Phase Change Materials and PCRAM

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Outline

- Phase Change Materials for PCRAM
- Physical Limitation and Nano-Phase Change
- PCRAM as Universal Memory
Operation of PCRAM

WRITE: ("1" to "0")
- Anneal
- Melting Point
- Crystalline Temperature
- Time

WRITE: ("0" to "1")
- Melt & Quench
- Melting Point
- Crystalline Temperature
- Time

READ
- OR
- Melting Point
- Crystalline Temperature
- Time

- Very Low Current
Chalcogenide Based Phase Change Materials

<table>
<thead>
<tr>
<th>Binary</th>
<th>Ternary</th>
<th>Quaternary</th>
</tr>
</thead>
<tbody>
<tr>
<td>GaSb</td>
<td>Ge$_2$Sb$_2$Te$_5$</td>
<td>AgInSbTe</td>
</tr>
<tr>
<td>InSb</td>
<td>Ge$_1$Sb$_2$Te$_4$</td>
<td>BiGeSbTe</td>
</tr>
<tr>
<td>InSe</td>
<td>Ge$_1$Sb$_4$Te$_7$</td>
<td>Ge$<em>{41}$Sb$</em>{12}$Te$_{41}$Se$_6$</td>
</tr>
<tr>
<td>As$_2$S$_3$</td>
<td>InSbTe</td>
<td>GeSnSbTe</td>
</tr>
<tr>
<td>Sb$_2$Te$_3$</td>
<td>SnSb$_2$Te$_4$</td>
<td>GeSbSeTe</td>
</tr>
<tr>
<td>GeTe</td>
<td>GaSeTe</td>
<td>Te$<em>{81}$Ge$</em>{15}$Sb$_2$S$_2$</td>
</tr>
<tr>
<td>GeSb</td>
<td>Si$_2$Sb$_2$Te$_5$</td>
<td>Ge$_2$Sb$_2$Te$_5$:N</td>
</tr>
</tbody>
</table>

**Storage Requirement**
- Writability: Easy amorphousing
- Stability: Stable amorphous phase
- Readability: Large s/n ratio
- Erasibility: Fast recrystallization
- Cyclability: Stable layer stack

**Materials Requirement**
- Writability
- Stability
- Readability
- Erasibility
- Cyclability

**Material Property**
- Melting point / layer design
- High activation energy
- High optical constant / high electrical resistance
- Simple crystalline phase, low viscosity
- Low stresses

**Temperature**
- Melt point & glass trans. temp. increase
- Phase-change speed increase
- Data retention (data stability) increase

**Chalcogenide elements**
- GeTe (Low crystallization speed, high stability)
- Sb$_2$Te$_3$ (High crystallization speed, low stability)
Superlattice-like (SLL) Phase Change Structures

Use artificial structures to engineer phase change materials’ properties

Theoretical consideration:
- Material consideration
- Crystallization consideration
- Thermal consideration
- Electrical consideration

![Diagram of SLL Phase Change Structures]

Theoretical consideration:
- Material consideration
- Crystallization consideration
- Thermal consideration
- Electrical consideration

![Diagram of SLL Phase Change Structures]

- Reduce 70% Current
- Increase Speed

Scalability of PCRAM

- the smallest volume of phase change materials that undergoes stable and reversible phase change

Nano-Phase Change - phase change behavior at the nano-scale is different from bulk due to large volume of interfaces:
  - Thickness (size) dependent
  - Interface dominated
  - Capping materials related

Important Factors:
  - Ratio of the atoms on interface/atoms in volume
  - Mean free path

Physical Limitation vs. Nano-Phase Change

- **How small? Lithography**
  - Electrode
  - Phase change
  - Insulator
  - Electrode

- **How small? Reversible Phase Change**

- **How small? Current**

- **How small? Cross-talk**

- **Phase Change**
  - Graph showing phase change with different thicknesses (2 nm, 3 nm, 5 nm, 8 nm, 20 nm)

- **Operation Window**
  - Graph showing temperature vs. thickness with melting point and crystalization point markers.

- **Density**
  - Graph showing density with doping and without doping.

- **Diffusion**
  - Graph showing resistance vs. temperature.

**Limitation of PCRAM:**

- ~ 5 nm
PCRAM as Universal Memory

- Non-volatile
- High density \( \approx 5.7 \, F^2 \)
- High speed
- Universal Memory
- High endurance \( > 10^{12} \)

(current: \( \approx 100 \, \text{ns} \))
High Speed PCRAM

Correlation between Phase Change Speed and Size

High Speed PCRAM with $10^8$ cycles

Thank You
Nano-scaling Effects on Small Cells

Smaller dimension change the boundary conditions, the material properties due to the nano-size effect and interface effect, resulting in the changes of the electrical performance.
PCRAM Introduction
PCRAM Introduction

- **At crystalline state**
  - High free electron density
  - High resistance

- **Melting Point**

- **Time**

- **Crystallization time**

- **Recording Layer Temperature**

- **Annealing**

- **Anneal**

- **Melt & Quench**

- **Electrode**

- **Chalcogenide**

- **Insulator**

- **DIGITAL DATA**
  - $0 \rightarrow 1$
PCRAM Introduction

- Anneal
- Melt & Quench

- Melting & Rapid Cooling
- Annealing

- Converting amorphous state to crystalline state
- High free electron density
- Low resistance

Digital Data: 1 → 0

Cell read by measuring resistance difference is several orders.
High Scalability

- Better performance with smaller size: lower current, lower power consumption and faster speed.
- Flat topology and lower voltage operation allow to remove scaling barriers.