Roadmap for the Future of Phase Change

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Introduction

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Phase change is here and now!

Optical Storage is obvious

Electrical Storage will soon be as widespread

Probe Storage is growing

Phase Change will be everywhere!

The technology of the future

Many new uses

For example, we are making the analogue to the transistor using Ovonic principles and materials

"A theory is the more impressive

the greater the simplicity of its premises is,

the more different kinds of things it relates,

and the more extended is its area of applicability".

Albert Einstein

History

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Basic theory

Threshold Switch

Electrical Memory

Optical Memory – started in the 1960's

- First Ovonic – 4GB by 1972
  - Huge!, water cooled lasers
  - Who needs 4GB (at that time)?

TeGe alloys – with As, Sn, Au, etc.

Crystallization without diffusion (congruent):

- Stoichiometric alloys - GeSbTe
- Eutectic alloys: Sb:Te with modifiers – Ag, In, Ge, etc.

Physical Principles

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Phase change materials for Optical & Electronic memory
Ideal for configurational and conformational changes

Crystalline ⟷ Amorphous

New Structural, Chemical, & Electronic properties

- Fundamental **Reconfiguration** through change in the total interactive environment
  - Influence of Lone pair bonds
  - Multitude of d-orbital interactions
    - Different bonding hybridization

Ge, In, Sb, Te ⟷ Se,, ...

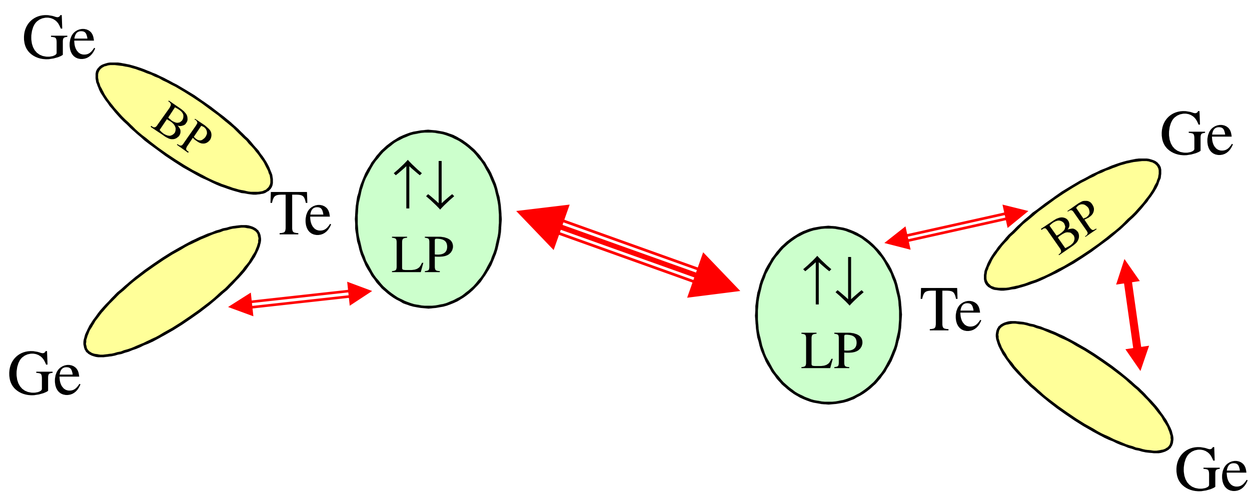
+ Transition metals, etc...

Causes of Conformation & Bonding Reorganization

Lone pair Orbitals….

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

They influence the **shape** of a molecule by exerting **strong repulsive forces** on the electron pairs in neighboring bonds and on other lone pairs as well as being able to **enter new bonding relationships** with other elements in their environment



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]

Lone Pairs are two electrons (spin up and spin down) that not only can contribute to repulsion but can be used for new bonding purposes since lone pairs are not generally 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

How these apply – new concept examples

Wider band gap materials

More transparent for use as first layer in dual layer media

- Chemical Modification to increase speed of selenium alloys

Crystallization enhancements

One material catalyzing a second material

Dual wavelength

initiate and complete the transformation

increase penetration

single layer and dual layer

Current Phase Change Optical

Audio, Data and Video Applications

CD – Huge success with large family of products

CD-RW for rewritable

Approximately one micron marks

DVD – RAM, -RW, +RW are growing strongly

Good products, but maybe too many formats

Approximately half micron marks

High Definition Television – 25 GB

Will we repeat the format confusion?
Blu-Ray is leader, but there are other proposals

Approximately quarter micron marks

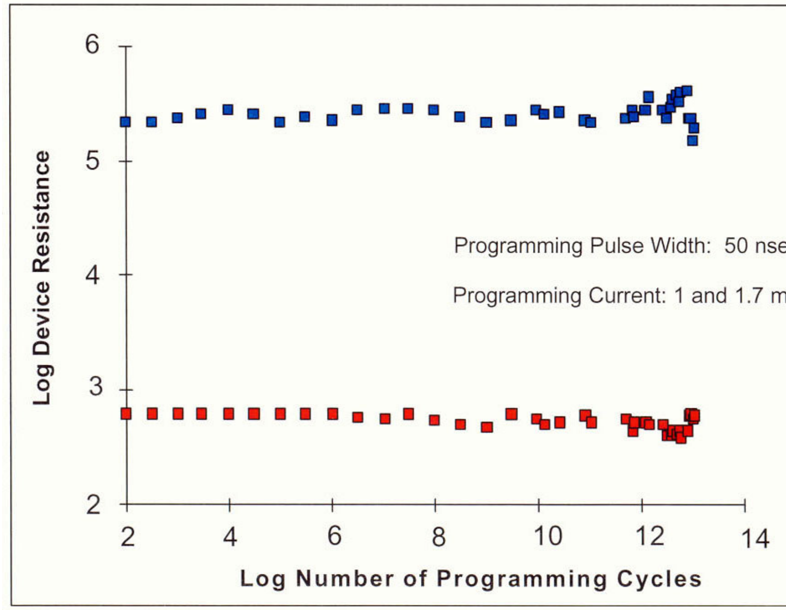
Lots of manufacturers, good growth industry

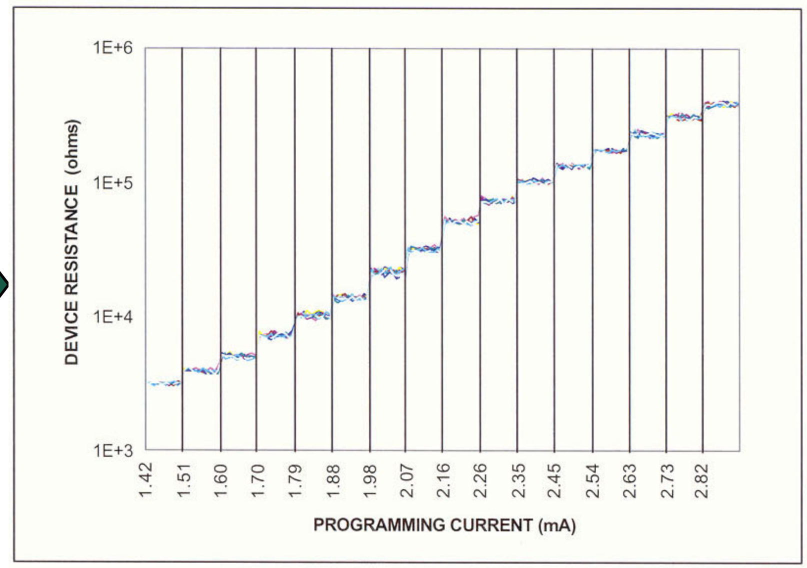
Current Phase Change Electrical

Ovonic Universal Memory

- Non-Volatile
- Nanosecond speed
- Long Life (>10^{13} cycles demonstrated, test stopped without failure),
- Low Voltage
- Low Energy
- Small cell size
- Multi-level
- Low Cost

Gray Scale





Current Phase Change Electrical

Ovonic Universal Memory

- Ovonyx: with Intel, STMicroelectronics, British Areospace

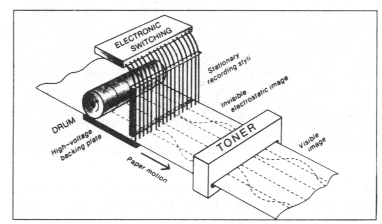
Ovonic Cognitive Computer

OUM Research Around the World

- Laboratoire d’Electronique et des Technologies de l’Information (LETI) (France)
- Data Storage Institute (Singapore)
- Samsung (Korea)
- Many Corporations and Universities (Japan)

Probe Storage

- ECD demonstrated in 1960’s
- Contact, Tunneling, and Field Emission Probes



The Ovshinsky Switch
Proceedings of the Fifth Annual National Conference on Industrial Research
September, 1969

Next Steps in Phase Change Optical Storage

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Higher Capacity Via Conventional Means

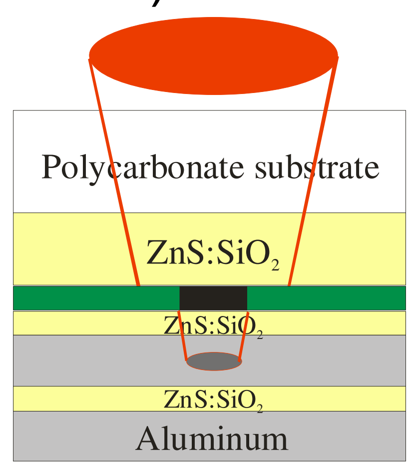
- Larger NA, Shorter Wavelength, Improved Coding – Blu-Ray, for example

Near Field

- Solid Immersion Lenses, Integrated optics, Very Small Aperature Lasers

Super-Resolution Near-Field Storage (Super-RENS)

- Simple, reversible phase change addition
- Perhaps Most Promising
- Tominaga



Probe Storage

- Vertical Cavity Surface Emitting Laser Arrays
  - Gotoh
- Near-field Scanning Optical Microscopy

Femtosecond Response

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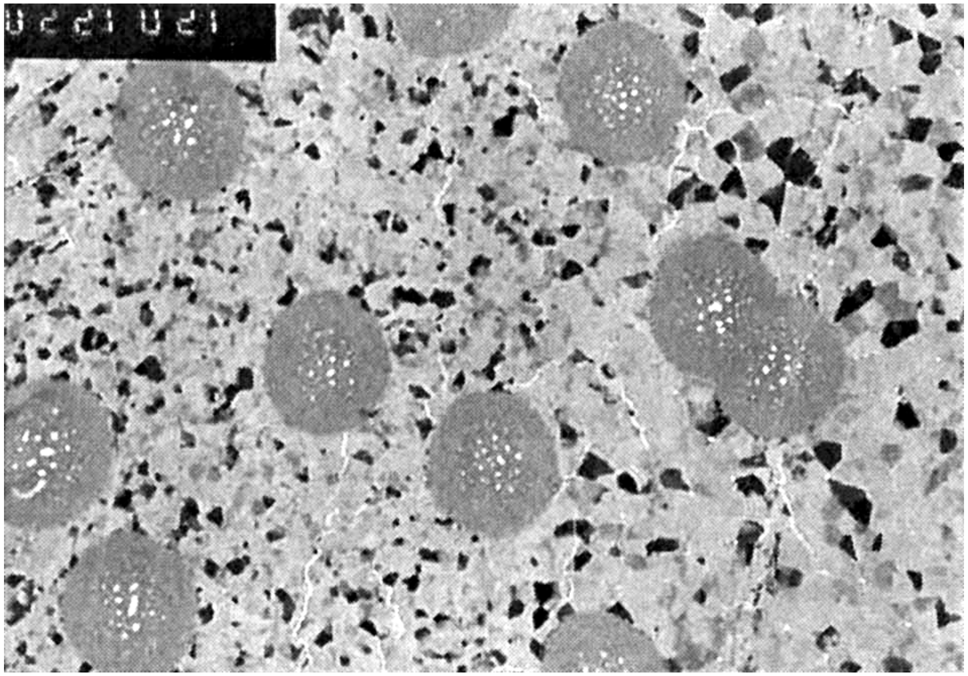
My proposal:

- Structural and conformational rearrangements come from electronic excitation/bond breakage, which starts through photon absorption and is much faster than a thermal process
- Escape the boundaries of heat by using very fast pulses

Takeo Ohta showed that amorphous marks can be made using 120 femto-second laser pulses

TEM Micrograph showing amorphous marks made using a 120 femto-second laser pulse. Edge quality is improved compared to conventional time scale recordings. This exposure corresponds to a data rate of over one terabit per second



Biasing Optical/Electrical

How can we increase sensitivity?

Structural Changes are initiated by electronic excitation, induced by either electrical current of optical absorption

Add sub-threshold bias

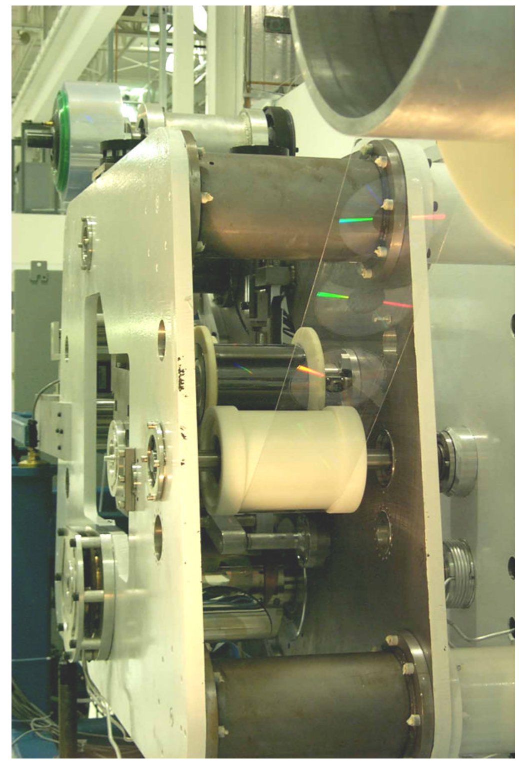
- Electronic including Surface Plasmons
- Optical
- Vibrational and Thermal

Low Cost Manufacturing

The 30 MW annual capacity photovoltaic manufacturing machine using ECD Ovonics proprietary continuous roll-to-roll solar cell deposition process.

ECD/Uni-Solar Auburn Hills, Michigan, USA

Roll-to-Roll production of optical disks



8 disks per second, about 20 times the molding rate

Pre-Crystallization Optical Storage

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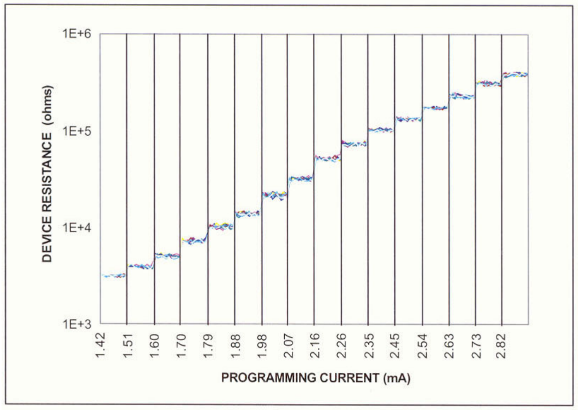
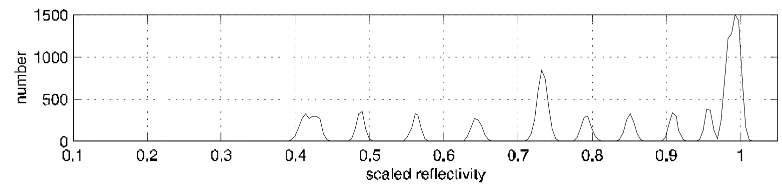


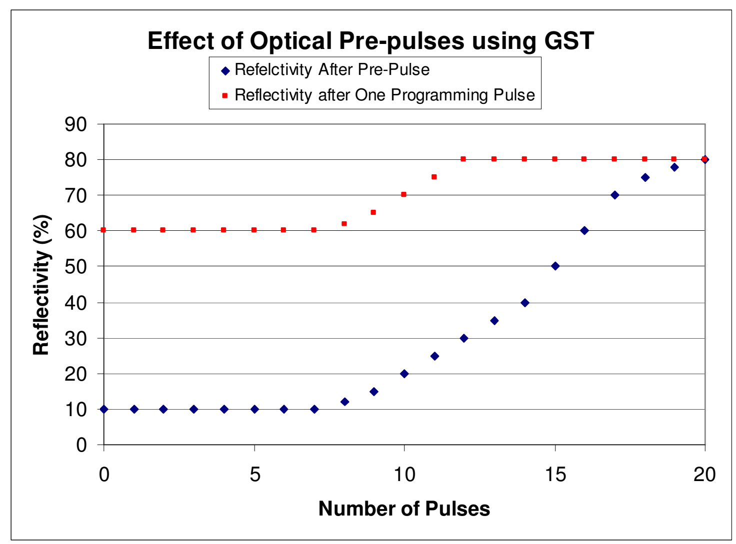
Multi-Level phase change first demonstrated in electrical devices at ECD

Uses gray-scale capability to increase storage density

Optical Multi-Level demonstrated at ECD (using Calimetrics coding)



Normal ML only uses the region showing optical change.
We can use the region that changes, but doesn't show optically!



Phase Change is Much More Than Making Marks

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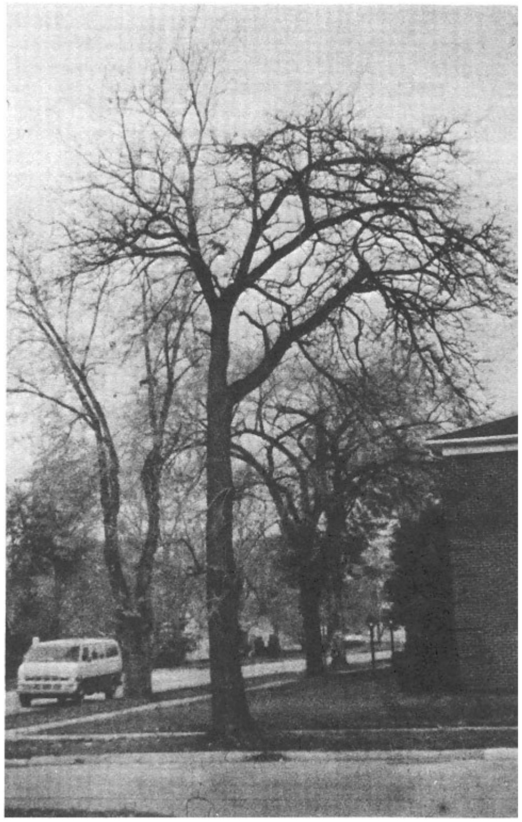
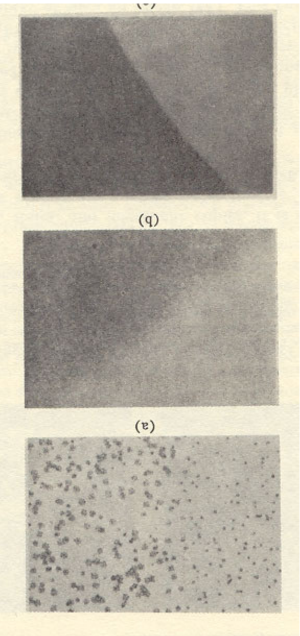
High Quality Images Recorded Using Various Ovonic Imaging Media



Thermal Process, Non-Silver, Gray-Scale Film with Amplification

Image Formed using Differential Etching

Phase Change Films Crystallized by Flash Lamp Exposure Showing Gray-Scale and Nucleation and Growth



Where else can we go

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Optical
- limited by the system
- 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

A Fundamentally New Approach to Computing

The Ovonic Cognitive Computer is a breakthrough technology that fulfills the long-awaited goal of achieving intelligent computing.

The Ovonic Cognitive Device offers multifunctionality that realistically simulates the neurosynaptic behavior of biological neurons

The Ovonic Cognitive Devices can be readily interconnected to many other such devices in highly dense two-dimensional or in three-dimensional, vertically integrated networks.

Ovonic devices can be used n a network configured to serve as weighting devices used to control the interconnection strength between Ovonic Cognitive Devices for neurosynaptic function

The unique capabilities offered by the proprietary Ovonic Cognitive Computer will transform the semiconductor and computer industries.

Conclusions

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Optical will continue to grow

- First by capacity
- Followed by speed

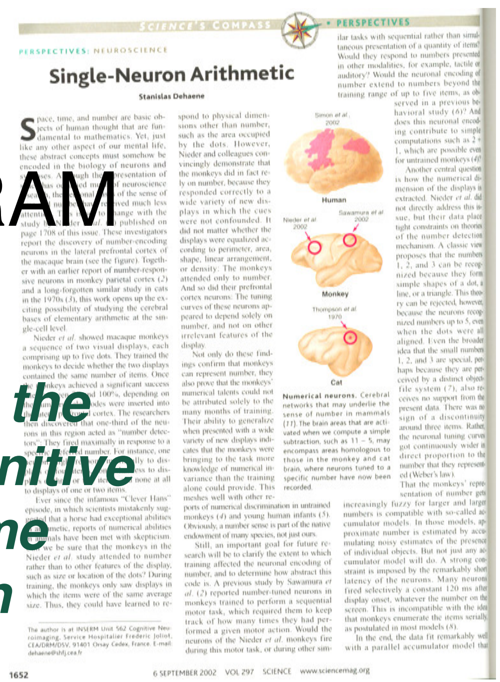
Electrical will be in products soon

- Flash first
- Followed by imbedded microprocessors

OUM Will replace Flash, DRAM and SRAM

Ovonic Cognitive Computer

A new species is born with the non-biological Ovonic Cognitive Computer acting in the same manner as the human brain


SCIENCE'S COMPASS • PERSPECTIVES

PERSPECTIVES: NEUROSCIENCE

Single-Neuron Arithmetic

Stanislas Dehaene

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***"Without vision,
the people perish"***