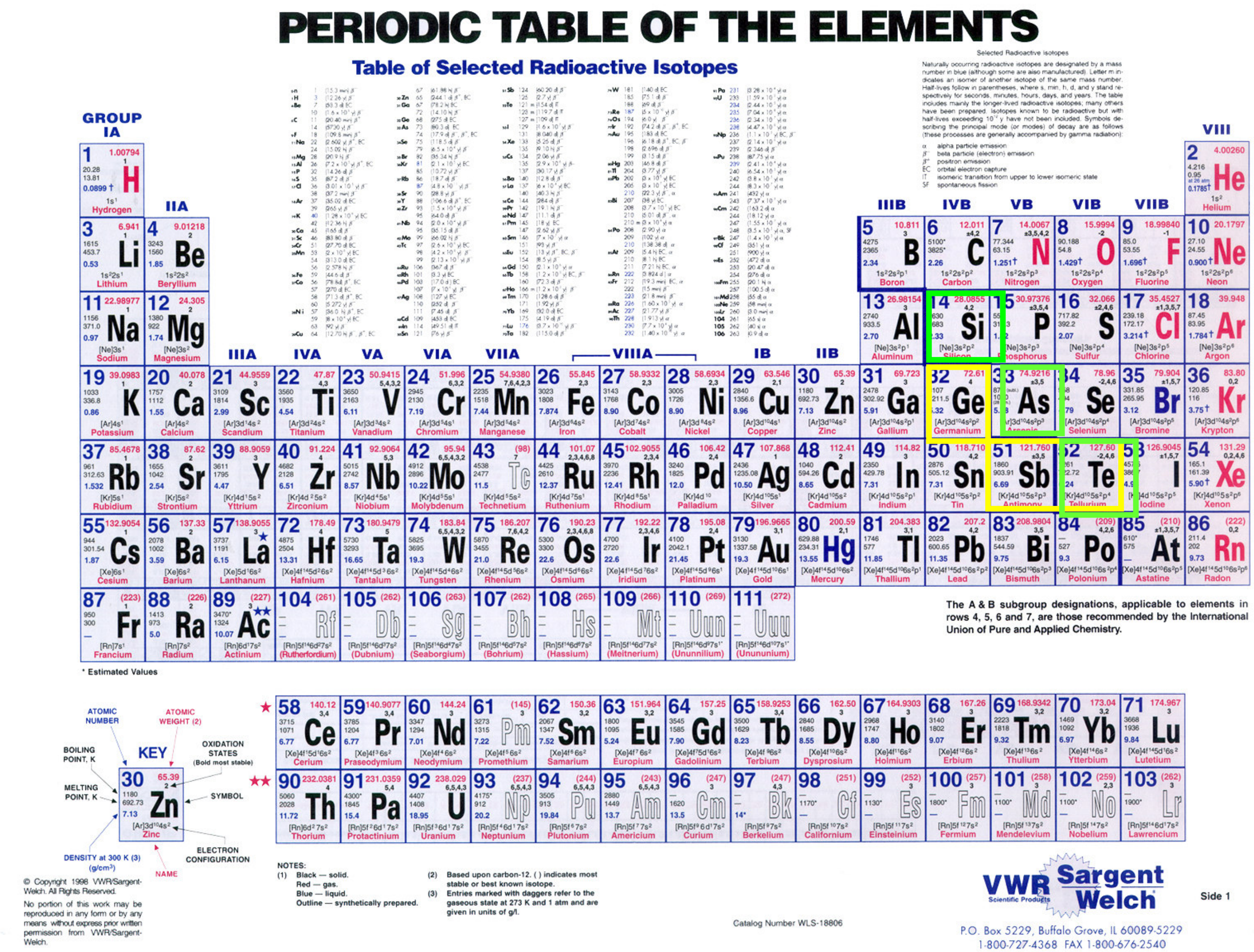
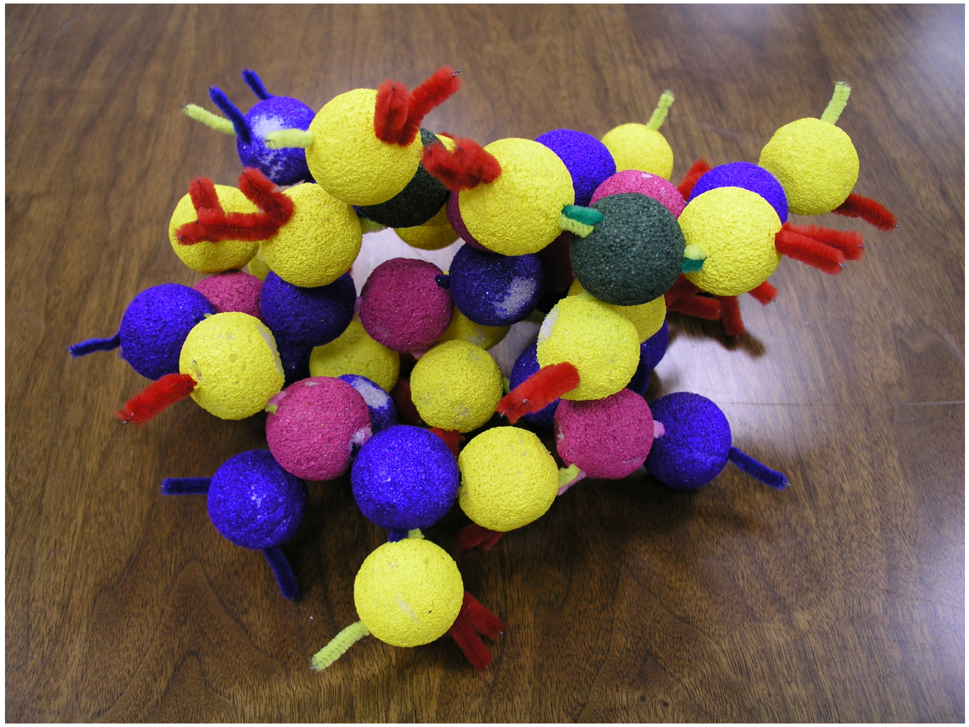
S. R. Ovshinsky
MRS Tutorial, December 1, 2003

Phase Change Data Storage



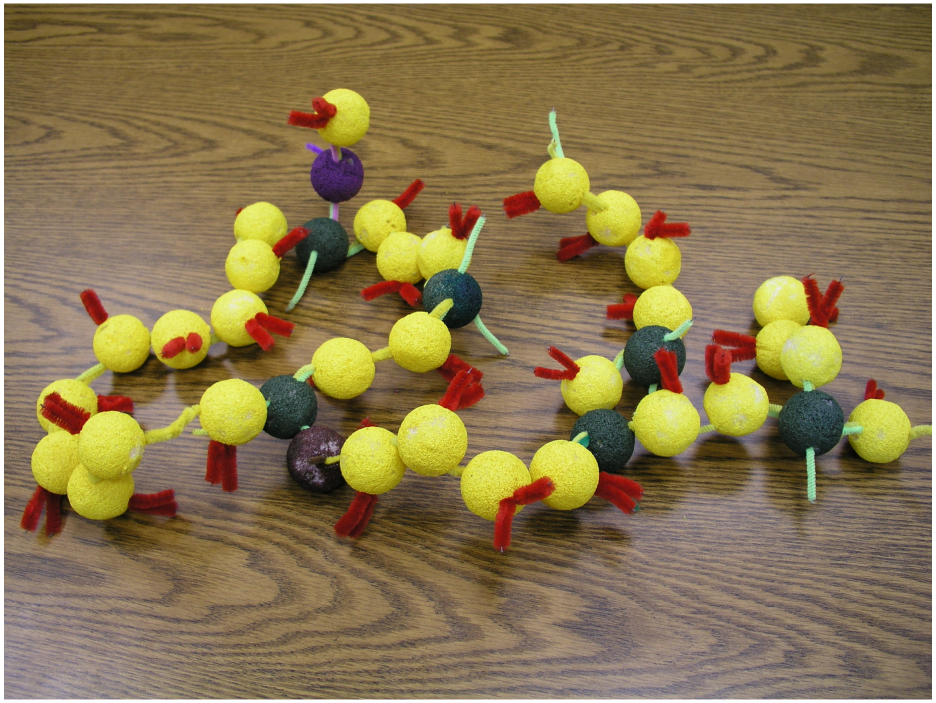
I will give **Atomic Design rules** for **Ovonic Threshold and Memory** materials

3-D Model of the Ovonic™ Threshold Material



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.

3-D Model of the Ovonic™ Memory Material

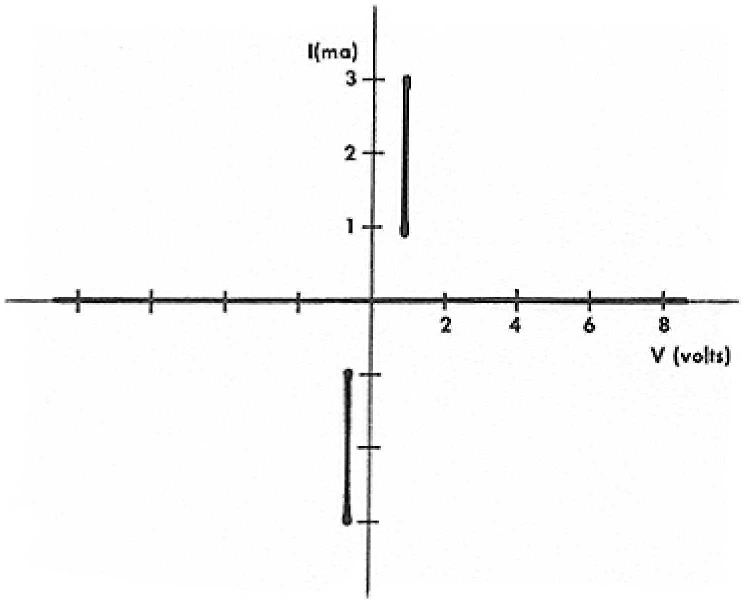


Yellow balls represent Te atoms and dark sticks represent their lone pairs. Dark balls are Ge atoms. The purple ball is Sb. To fit particular device needs other elements can be added.

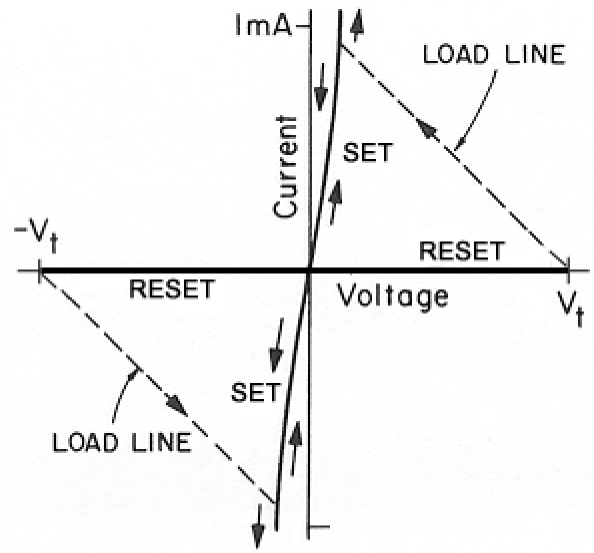
Note: Polymeric chain structure and crosslinking

I-V Characteristics

Ovonic Threshold Device



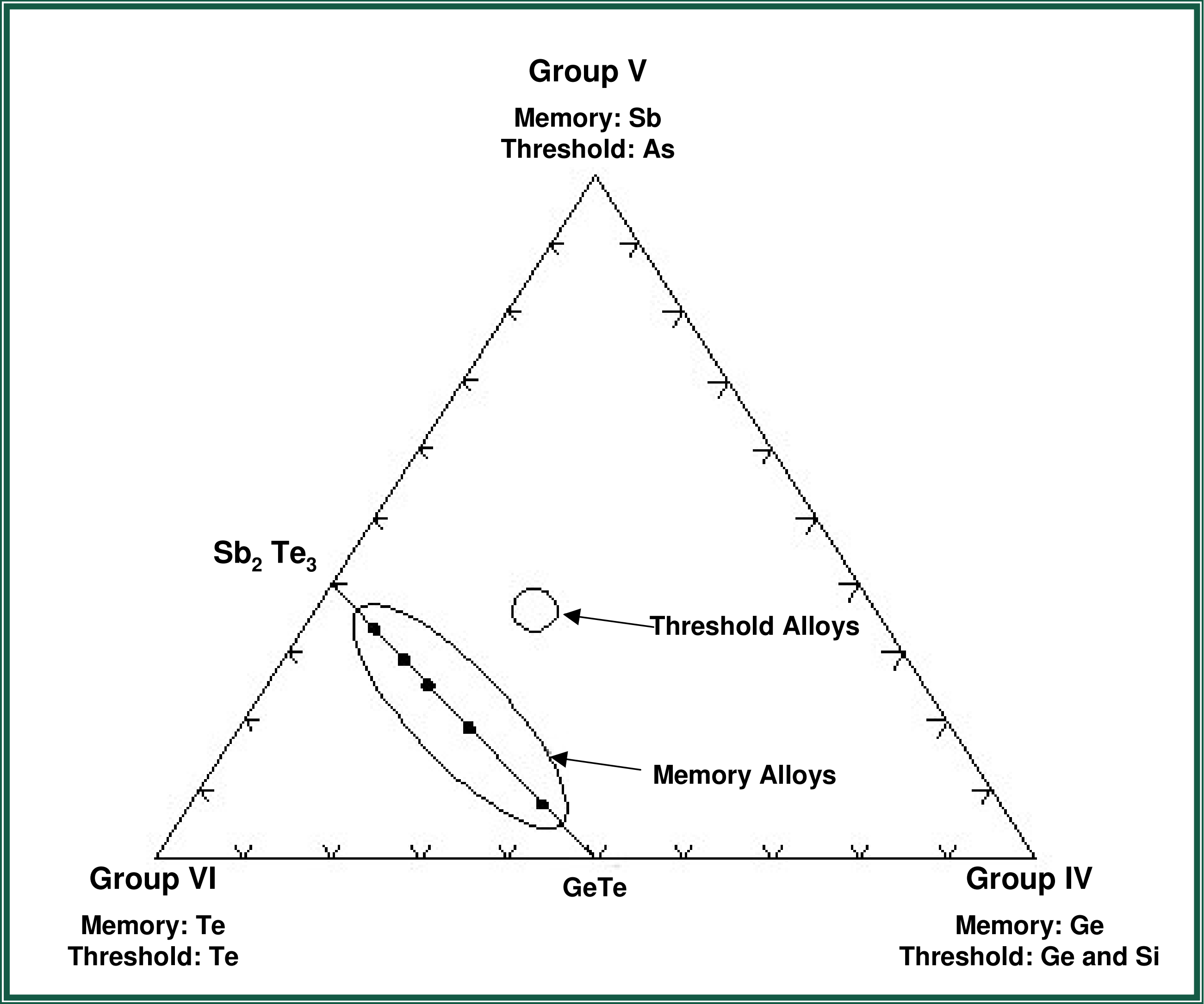
Ovonic Memory Device



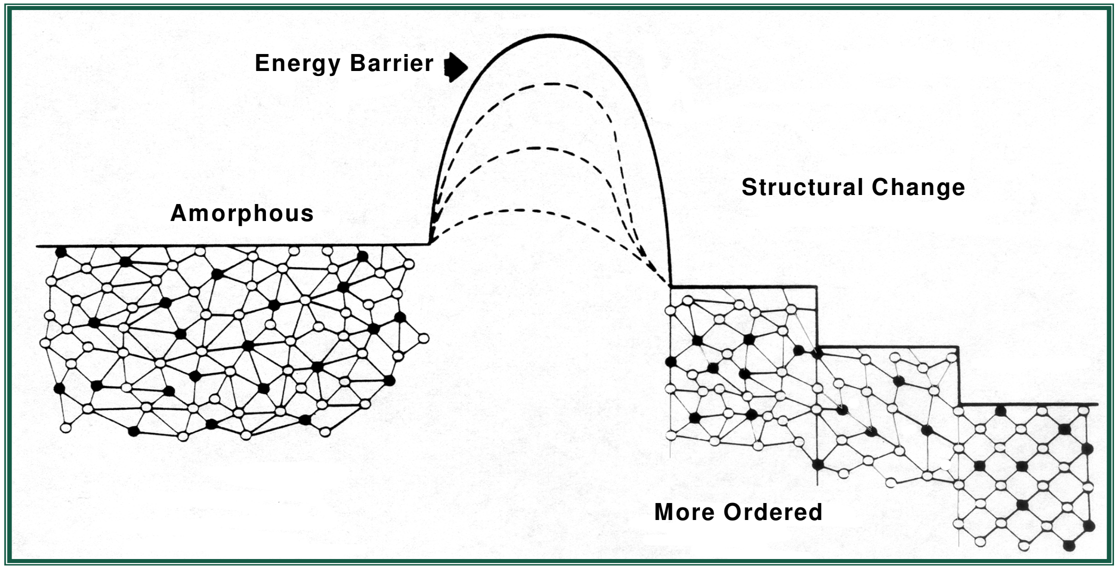
Switching in chalcogenide materials based on lone-pair excitation:

- **Threshold --- noncrystallizing --- OTS**
- **Memory --- phase change --- OMS**

IV-V-VI Ternary Phase Diagram



Ovonic Information Storage/Retrieval and Display By Structural Transformation



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.

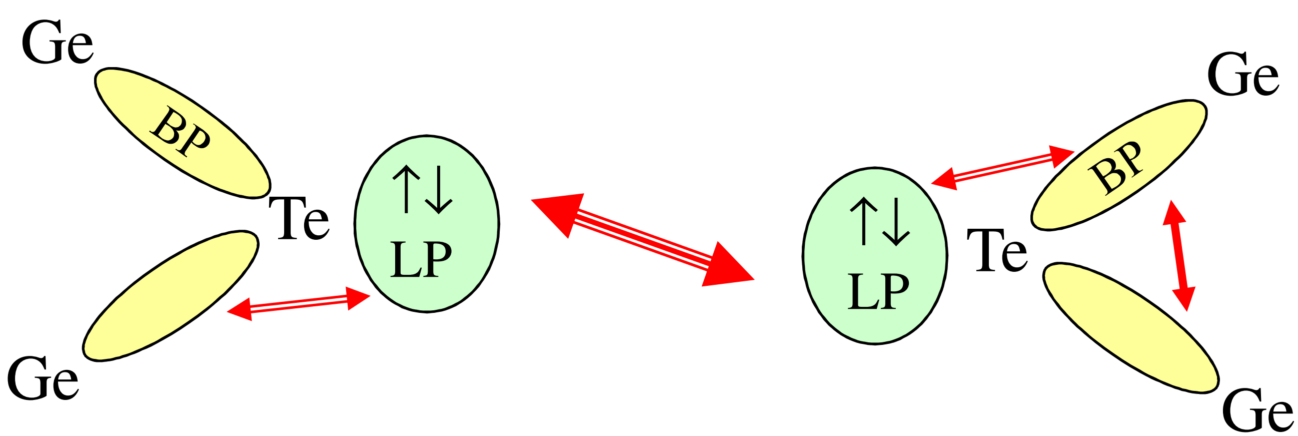
In the **Ovonic Memory material**, the lone pair excitation process causes conformational/configurational structural phase change transformations.

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

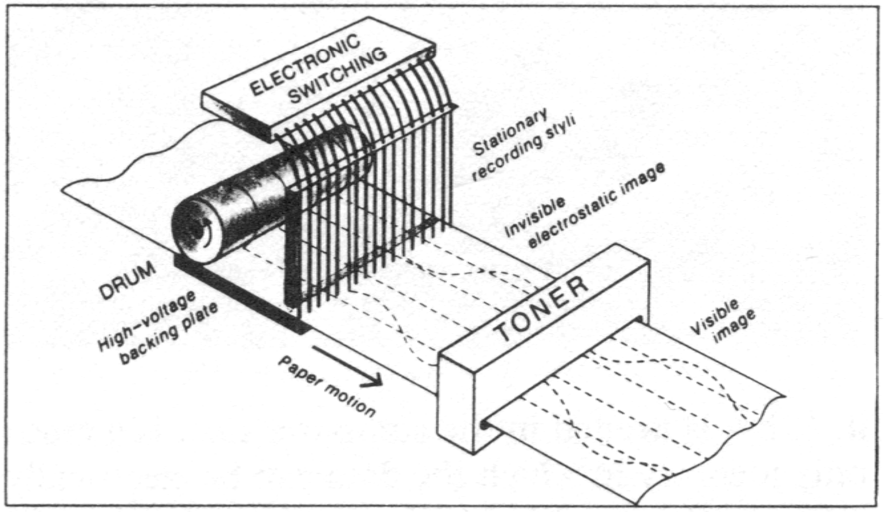
Electron beam

- 100 angstroms
- no moving parts

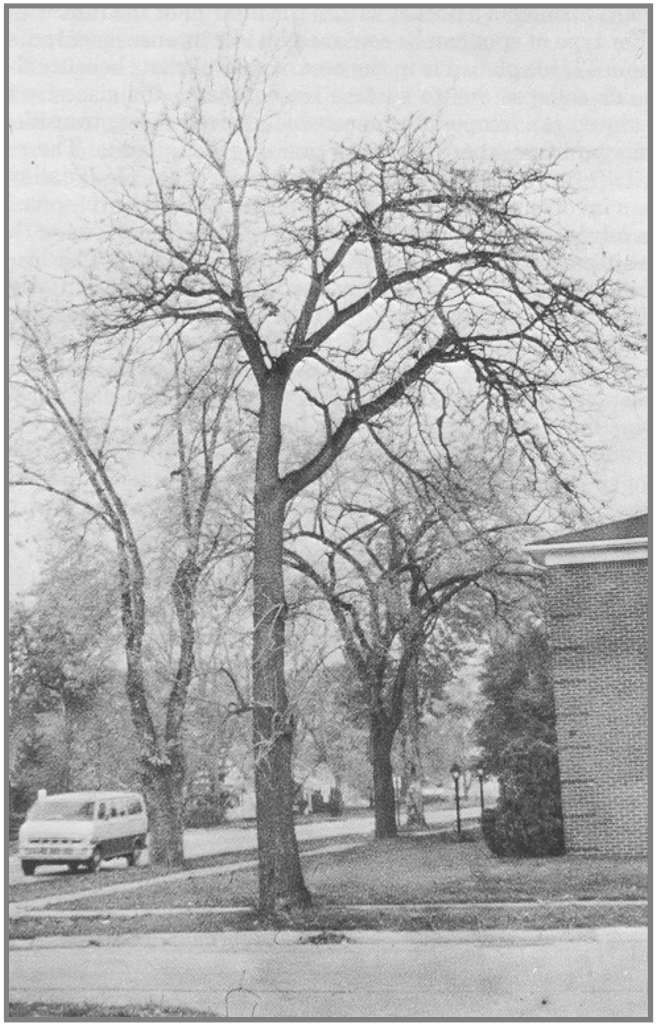
Probe storage

- 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



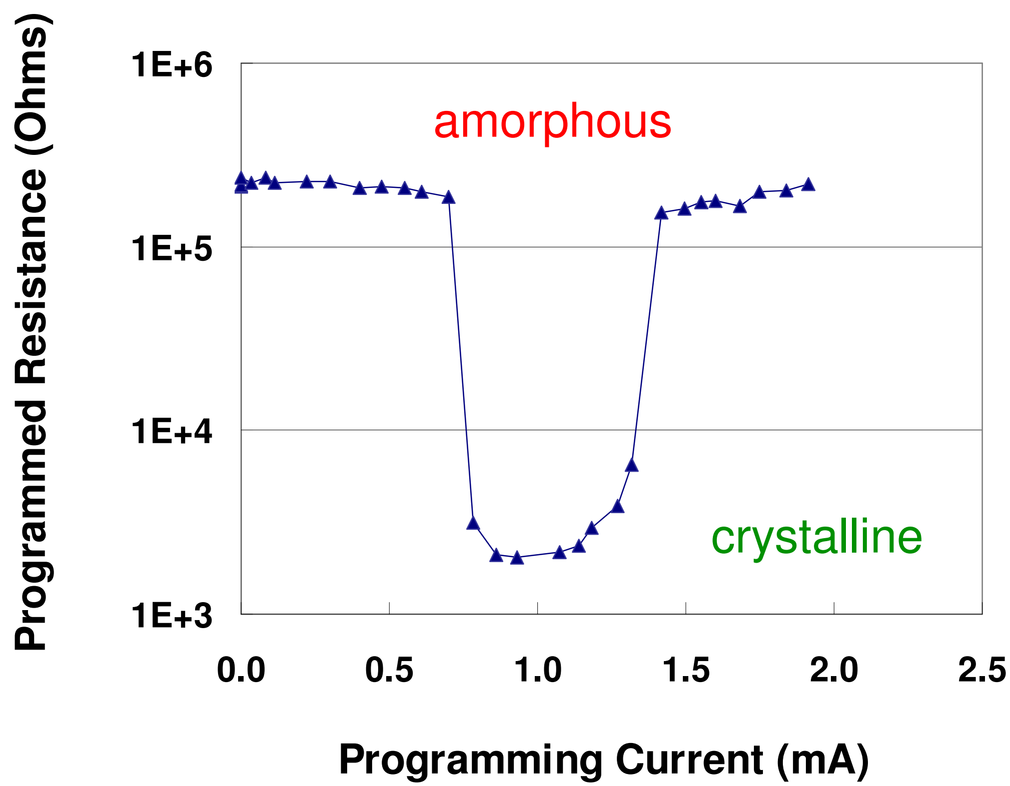
Instant Imaging

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

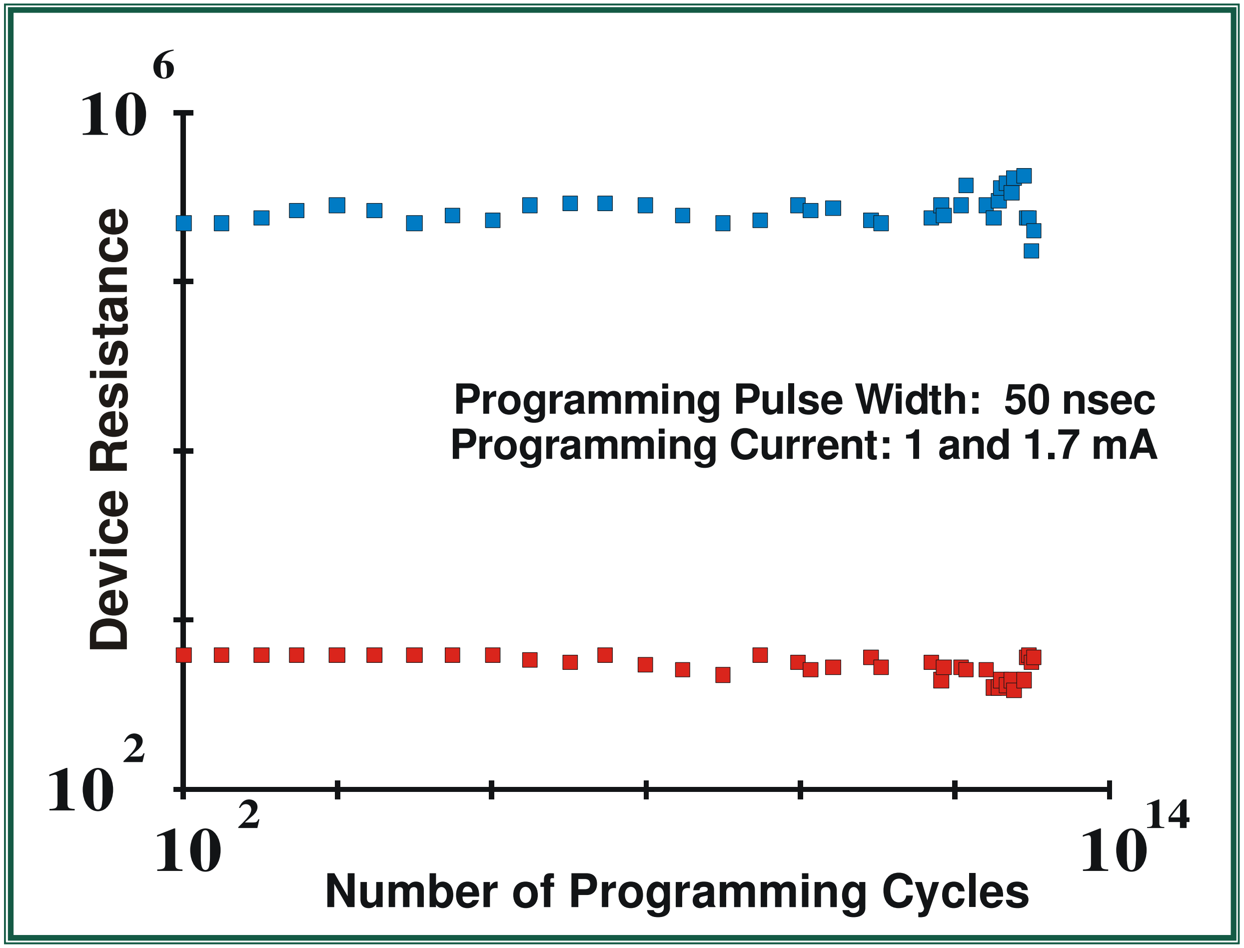
The material was organo-tellurium. It had no grain boundaries, was very sensitive to light and had amplification.

It did not require a chemical process.

Resistance vs. Current for an Ovonic™ Phase Change Binary Memory Device

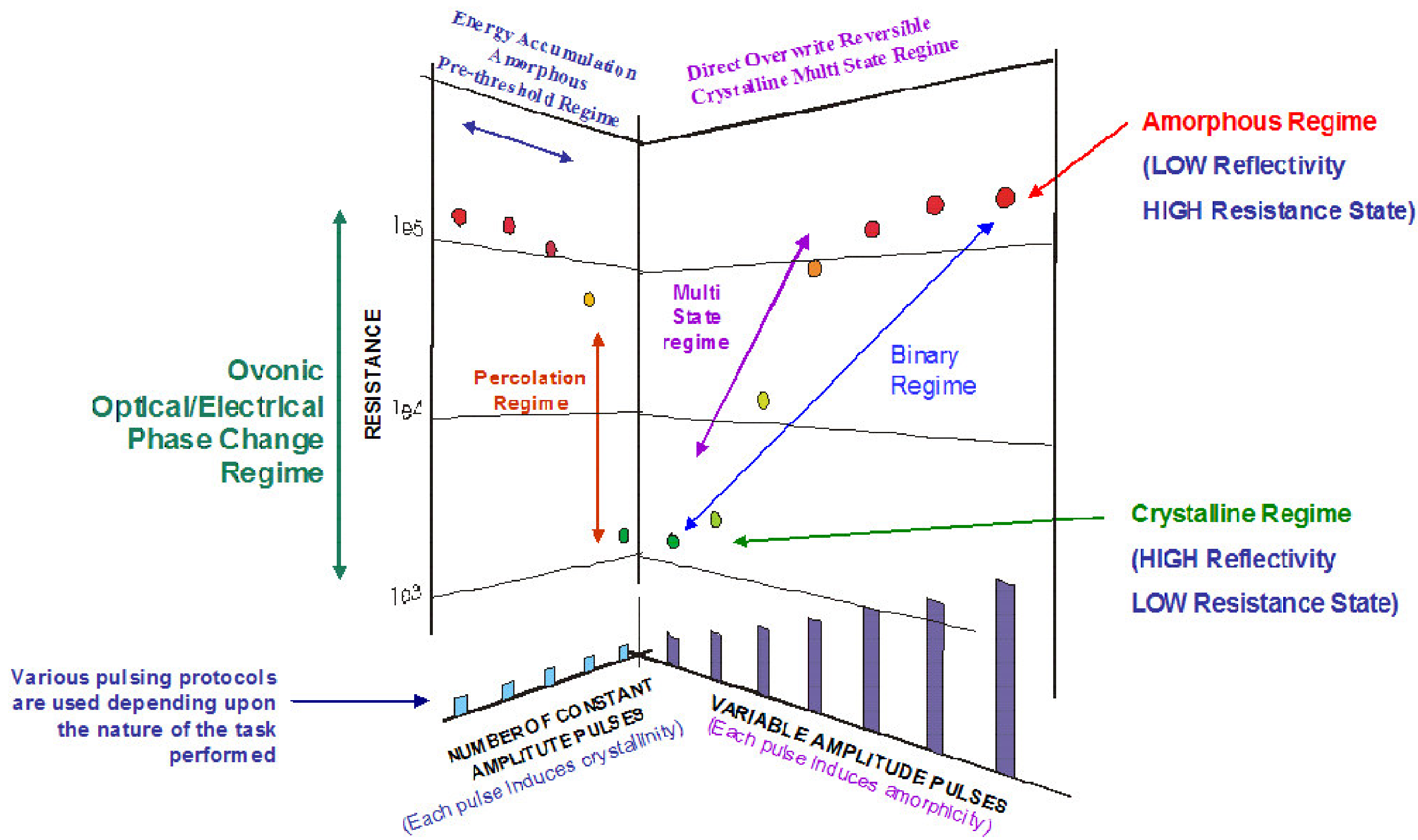


Cycle Life

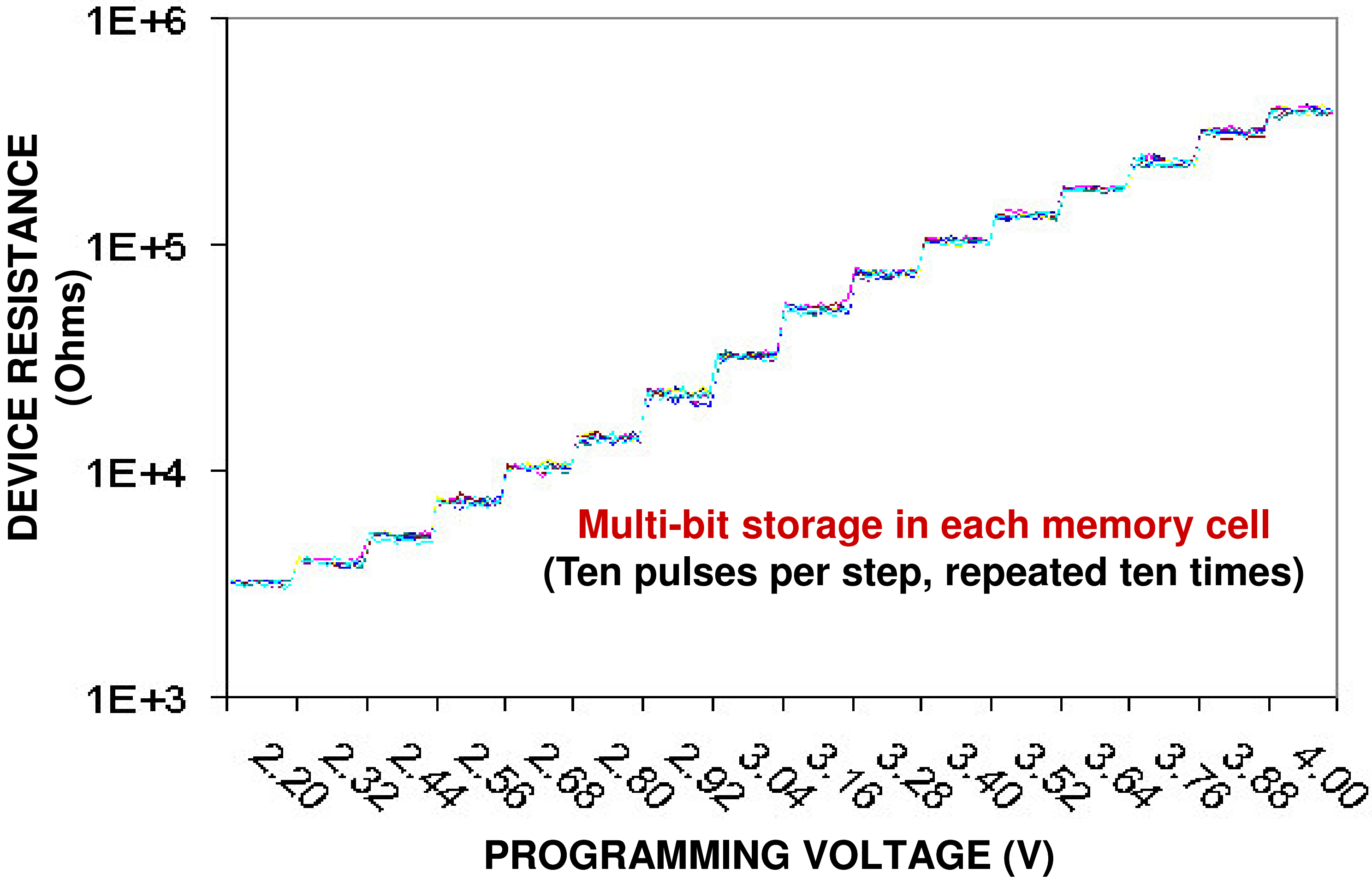


Continued testing to 10^{14} would have taken another year

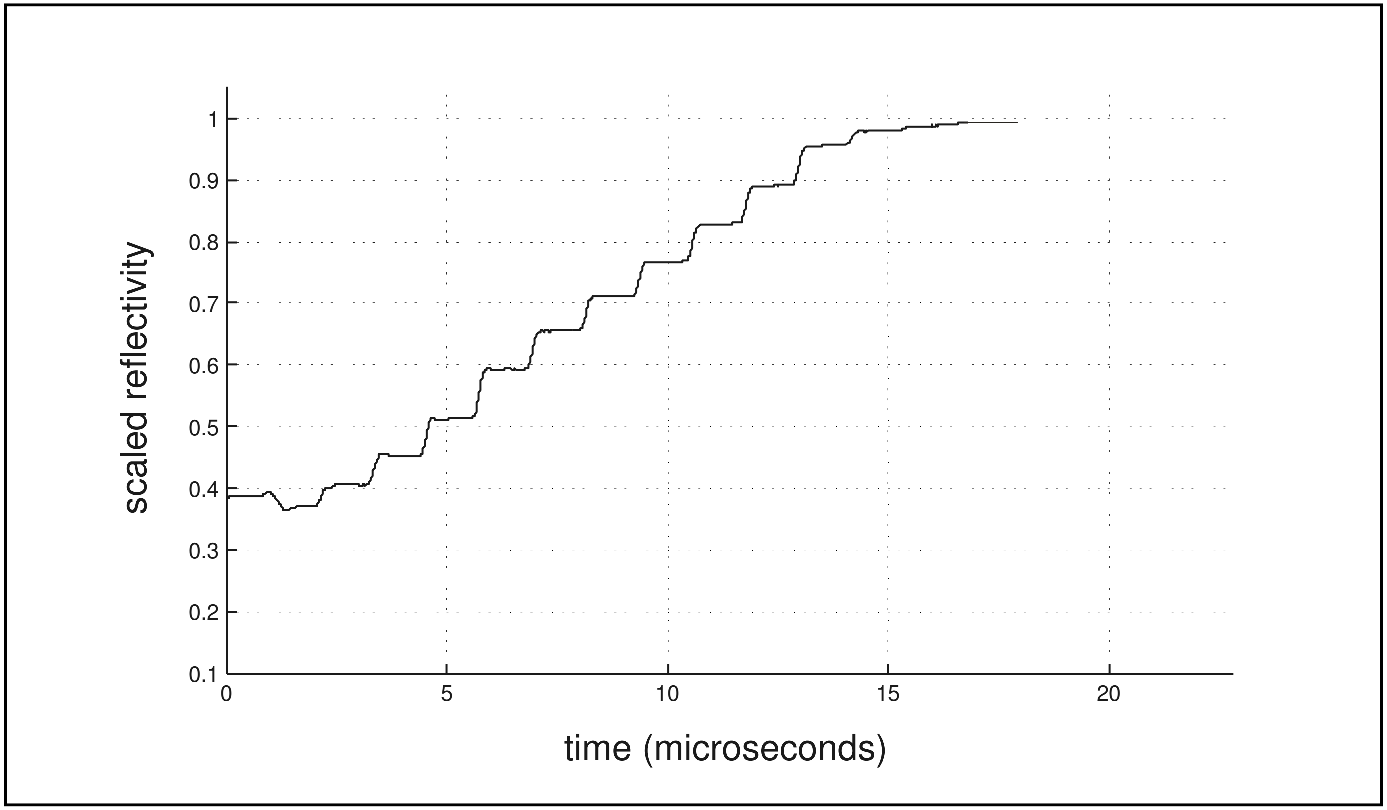
Operation of Ovonic™ Cognitive Device



Ovonic™ Electrical Multi-State Data Storage



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