reflow

<table>
<thead>
<tr>
<th></th>
<th>CBRAM</th>
<th>STT-MRAM</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endurance</td>
<td>$10^5$</td>
<td>$10^7$ [1]</td>
<td>MRAM: Endurance is beyond practical eNVM requirements</td>
</tr>
<tr>
<td>Write speed</td>
<td>Comparable</td>
<td>250ns [2]</td>
<td>For both, current driven by need for high-T retention</td>
</tr>
<tr>
<td>Write current</td>
<td>$&gt;100uA$</td>
<td>$&gt;100uA$</td>
<td></td>
</tr>
<tr>
<td>Write voltage</td>
<td>$&lt;3V$</td>
<td>$&lt;2V$</td>
<td></td>
</tr>
<tr>
<td>Forming</td>
<td>Needed</td>
<td>Not needed</td>
<td>CBRAM: Can do forming economically at SORT</td>
</tr>
<tr>
<td>Cost</td>
<td>1 mask adder</td>
<td>$&gt;30%$ cost adder</td>
<td>STT-MRAM: 3-4 masks, many layers, difficult etch</td>
</tr>
<tr>
<td>Complexity</td>
<td>3-4 thin films</td>
<td>20-30 thin films</td>
<td>STTMRAM: Increased tool costs &amp; lower throughput</td>
</tr>
</tbody>
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Historical Tale of RRAM….

Where did it come from?
Heaven or Hell, depending on your experience

Why is it still here?
Excellent as eNVM – Adesto engaged in multiple fab insertions

Where is it going?
CBRAM for AI (a.k.a., neuromorphic, in-memory, etc.)

**Analog NVM enables the fast, low-power vector-matrix multiplication used in AI**

<table>
<thead>
<tr>
<th>Technique</th>
<th>Control circuitry &amp; algos</th>
<th>Use high-G regime of cell</th>
<th>Proprietary arch/circuits</th>
<th>Proprietary algos</th>
<th>Scaling and/or 3D</th>
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</thead>
<tbody>
<tr>
<td>Small changes possible</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
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<tr>
<td>Stable over time, temp &amp; usage</td>
<td></td>
<td>X</td>
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<td>X</td>
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<tr>
<td>Low current / power during inference</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
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<tr>
<td>Linear IV curve</td>
<td></td>
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<tr>
<td>Low weight-to-weight variation</td>
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<td>X</td>
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<tr>
<td>Low cycle-to-cycle variation</td>
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<tr>
<td>Small size</td>
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</table>
CBRAM for AI?

Analog NVM → Fast, low-power vector-matrix multiplication

Cells must provide a stable “analog” conductance
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Why is it still here?
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Where is it going?
AI? – Adesto leveraging IP/maturity and collaborating with partners
Thank you