

# Phase Change Data Storage

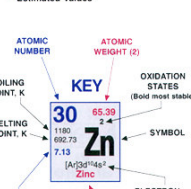


# PERIODIC TABLE OF THE ELEMENTS

Table of Selected Radioactive Isotopes

GROUP IA										GROUP IIA										GROUP IIIA										GROUP IVA										GROUP VA										GROUP VIA										GROUP VIIA										GROUP VIIIA										GROUP IIIB										GROUP IVB										GROUP VB										GROUP VIB										GROUP VIIB										GROUP VIII																																																																																																																																																																																		
1	1.00794	H	1	4.00260	He	2	6.941	Li	4	9.01218	Be	5	10.811	B	6	12.011	C	7	14.0067	N	8	15.9994	O	9	18.99840	F	10	20.1797	Ne	11	22.98977	Na	12	24.305	Mg	13	26.98154	Al	14	28.0855	Si	15	30.97376	P	16	32.066	S	17	35.4527	Cl	18	39.948	Ar	19	39.0983	K	20	40.078	Ca	21	44.9559	Sc	22	47.87	Ti	23	50.9415	V	24	51.9961	Cr	25	54.9380	Mn	26	55.845	Fe	27	58.9332	Co	28	58.9332	Ni	29	63.546	Cu	30	63.546	Zn	31	69.723	Ga	32	72.61	Ge	33	72.61	As	34	78.96	Se	35	79.904	Br	36	83.80	Kr	37	85.4678	Rb	38	87.62	Sr	39	88.9059	Y	40	91.224	Zr	41	92.9064	Nb	42	95.94	Mo	43	101.07	Tc	44	101.07	Ru	45	102.9055	Rh	46	106.42	Pd	47	107.868	Ag	48	112.411	Cd	49	114.82	In	50	118.710	Sn	51	121.760	Sb	52	127.60	Te	53	128.9045	I	54	131.29	Xe	55	132.9054	Cs	56	137.33	Ba	57	138.9055	La	58	140.12	Ce	59	140.9077	Pr	60	144.24	Nd	61	144.9128	Pm	62	150.36	Sm	63	151.964	Eu	64	157.25	Gd	65	158.9253	Tb	66	162.50	Dy	67	164.9303	Ho	68	167.26	Er	69	168.9340	Tm	70	173.04	Yb	71	174.967	Lu	72	175.94	Hf	73	180.9479	Ta	74	183.84	W	75	186.207	Re	76	186.207	Os	77	192.22	Ir	78	196.08	Pt	79	196.9665	Au	80	200.59	Hg	81	204.383	Tl	82	207.2	Pb	83	208.9804	Bi	84	208.9804	Po	85	210	At	86	222	Rn	87	223	Fr	88	226	Ra	89	227	Ac	90	232.0377	Th	91	232.0377	Pa	92	238.0289	U	93	238.0289	Np	94	241	Pu	95	243	Am	96	243	Cm	97	247	Bk	98	247	Cf	99	251	Es	100	257	Fm	101	257	Md	102	259	No	103	262	Lr

Selected Radioactive isotopes  
Naturally occurring radioactive isotopes are designated by a mass number in blue (though some are also manufactured). Letter in parentheses indicates an isomer of another isotope of the same mass number. Half-lives follow in parentheses, where s, min, h, d, and y stand specifically for seconds, minutes, hours, days, and years. The table includes many the longer-lived radioactive isotopes. Many others have been prepared, isotopes known to be radioactive but with half-lives exceeding 10<sup>10</sup> y have not been included. Symbols describe the principal mode (or modes) of decay, as are as follows: (these processes are generally accompanied by gamma radiation):  
α alpha particle emission  
β beta particle (electron) emission  
β+ positron emission  
EC orbital electron capture  
IT isomeric transition from upper to lower isomeric state  
SF spontaneous fission



58	140.12	Ce	59	140.9077	Pr	60	144.24	Nd	61	144.9128	Pm	62	150.36	Sm	63	151.964	Eu	64	157.25	Gd	65	158.9253	Tb	66	162.50	Dy	67	164.9303	Ho	68	167.26	Er	69	168.9340	Tm	70	173.04	Yb	71	174.967	Lu
90	232.0377	Th	91	232.0377	Pa	92	238.0289	U	93	238.0289	Np	94	241	Pu	95	243	Am	96	243	Cm	97	247	Bk	98	247	Cf	99	251	Es	100	257	Fm	101	257	Md	102	259	No	103	262	Lr

NOTES:  
(1) Black — solid.  
Red — gas.  
Blue — liquid.  
Outline — synthetically prepared.  
(2) Based upon carbon-12. (1) indicates most stable or best known isotope.  
(3) Entries marked with daggers refer to the gaseous state at 273 K and 1 atm and are given in units of g/l.



Catalog Number WLS-18006  
P.O. Box 5229, Buffalo Grove, IL 60089-5229  
1-800-727-4368 FAX 1-800-676-2540

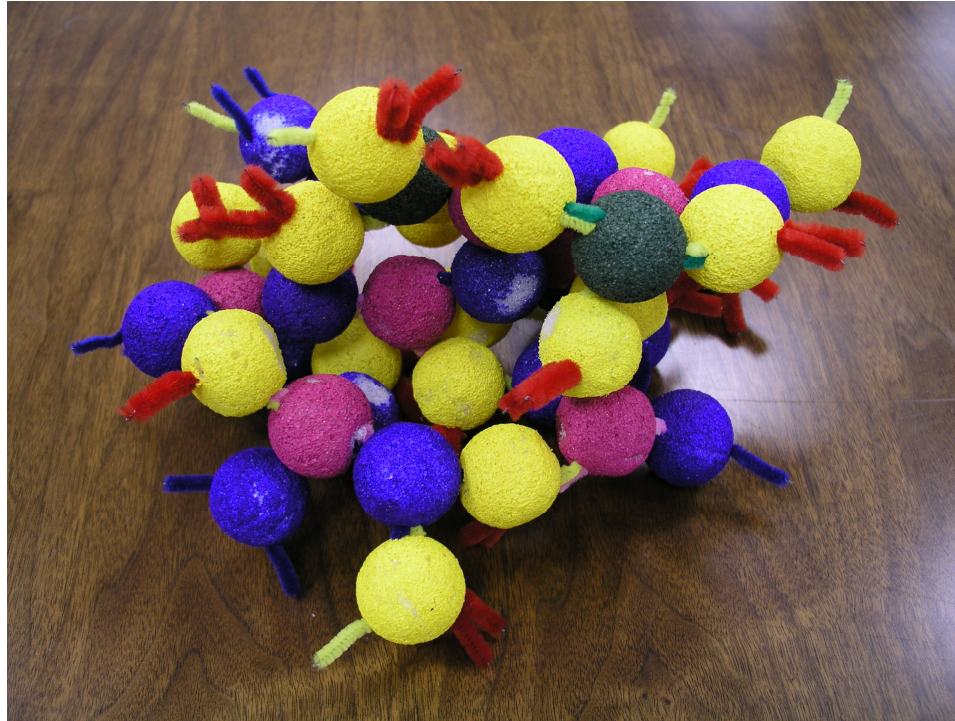
I will give Atomic Design rules for Ovonic Threshold and Memory materials



# OVONIC INFORMATION SOLUTIONS

# 3-D Model of the Ovonic™ Threshold Material

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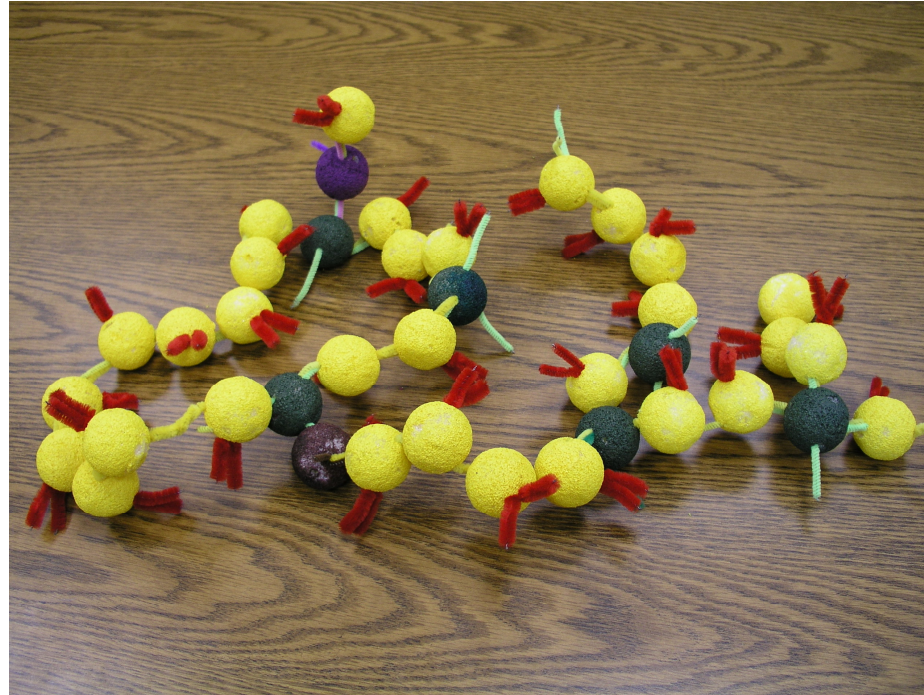


**Yellow balls represent Te atoms and red sticks represent their lone-pairs. The dark balls are Ge, Si and As. The coordination can vary from site to site, however, in the model we have shown Ge and Si as 4-coordinated and As as 3-coordinated.**



# 3-D Model of the Ovonic™ Memory Material

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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.

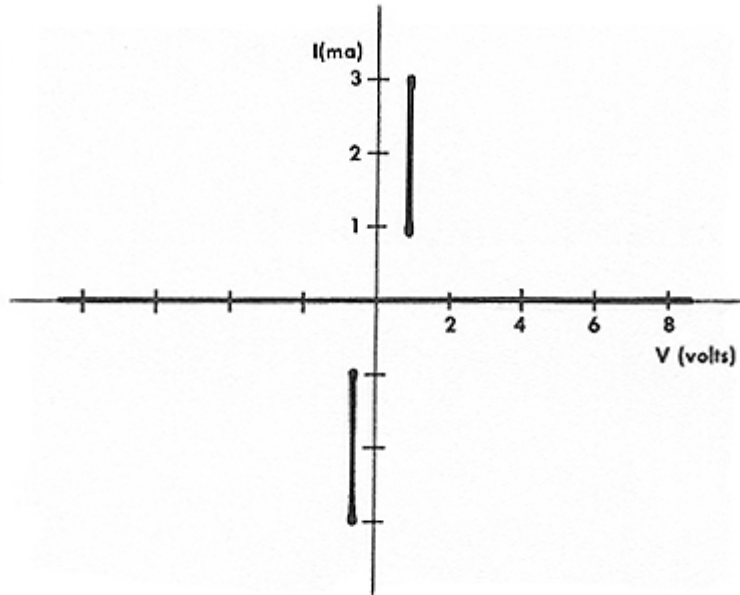
**Note: Polymeric chain structure and crosslinking**



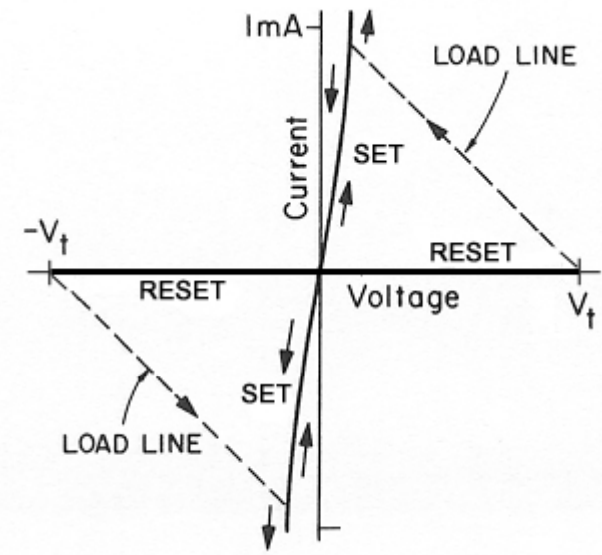
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# I-V Characteristics

## Ovonic Threshold Device



## Ovonic Memory Device

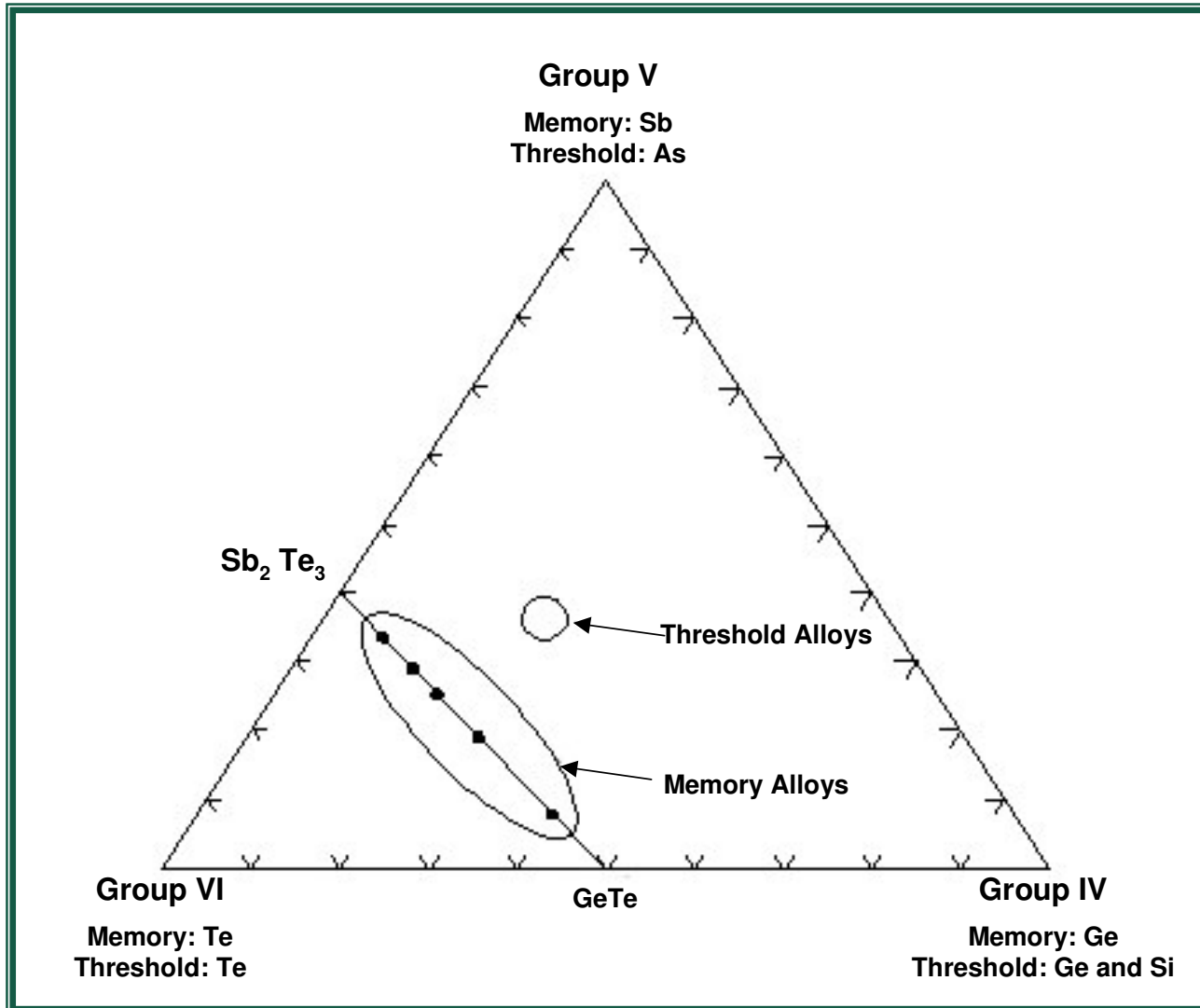


Switching in chalcogenide materials based on lone-pair excitation:

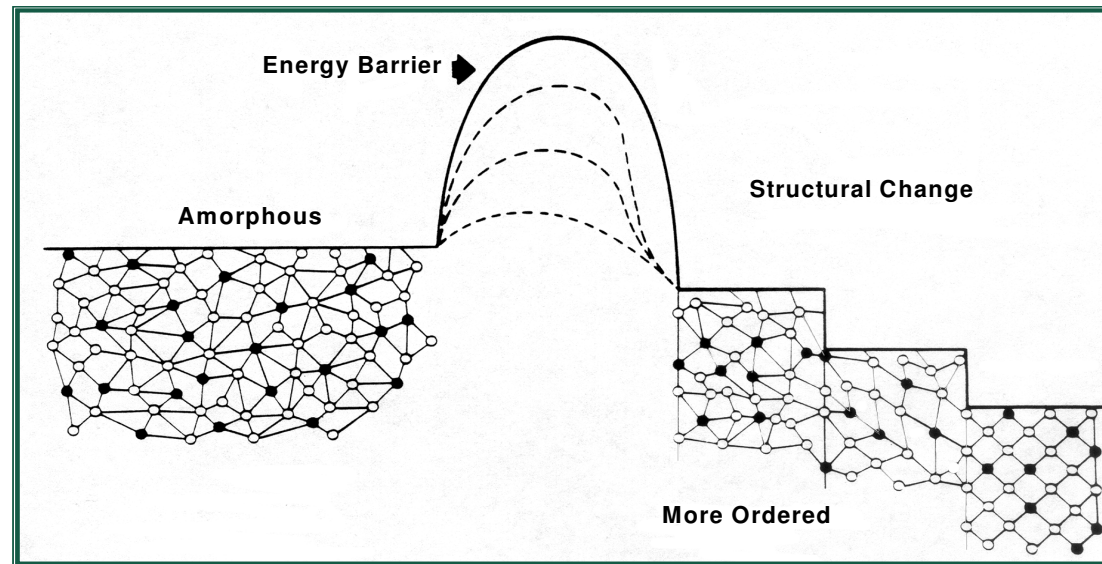
- **Threshold** --- noncrystallizing --- **OTS**
- **Memory** --- phase change --- **OMS**



# 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



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# Physical Principles

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## 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

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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.

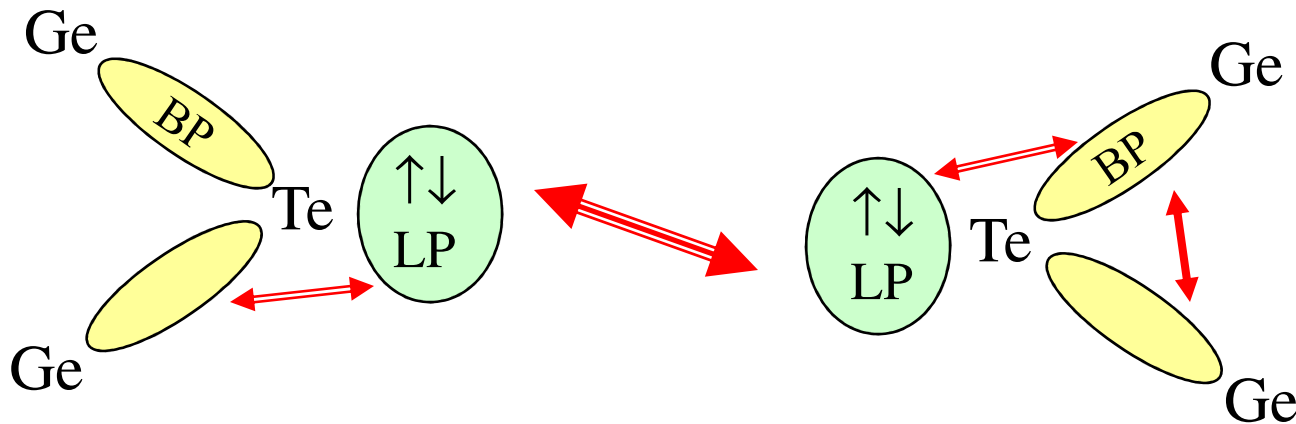


# Causes of Conformation & Bonding Reorganization

## 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

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

**The strongest ...** [Lone Pair  $\longleftrightarrow$  Lone Pair]

**Next.....** [Lone Pair  $\longleftrightarrow$  Bonding Pair]

**The weakest .....** [Bonding Pair  $\longleftrightarrow$  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

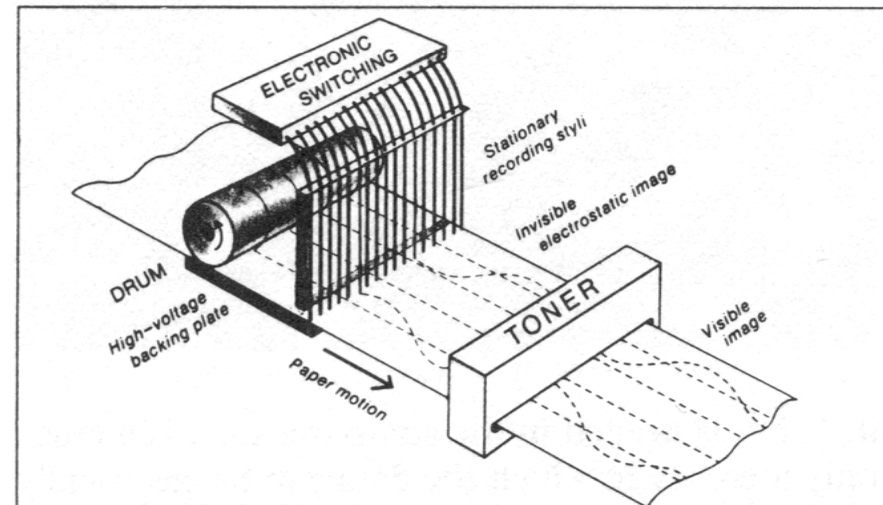
## Electron beam

- 100 angstroms
- no moving parts

## Probe storage

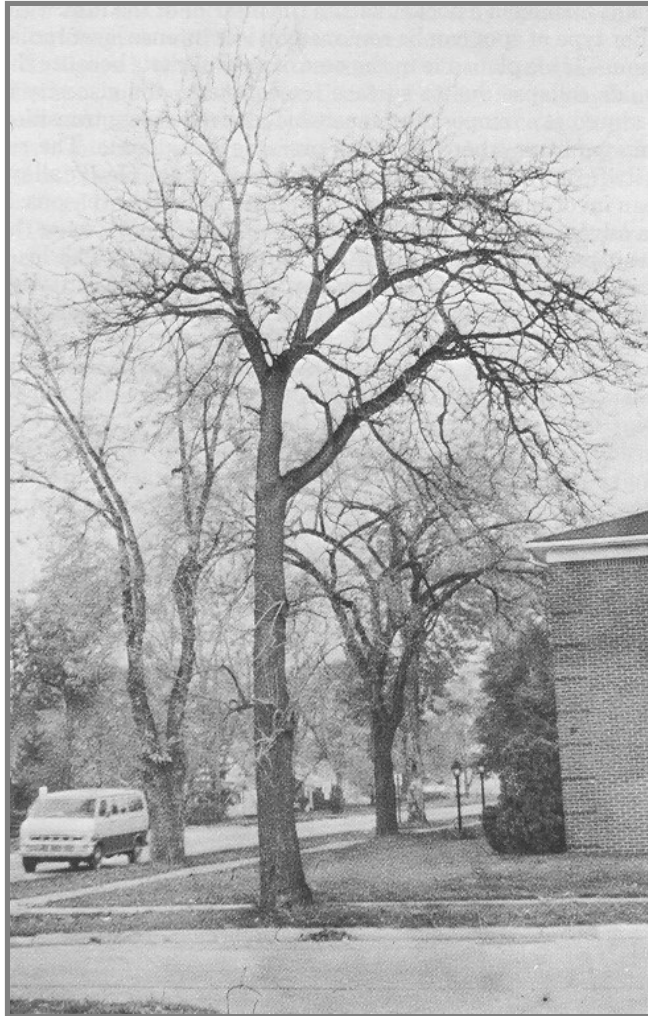
- smaller than 100 nm
- massively parallel

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

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## Instant Imaging

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

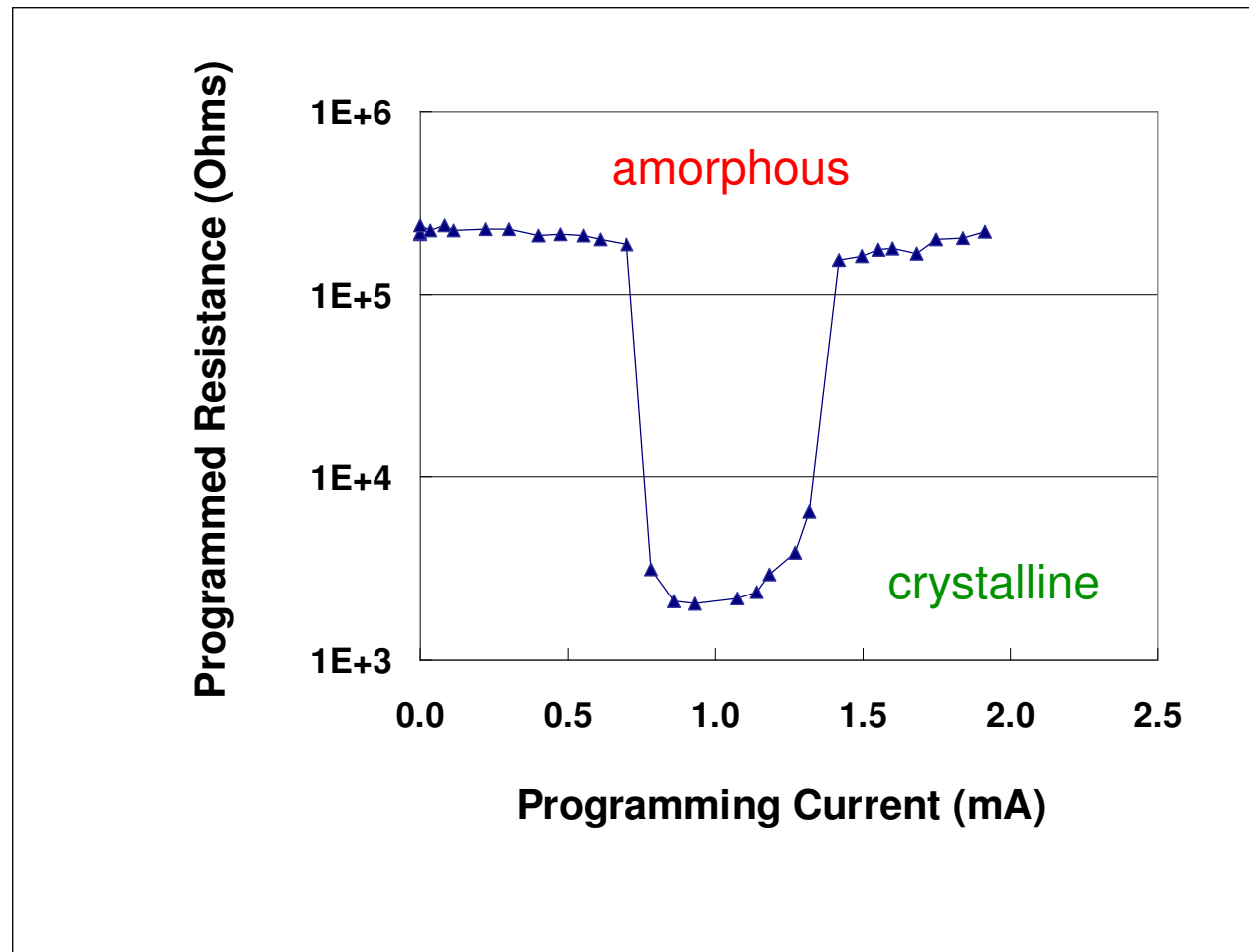
The material was **organo-tellurium**. It had no grain boundaries, was very sensitive to light and had amplification.

**It did not require a chemical process.**

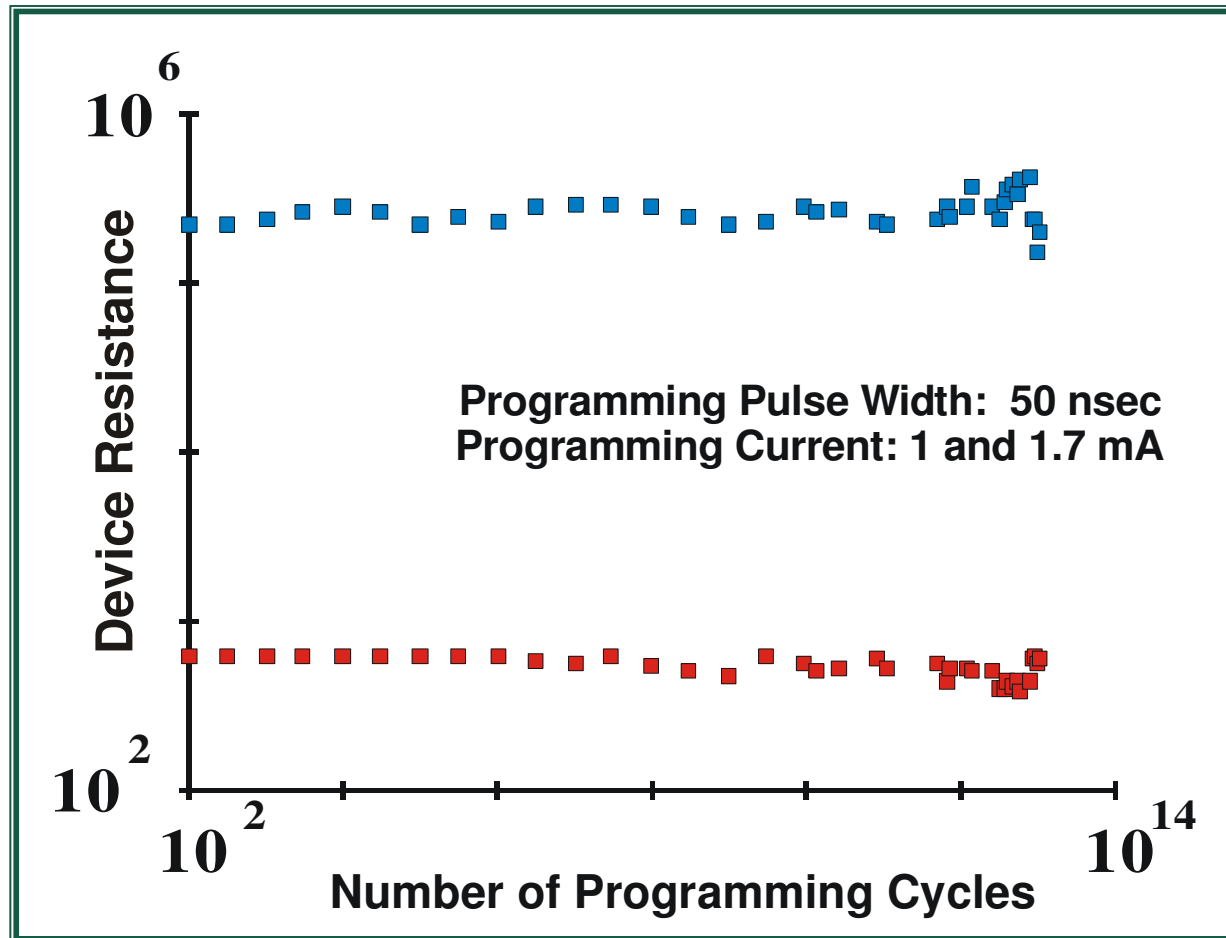


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# Resistance vs. Current for an Ovonic™ Phase Change Binary Memory Device



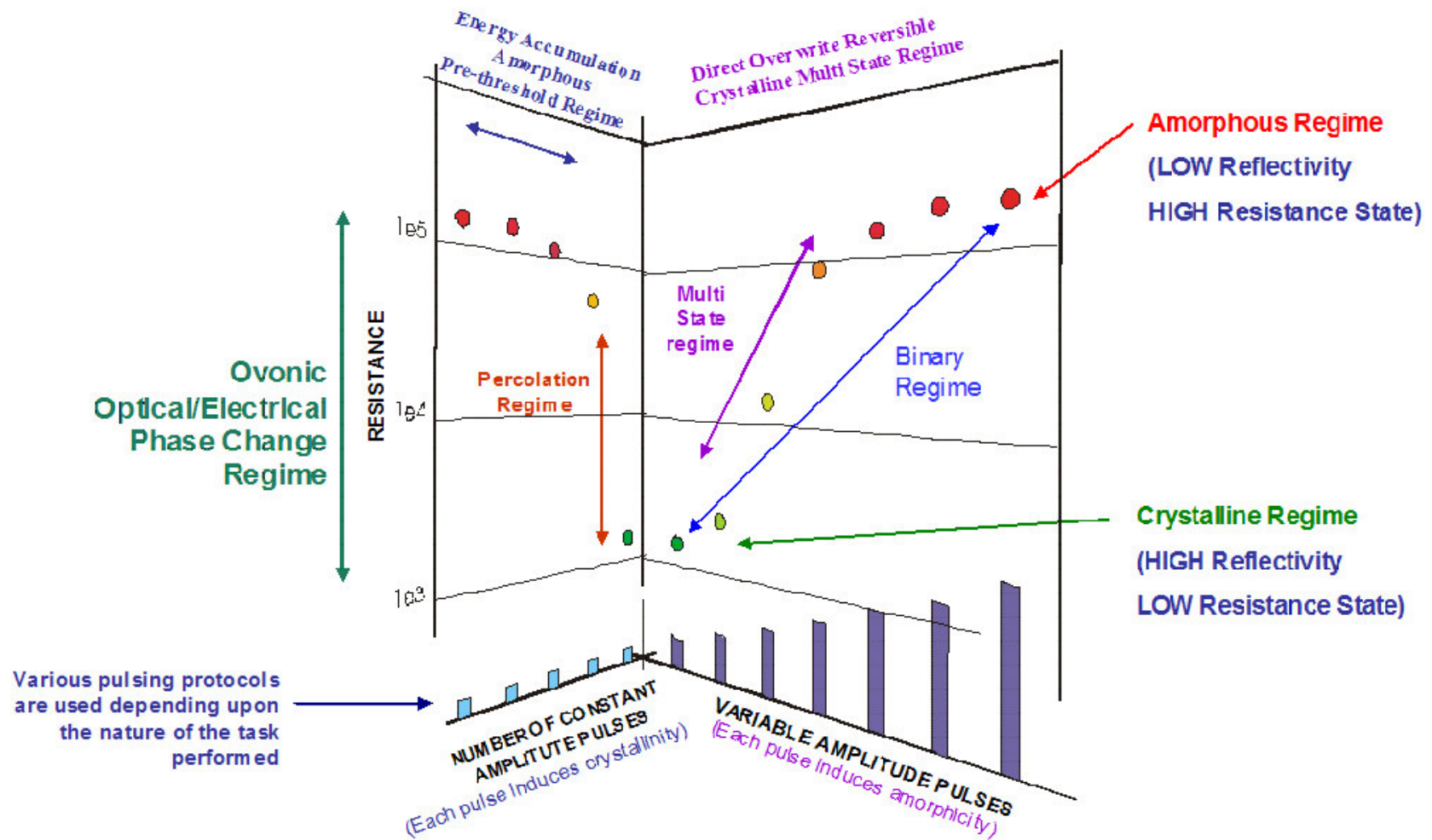
# Cycle Life



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



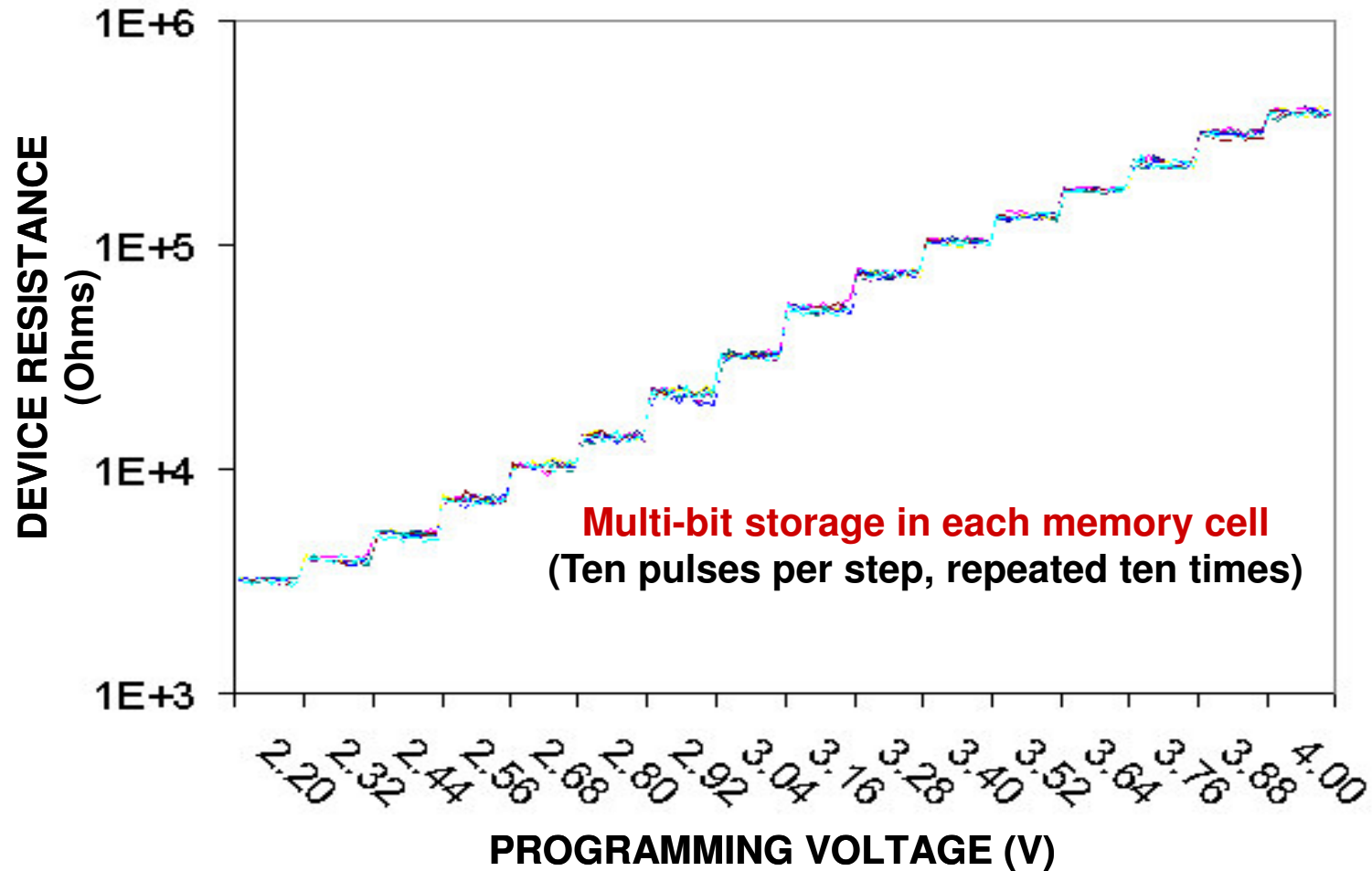
# Operation of Ovonic™ Cognitive Device



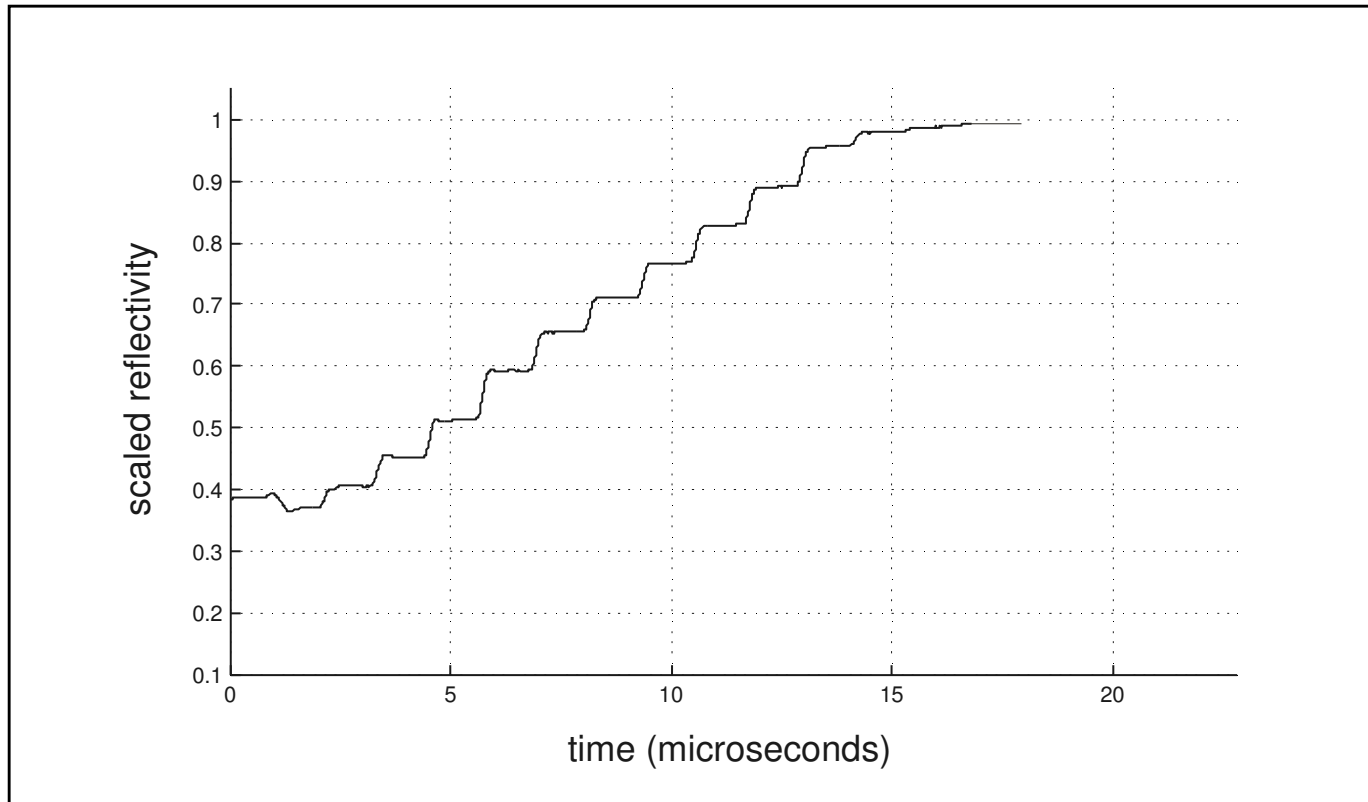
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# Ovonic™ Electrical Multi-State Data Storage



# Ovonic™ Optical Multi-State Data Storage



See, Keynote Talk, in **ISOM'03, Nara , Japan**  
To be published: **Japanese Journal of Applied Physics**



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## 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**



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