Phase Change Data Storage
I will give Atomic Design rules for Ovonic Energy Conversion Devices, Inc. Ovonic Threshold and Memory materials.
Yellow balls represent Te atoms and red sticks represent their lone-pairs. The dark balls are Ge, Si and As. The coordination can vary from site to site, however, in the model we have shown Ge and Si as 4-coordinated and As as 3-coordinated.
Yellow balls represent Te atoms and dark sticks represent their lone pairs. Dark balls are Ge atoms. The purple ball is Sb. To fit particular device needs other elements can be added.

Note: Polymeric chain structure and crosslinking
Switching in chalcogenide materials based on lone-pair excitation:

- **Threshold** --- noncrystallizing --- OTS
- **Memory** --- phase change --- OMS
IV-V-VI Ternary Phase Diagram

- **Group V**
  - Memory: Sb
  - Threshold: As

- **Group IV**
  - Memory: Ge
  - Threshold: Ge and Si

- **Group VI**
  - Memory: Te
  - Threshold: Te

- **Sb₂Te₃**

- **Threshold Alloys**
- **Memory Alloys**
Energy barrier can be reduced by any of the following—applied singly or in combination:

- Light
- Heat
- Electric field
- Chemical catalyst
- Stress-tension pressure

Transformations in amorphous materials produce changes in:

- Resistance
- Capacitance
- Dielectric constant
- Charge retention
- Index of refraction
- Surface reflection

- Light absorption, transmission and scattering
- Differential wetting and sorption
- Others, including magnetic susceptibility
Physical Principles

Phase change materials for Optical & Electronic Ovonic chalcogenide memory

- Reversible Crystalline-Amorphous Transitions

New Structural, Chemical & Electronic Properties

- Fundamental Reconfiguration through changes in the total interactive environment
Physics of Ovonic™ Threshold and Memory Devices

is based on the amorphous nature that provides degrees of freedom of atomic design and is related to stereochemistry and polymer science.

Depends on change in the:

- Length of chains and size of rings
- Number and strength of cross-links
- Strength of bonding configurations
- Spectrum and number of lone pairs

These properties make the group of chalcogenides a much different type of semiconductor than amorphous Silicon.

In the Ovonic Threshold Switch material, the number and strength of cross-links assures structural integrity, while non-bonded and weakly bonded lone pairs are excited by the electric field and form a constant current electronic plasma.

In the Ovonic Memory material, the lone pair excitation process causes conformational/configurational structural phase change transformations.
Causes of Conformation & Bonding Reorganization

Lone Pair Orbitals….

- Lone pairs are important **structurally**, **chemically** and **electronically**

They influence the **conformation/configuration** of a molecule by exerting **strong repulsive forces** on the electron pairs in **neighboring bonds** and on other lone pairs.
Causes of Conformation & Bonding Reorganization

Lone Pair Orbitals…. **Strength of Repulsions**

- **The strongest** … [Lone Pair ← Lone Pair]
- **Next** …… [Lone Pair ← Bonding Pair]
- **The weakest** ….. [Bonding Pair ← Bonding Pair]

Since lone pairs are **not tied down** into a bonding region by a second nucleus, they can contribute to moderately low energy electronic transitions…

Therefore:

**Light** and **Electric Fields** can **couple** to Lone Pairs
Where else can we go

**Optical**
- similar mechanism as the Ovonic electrical memory, including multi-state operation and cognitive function
- opportunities for continued media optimization

**Electrical**
- greater than $10^{13}$ cycle life
- Sub-nanosecond programming speed

**Electron beam**
- 100 angstroms
- no moving parts

**Probe storage**
- smaller than 100 nm
- massively parallel

In the early 60s, we made an Ovonic memory tape using probes to induce a reversible phase change
Example of ECD’s Dry Process Film

**Instant Imaging**

Example of ECD dry process film, showing continuous tone gray scale.

The material was *organo-tellurium*. It had no grain boundaries, was very sensitive to light and had amplification.

It did not require a chemical process.
Resistance vs. Current for an Ovonic™ Phase Change Binary Memory Device

![Graph showing the relationship between Programming Current (mA) and Programmed Resistance (Ohms). The graph indicates a transition from amorphous to crystalline phases. The x-axis represents Programming Current ranging from 0.0 to 2.5 mA, and the y-axis represents Programmed Resistance ranging from 1E+3 to 1E+6 Ohms. The graph highlights a sharp decrease in resistance at around 1.5 mA, indicating the phase change.]
Cycle Life

Programming Pulse Width: 50 nsec
Programming Current: 1 and 1.7 mA

Continued testing to $10^{14}$ would have taken another year
Operation of Ovonic™ Cognitive Device

Various pulsing protocols are used depending upon the nature of the task performed.

- Amorphous Regime (LOW Reflectivity, HIGH Resistance State)
- Crystalline Regime (HIGH Reflectivity, LOW Resistance State)

Ovonic Optical/Electrical Phase Change Regime

Energy Accumulation Amorphous Pre-threshold Regime

Direct Overwrite Reversible Crystalline Multi State Regime
Ovonic™ Electrical Multi-State Data Storage

Multi-bit storage in each memory cell
(Ten pulses per step, repeated ten times)
Ovonic™ Optical Multi-State Data Storage

See, Keynote Talk, in ISOM’03, Nara, Japan
To be published: Japanese Journal of Applied Physics
Tomorrow morning (8:30 am)
in my invited talk

I will show the new deep and rich physics of the Ovonic multi-element amorphous phase change chalcogenide devices that allows us to achieve Cognitive Computing and build intelligence, such as learning capability, into the computer.

Various papers are available as you exit