The Future of Ovonic Phase Change Optical and Electrical Devices

Stanford R. Ovshinsky
Energy Conversion Devices, Inc.
2956 Waterview Drive
Rochester Hills, Michigan 48009 (USA)

Abstract

Ovonic Optical and electrical phase change devices are opening up new areas that have great transformative value to the entire information field.

I will describe the product potential inherent in these devices and show that their importance is not only in their ability to hugely increase the density of information storage, but as importantly, in their ability to uniquely generate information in the same device.

Logic and memory have always been divided in computers. I will describe how we can go beyond conventional logic and memory approaches and achieve the Holy Grail of cognitive computing. This non-biological cognitive activity can replace the Von Neumann paradigm that is the basis of all modern day computers and open up a new scientific and technological era in the information field which also can combine both optical and electrical approaches.

Our devices are capable of building new industries just as the transistor was the cornerstone of conventional information.

Keywords: Amorphous, chalcogenide, disordered, neurosynaptic computing, Ovonic, phase-change memories, threshold switching

Discussion

I am honored to be here among so many old friends, colleagues and collaborators.

As you know, I feel that as a keynote speaker I have the responsibility to stimulate creative thinking in our wonderful field and to illuminate the potential for growth.

Before I start on the scientific and technical portions of my talk, I would like to tell you an old parable whose meaning I think will be very clear to you.

A donkey was given 2 bales of hay, one on each side of him. He couldn't choose between them and therefore starved to death.

The battle between BluRay and HD-DVD is reminiscent of that tale. Since our Ovonic phase change material is the same for both formats, one may say we are indifferent to the choice but no, to us as well as to all of our colleagues here today and their companies it does make a difference and we are looking forward to a decision so the field can grow much faster.

I would like today to focus on the deep and rich physics that resides not only in our Ovonic nanostructure phase change dot but in the related Ovonic electrical devices.

These latter devices can be the bridge to combining phase change with the optoelectronic field and open up unique important areas as well. It is well known that the transistor is the basis of the trillion dollar a year information industry (1).

I will now show data that support my position that the Ovonic chalcogenide devices can generate the same kind of revolutionary changes that one associates with the transistor.

First of all, crystalline materials do not scale, our devices do. Therefore we do not face the same physical barrier that limits future generations of transistors.

Let me show you the evidence.

The well-known Ovonic Threshold Switch (Fig. 1) is smaller, faster – its speed has never yet been measured-- and has 50 times more current carrying capacity than does the transistor (see Fig. 2) .

It is volatile as is the transistor, differentiating itself from its sibling, the nonvolatile Ovonic memory switch.

The material differences between the Ovonic Threshold Switch/Ovonic three terminal device (which I will discuss further) and the Ovonic Universal Memory reside in the number of cross-linked bonds, and the bonding strengths of the cross-links in the materials of which they are composed.

Unlike the Ovonic phase change memory, the Ovonic Threshold Switch has many more and stronger crosslinks – instead of antimony it has arsenic, instead of just germanium, one can add silicon.

The Ovonic threshold switch is amorphous and remains so. It, like the phase change memory, is long lived. In fact, recent tests confirm that it can achieve 10^{23} cycles. (See Fig. 3.)

Tellurium and its isomorph, selenium, with their lone pairs are the foundation for both the memory and threshold devices. In fact, in Fig. 4, one can see that the electronic threshold action which excites the lone pairs is a part of the phase change mechanism which initiates the phase change.

I am happy to report here that we are continuing to demonstrate the 3-terminal version of this device (Fig. 5) which can replace transistors since it modulates both voltage and current and still retains its incredibly fast and powerful switching. And of course it has gain.

We will be publishing this coming year complete details and particularly that several of these devices can become light responsive and, in fact, have other exciting optical features which I am sure will be of great interest to this audience.

It is also important that a version of the Ovonic threshold switch has the potential to become a powerful nanostructure oscillator.

There are many other unique usages for these devices. Of course, they can be used in conjunction with the Ovonic phase change memory.

In fact, while we use plastic substrates for our Ovonic optical phase change memories and crystalline substrates for the Ovonic Universal Memory, we have shown many years ago that a complete thin-film circuit is possible with all the necessary devices being chalcogenides.

There are also important optical switching and wave guide applications of our work under the inspired leadership of my colleague and collaborator David Strand who is not only the head of our optical phase change memory work but is involved in the rest of our chalcogenide semiconducting work as well.

The following is a brief description of that activity:

Optical Routers

The large change in the optical properties of Ovonic phase change materials between the amorphous and crystalline structures makes them ideally suited for a number of optical switching devices. We are currently developing two types of switches that can be used in optical routers. Both devices have key properties of non-volatility and high speed switching. Further, the large optical contrast between the two structures allows us to design simple devices which are therefore low in cost.

One device is a broadband router. In this device we use the capability of the Ovonic materials to exist in stable amorphous, crystalline and intermediate structures. We developed the multi-state optical storage properties of our materials earlier, and now we extend that operation to build a stationary mirror that can reflect light in a number of directions. The concept is like a phased array radar system, where in our device the phase angle of the light is changed differently across the reflective surface as a consequence of the intermediate structural states, thereby imparting a programmable reflection angle. We can program the Ovonic material using either a laser or electrical signals.

A second device is a photonic crystal structure, having a resonator between two waveguides. There is a small region of Ovonic phase change material in the resonator, within the higher index phase part of the crystal. We create a sub-wavelength region having a refractive index very close to that of the background when the Ovonic material is amorphous, and so it has no effect. When we convert the Ovonic material to its crystalline structure the large change in optical constants disrupts the function of the resonator. In this way we can couple light from one waveguide to the other using amorphous material, and switch the transfer off by changing to crystalline. Since the resonator is a narrowband device, the device functions as an add/drop filter, separating a single channel from a wavelength multiplexed bundle. As with the broadband device, the Ovonic phase change material can be switched with either light or current.

Embossing

The continued use of Ovonic phase change materials in CD, DVD and now BluRay and HD-DVD has led to work at ECD in developing a continuous embossing process to fabricate disk substrates for disks with substrates of 0.6 mm thickness and less. Our technology is particularly well suited for dual layer BluRay and triple layer HD-DVD. We have used our process to make disks and attained 6% jitter at BluRay feature sizes. Our background in roll-to-roll continuous production processes has led to improvements in manufacturing which could provide cost advantages for both of these third-generation optical storage candidates.

Keep in mind that we are speaking of achieving optoelectrical applications. As you all know, I believe that in the future a great part of our work will be optoelectronic.

Now let me remind you of the exciting possibilities for a new information industry that can combine optoectronic principles with the Ovonic cognitive computer which I described in my paper for E*PCOS 04.(2) (See Figs. 6- 8 and References 3-6).

Please note that whatever we accomplish electrically also can be achieved optically. Most importantly for this audience is that the Ovonic phase change device described is virtually the same as what is made and sold all over the world by your companies for CD-RWs, rewritable DVDs. etc.

I have shown the seemingly inexhaustible new physics and mechanisms in a tiny nano spot of atomically engineered amorphous and disordered material which can be the spot that Archimedes (Fig. 9) spoke about- "Give me the spot to stand on, and I will use my lever to change the world." Our lever is the creativity of all of us who utilize Ovonic science for which our beloved organization is named.

References

1) J. Markoff: "Jack S. Kilby, an Inventor of the Microchip, Is Dead at 81": New York Times, June 22, 2005. http://query.nytimes.com/search*
2) S.R. Ovshinsky: "The Ovonic Cognitive Computer – A New Paradigm": Presented at the Third European Symposium on Phase Change and Ovonic Science: E*PCOS 04: Liechtenstein, Germany: Sept. 6-7, 2004.
3) S.R. Ovshinsky and B. Pashmakov: "Innovation Providing New Multiple Functions in Phase-Change Materials to Achieve Cognitive Computing": Reprinted from MRS Symposium Proc.: Vol. 803, HH1.1, pp. 49-60 (2004)
4) S.R. Ovshinsky: "Optical Cognitive Information Processing – A New Field": Reprinted from Jpn. J. Appl. Phys., Vol. 43, No. 7B, pp. 4695-4699: © 2004 The Japan Society of Applied Physics (2004).

5) S.R. Ovshinsky: "A New Information Paradigm – The Ovonic Cognitive Computer": Bucharest, Romania: INOE Publishing House: Non-Crystalline Materials for Optoelectronics, Vol 1, 2004, pp. 1-14 (2004).
6) S.R. Ovshinsky: "Phase Change Electronic Memories: Towards Cognitive Computing": Encyclopedia of Materials: Science & Technology: Oxford, United Kingdom, Elsevier Limited, Copyright ©2005 Elsevier Ltd., pp. 1-6 (2005).

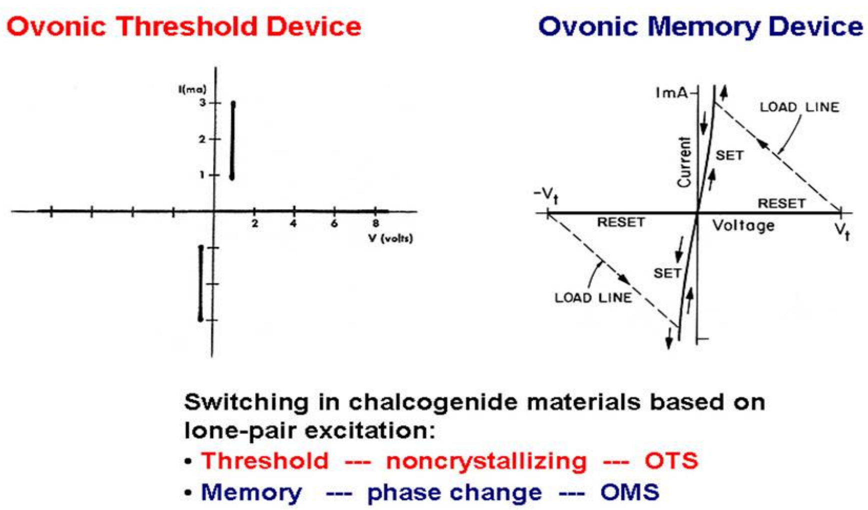

Figure 1

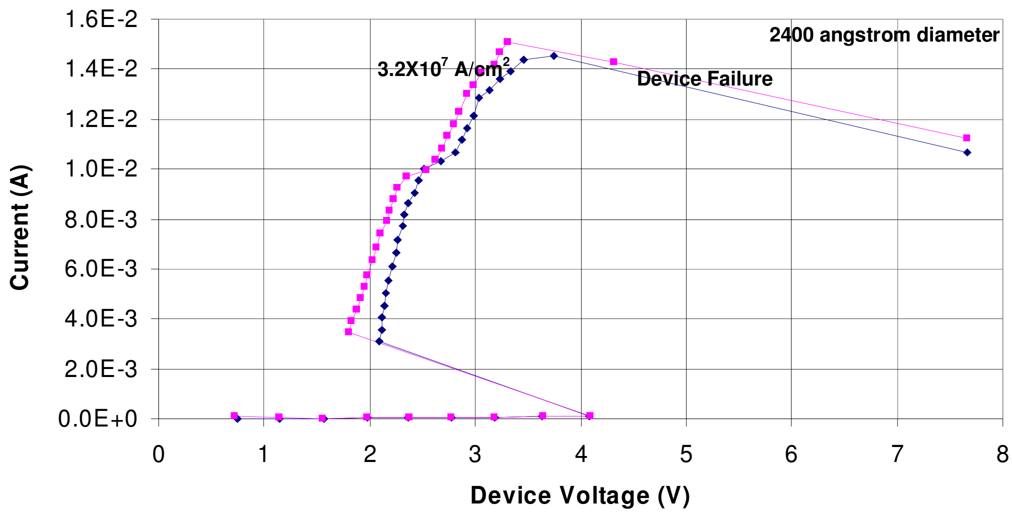

Figure 2

Ovonic Threshold Switches can withstand well over 30 million Amperes per square centimeter. 50 times the current of Bipolar silicon devices.

Accelerated Lifetime Testing Protocol - OTS Device Life vs. Pulse Current at 10MHz

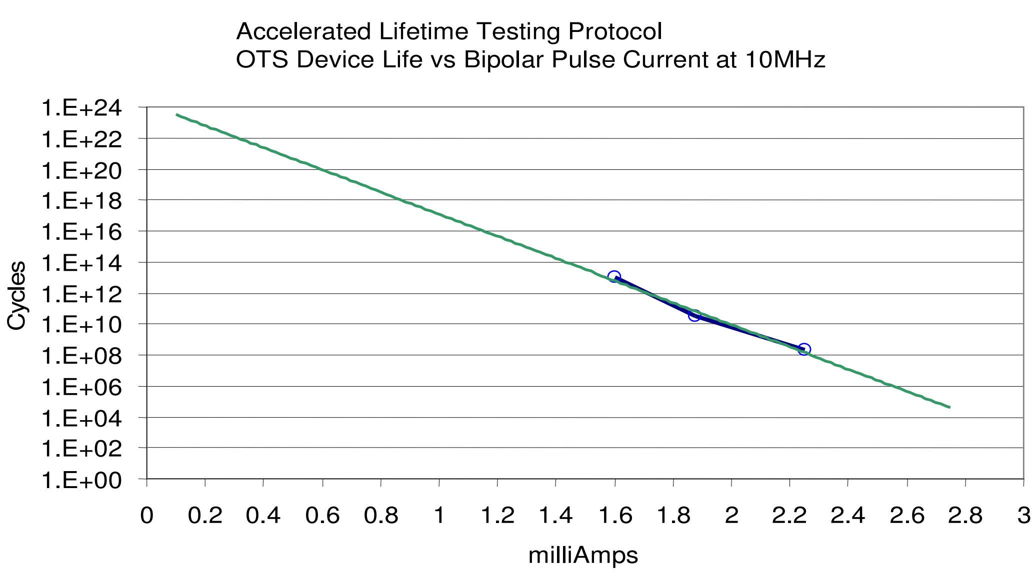

Figure 3

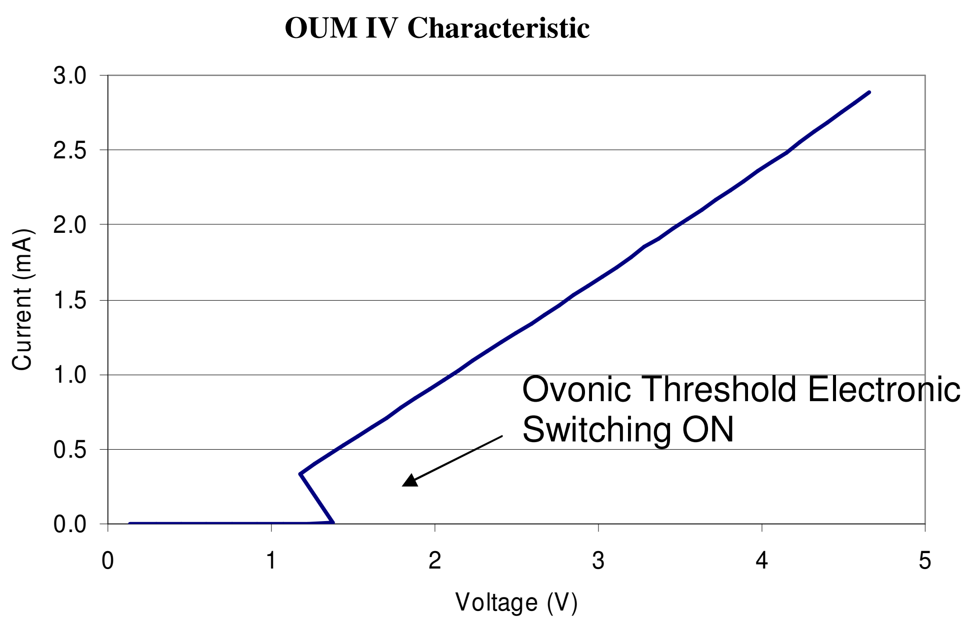

Figure 4

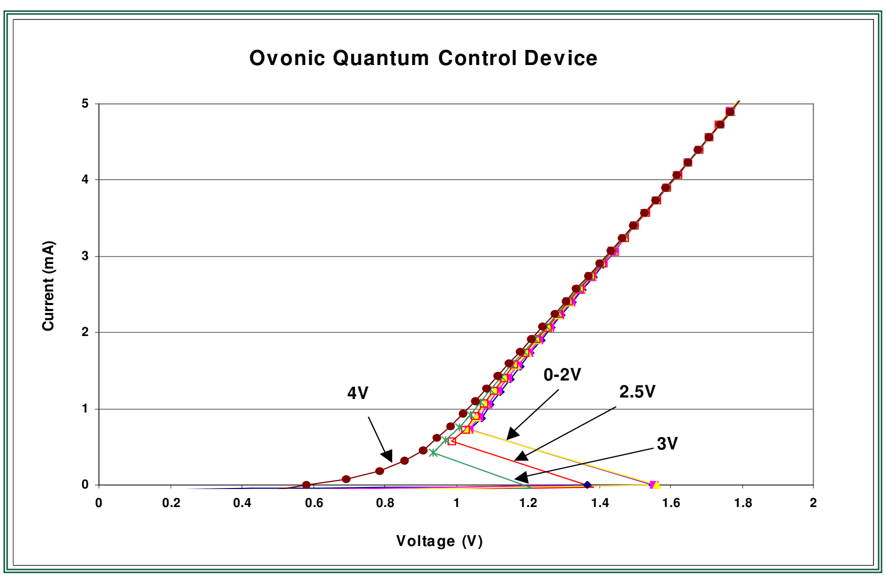

Figure 5

Figure 5   I-V CURVES of Multi-Terminal OQCD

The Ovonic™ Cognitive Computer

Conventional Silicon Computers	**Ovonic Cognitive Computer**
Each Element: ➢ Computes based on single bit (binary) manipulation ➢ Manipulates data sequentially, bit by bit	**Each Element:** ➢ Manipulates, processes and stores information in non-volatile fashion ➢ Hardware and software are unified ➢ Low voltage and low current operation ➢ Performs arithmetic operation s(**+,-,x,÷**) on multi-bit numbers (0,1,2,3…n) ➢ Performs modular arithmetic ➢ Combines logic and memory in a single device ➢ Executes multi-valued logic ➢ Stores the result in a non-volatile manner ➢ Simple, powerful encryption ➢ Acts as a neurosynaptic cell; i.e. possesses intelligence capability ➢ Scales down to angstrom scale dimensions; huge density ➢ OMS device speed in the low nanosecond range and OTS device speed in the under picosecond range* ➢ Capable of massive parallelism ➢ Has attributes of proposed quantum computers without their limitations, such as analogs of quantum entanglement and coherence at practical conditions and environments.
*Ohta achieved phase change in our devices in the femtosecond ranges. Reference: T. Ohta, N. Yamada, H. Yamamoto, T. Mitsuyu, T. Kozaki, J. Qiu, K. Hirao: "Progress of the Phase-change Optical Disk Memory": MRS 1001 Spring, Proc. Vol. 674, V1.1.1 (2001).	

Figure 6

The Ovonic™ Cognitive Computer

Arrays of computation and storage elements are combined in a conventional computer which:	**An Array of Ovonic elements:**
➢ Requires separate storage and processor units or regions ➢ Has limited parallel processing capability ➢ Is limited to Von Neumann operations	➢ Easily factors large numbers ➢ Has attributes of proposed quantum computers without their limitations, such as analogs of quantum entanglement and coherence at practical conditions and environments ➢ Performs high level mathematical functions (e.g. vector and array processing) ➢ Has high 3-dimensional interconnectivity, huge density, giving rise to high speed, hyper-parallel processing (i.e. millions of interconnected processors) ➢ Interconnectivity is simple and inherently reconfigurable ➢ Has adaptive learning capability **The Ovonic Devices are:** ➢ Mass produced in exceptionally dense, all thin film, uniquely interconnected arrays ➢ Mass manufactured as a thin film, flexible device using proven technologies ➢ Ovonic Quantum Control Device - unique, high speed, low cost 3 or more terminal device. Nanostructure capable of carrying large current density

Figure 7

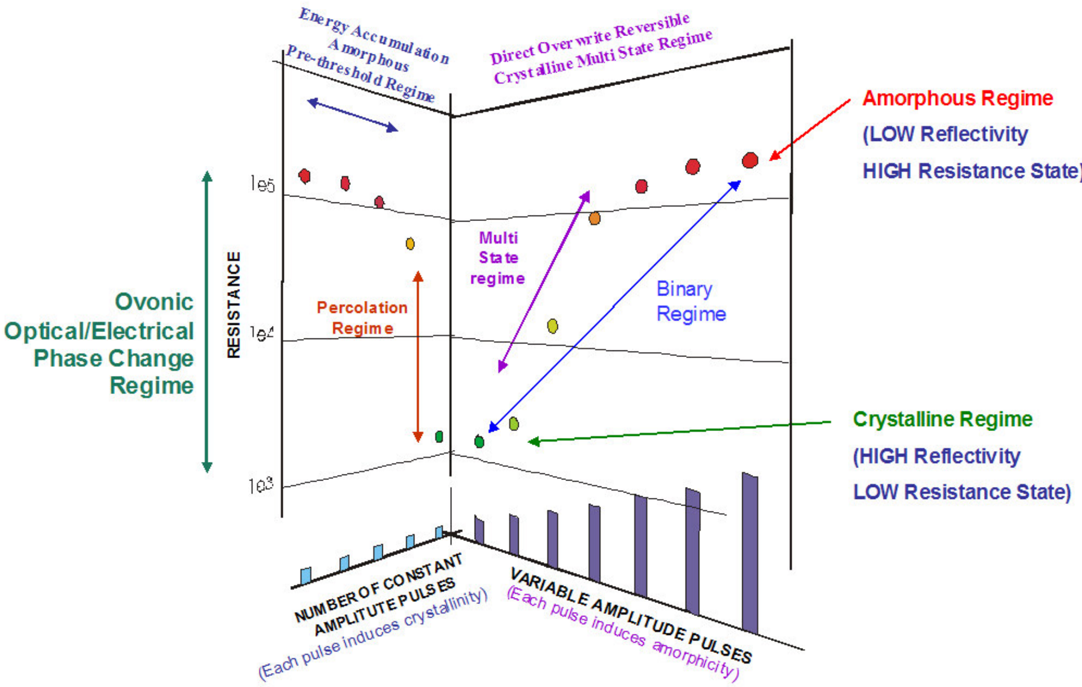

Figure 8

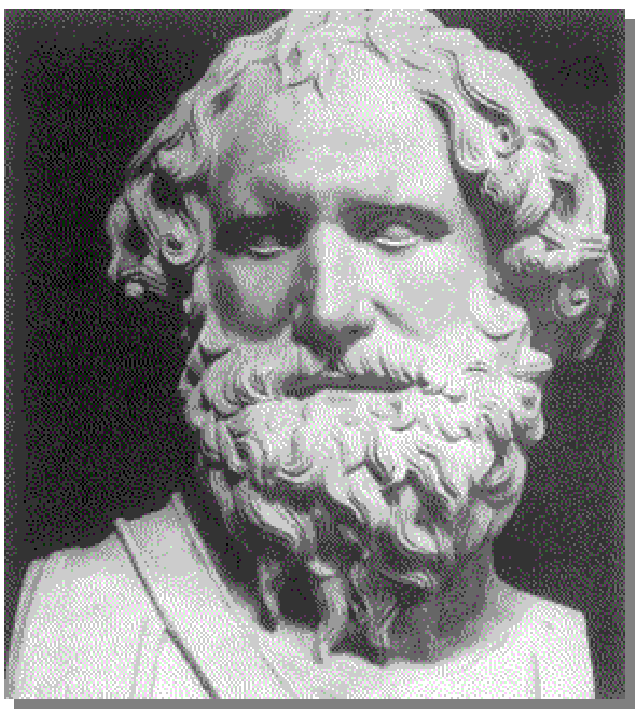

Figure 9 - Archimedes (287 BC–212 BC)