Hakob P. Bezirganyan
Siranush E. Bezirganyan
Robert H. Bezirganyan

PROFESSIONAL
RESEARCH
X-ROM
X- ROM, Inc.

Introduction to Hard X-ray Optical Data Storage

X-ROM, Inc.

X-Ray Optical Memory (X-ROM)

by Hakob (Jacob) P. BEZIRGANYAN,[a)] R & D Director, Ph.D.
Siranush E. BEZIRGANYAN,[a), b)] Leading Research Scientist, Ph.D.
and Robert Bezirganyan, [b)] Student

[a)] *X-ROM, Inc. & V Group, Inc., King County, WA 98007, USA*
[b)] Bellevue College*, King County, WA 98007, USA*

1. INTRODUCTION

We have worked on and currently are promoting ***X-Ray Optical Memory*** (or "***X-ROM***") - the next-generation ultra-high definition hard x-ray optical storage device with the digital data density of about 10 Tbits per square inch for each storage layer of developed "***X-ROM disc*** ".

Proposed "***X-ROM***" is the radically new x-ray-based optical data storage technology. Digital data reading procedure from such ultrahigh-density x-ray optical data storage media is performed via grazing-angle incident x-ray micro beam. Proposed x-ray-based optical data storage system detects data by measuring the changes in x-ray micro beam intensity reflected from the various surface points of data storage media. Grazing-angle incident x-ray configuration allows the simultaneous handling of digital data from very large area, which is limited only by the hard x-ray receiving surface of the charge coupled device (or "***CCD***" ***camera***), and, consequently, the data read-out speed is much faster, in principle, than the data read-out speed of modern optical data read-out systems.

2. THE OPTICAL DEVICES FOR DIGITAL DATA READ-OUT ON THE BASIS OF ANGSTRÖM WAVELENGTH

New Global Economy - is the Low-Carbon Economy. Most amount of the carbon on Earth is in the plants, coal, and oil. Plants absorb the carbon from atmosphere and store it in the wood fiber. In the Low-Carbon Economy, forestry operations will be focused on low-impact practices and re-growth. Forest managers will make sure that they do not disturb soil based carbon reserves too much. Specialized tree farms will be the main source of material for many products. Quick maturing tree varieties will be grown on short rotations in order to maximize output.

One of the pathways towards the Low-Carbon and Forestry Economies could be a Paper-Less Economy, because paper is typically made from the wood fiber, and its consumption puts substantial pressure on the world's forest ecosystems. It is evident that the ultra-high density digital storage of data and documents in electronic form would lead to a decline in paper consumption. Hence the incessant interest to various techniques and technologies developed for the creation and storage of the huge volumes of digital information.

Forthcoming devices with the increasing digital data storage capacities necessarily require an optical read-out devices operating on the basis of Angström wavelength radiation that is on the hard x-ray wavelength.

3. BENEFICIARIES FROM THE X-ROM IMPLEMENTATION

The volume of data is growing exponentially around the world, so the ***X-ROM*** implementation would be a temporary success in the "combat" against nowadays information explosion. ***X-ROM*** is mainly designed for the following target customers:

- Any organization that has the need to store and keep available digital information over many years such as Deposit Libraries, National Archives, Governmental Institutions, Pharmaceuticals, Banks and Insurance Companies.

- Today the topical problem is to bring the concept of "distance learning" technology beyond the classroom and the auditorium to public settings and more personally to the home i.e. much more access to better education (for example, see [1]).

- Much easier re-use of the archived information to create new or adjusted (digital) information. Commercial interests can become very large, e.g. when a building or an airplane needs to be modified and the digital "blue print" can't be viewed anymore, because the technology, with which it was made, has become obsolete. In such cases it might cost a person-year or more to re-create the original drawings. Sometimes, long term digital preservation is a necessity; e.g. for compliance reasons.

Thus, ***X-ROM*** is designed for any type of long-term digital information archiving system (***DIAS***).

4. BRIEF REVIEW OF THE X-ROM THEORY AND NANOTECHNOLOGY

The study of wave propagation in one-dimensional periodic media was pioneered by G. Floquet in 1883 [2]. This theory was extended for three-dimensional periodic media by F. Bloch in 1928 [3]. Bloch proved that waves in such a medium can propagate without scattering, their behaviour governed by a periodic envelope function multiplied by a plane wave.

The same technique can be applied to electromagnetism by considering Maxwell's equations as an eigenvalues and eigenfuctions problem in analogue with Schrödinger's equation (e.g. see [4, 5]). Using such approach, we are treating the dynamical diffraction of x-rays by a set of diffracting lattice planes (hkl) of perfect crystal as the superposition of x-ray "Bloch waves" in a medium with harmonically varying dielectric susceptibility (polarizability) $\chi_{hkl}(\mathbf{r})$. Therefore, the problem of x-ray wave field propagation through an arbitrary set of diffracting lattice planes of periodic structure with the symmetry centre can be brought mathematically to an analogous problem of the solution of stationary Schrödinger equation with cosine-like coefficient [4].

Data storage media are particularly produced on the basis of the semiconductor nanostructured crystalline materials, so the semiconductor nanostructure devices could, for example, perform using the grazing-angle incidence x-ray backscattering diffraction (***GIXB***) technique [4, 5], which takes place in the conditions of specular vacuum wave suppression phenomenon. In the conditions of the reflected wave suppression mode, the specular wave (contrary to other existing X-ray diffraction methods) practically carries only the information about the non-diffracting subsurface reflectors [6-8]. The ***GIXB*** is a high-resolution and non-destructive technique, which is possible to perform only if the Bragg angle is close to 90^o. ***GIXB*** configuration first was considered in 1985 (see English version [4, 5] of origin papers, which concern ***GIXB*** by single crystals and very thin crystalline films).

Another mechanism of the digital information read-out procedure [9] utilizes the grazing-angle incidence x-ray reflection (***GIX***) technique. These two mechanisms of the digital information read-out procedure enable, in principle, the fabrication and exploitation of two-layer ***X-ROM***. Angle of incidence of the x-ray micro beam is different for each storage layer of the proposed two-layer ***X-ROM*** [10].

The resolution of digital data read-out device could be increased by the grazing-angle incidence hard-x-ray nanoscope (or ***"GIXN"***) proposed in [11], which is an essential detail of the ultra-high density digital data read-out device. Detailed evaluation of storage data-layer's effective (optimal) thickness best fitted for a digital data read-out procedure is presented in [12, 13].

Information about ***X-ROM*** nanotechnology has been presented in various International Scientific Conferences [12-24].

5. REFERENCES

1. A.H. Bezirganyan, Analysis and estimation of emotionally coloring of music performance. //in *Proceedings of the 8th International Conference on Music Perception & Cognition (ICMPC8)*, edited by S.D. Lipscomb, R. Ashley, R.O. Gjerdingen, and P. Webster, Evanston, IL (USA), 3rd - 7th August 2004, pp. 710-712. http://www.icmpc8.umn.edu/proceedings/ICMPC8/PDF/AUTHOR/MP040045.PDF

2. G. Floquet, Sur les équations différentielles linéaires à coefficients périodiques. //*Ann. École Norm. Sup.*, 1883, **v. 12**, pp. 47 - 88.

3. F. Bloch, Über die Quantenmechanik der Elektronen in Kristallgittern. // *Z. Physik*, 1928, **v. 52**, pp. 555 - 600.

4. H.P. Bezirganyan and P.H. Bezirganyan, Solution of the Two-dimensional Stationary Schrödinger Equation with Cosine-Like Coefficient (in View of X-ray Diffraction). //*Phys. Stat. Sol. (a)*, 1988, **v. 105**, pp. 345 - 355. http://www.bezirganyan.com/hakob/pdf/1988_PSS_105_345-355.pdf

5. H.P. Bezirganyan, X-ray Reflection from and Transmission through a Plane-Parallel Dielectric Plate with Cosine-Like Polarizability (Symmetrical Laue Case; θ_B close on $\pi/2$). //*Phys. Stat. Sol. (a)*, 1988, **v. 109**, pp. 101 - 110. http://www3.interscience.wiley.com/cgi-bin/abstract/112430155/ABSTRACT

6. H.P. Bezirganyan, H.H. Bezirganyan (Jr.), S.E. Bezirganyan, and P.H. Bezirganyan (Jr.), Specular beam suppression and enhancement phenomena in the case of grazing-angle incidence X-rays backdiffraction by the crystal with stacking fault. //*Opt. Commun.*, 2004, **v. 238** (Issues 1-3), pp. 13-28. http://dx.doi.org/10.1016/j.optcom.2004.04.038

7. H.P. Bezirganyan, H.H. Bezirganyan (Jr.), S.E. Bezirganyan, P.H. Bezirganyan (Jr.) and Y.G. Mossikyan, An ultrahigh-density digital data read-out method based on grazing-angle incidence x-ray backscattering diffraction. //*J. Opt. A: Pure Appl. Opt.*, 2005, **v. 7** (issue 10), pp. 604-612. http://dx.doi.org/10.1088/1464-4258/7/10/013

8. H.P. Bezirganyan and S.E. Bezirganyan, X-ray optical memory (X-ROM). //*Transactions of anniversary scientific session: 50th Anniversary of the Chair of Solid State Physics of Yerevan State University* (Yerevan, Armenia: Yerevan State University Press), 2007, pp. 15-20.

9. H.P. Bezirganyan, S.E. Bezirganyan, H.H. Bezirganyan (Jr.) and P.H. Bezirganyan (Jr.), Two-dimensional

ultrahigh-density x-ray optical memory. //*J. Nanosci. Nanotechnol.*, 2007, **v. 7,** No. 1, pp. 306-315.
http://www.ingentaconnect.com/content/asp/jnn/2007/00000007/00000001/art00025

10. H.P. Bezirganyan, S.E. Bezirganyan, H.H. Bezirganyan (Jr.) and P.H. Bezirganyan (Jr.), Two-layer ultrahigh-density x-ray optical memory. //Proc. of the NATO Advances Research Workshop (http://www.candle.am/ARW06/) on Brilliant Light Facilities and Research in Life and Material Sciences, held at CANDLE in Yerevan (Armenia), 17th -21st July 2006, in Subseries: NATO Security through Science Series B: Physics and Biophysics, edited by Tsakanov V.M. and Wiedemann H., Springer, Netherlands, 2007, pp. 495-498.
http://dx.doi.org/10.1007/978-1-4020-5724-3_50

11. H.P. Bezirganyan, S.E. Bezirganyan, P.H. Bezirganyan (Jr.) and H.H. Bezirganyan (Jr.), An application of the grazing-angle incidence hard x-ray optical nanoscope in ultra-high density digital data read-out device. //Proc. of the SPIE Symposium on Optical Engineering + Applications, held in San Diego, CA (USA), 10th-14th August 2008, in: Advances in X-Ray/EUV Optics and Components III (OP322), edited by Shunji Goto, Ali M. Khounsary, Christian Morawe, SPIE, Bellingham, WA, USA, 2008, **v. 7077**, 70770P, 7 pp.
http://dx.doi.org/10.1117/12.796346

12. H.P. Bezirganyan, S.E. Bezirganyan, P.H. Bezirganyan (Jr.) and H.H. Bezirganyan (Jr.), Evaluation of data storage layer thickness best fitted for digital data readout procedure from hard x-ray optical memory. //Proc. of the SPIE Symposium on Optical Engineering + Applications, held in San Diego, CA (USA), 2nd- 6th August 2009, in: Advances in X-Ray/EUV Optics and Components IV, edited by Shunji Goto, Ali M. Khounsary, Christian Morawe, SPIE, Bellingham, WA, USA, 2009, **v. 7448**, 74480T, 10 pp.
http://dx.doi.org/10.1117/12.826034

13. H.P. Bezirganyan, S.E. Bezirganyan, H.H. Bezirganyan (Jr.) and P.H. Bezirganyan (Jr.), X-ROM presentation.
http://www.x-rom.org/doc/presentations/1340_tuesday_7448-29_hakob_bezirganyan.pdf

14. H.P. Bezirganyan S.E. Bezirganyan, H.H. Bezirganyan (Jr.) and P.H. Bezirganyan (Jr.),
http://www.bezirganyan.com/hakob/pdf/collaborative_projects.pdf

15. H.P. Bezirganyan, H.H. Bezirganyan (Jr.), S.E. Bezirganyan, and P.H. Bezirganyan (Jr.), Ultrahigh-Density Semiconductor Data Storage Media Useful for Data Readout by X-ray Microbeam. //Book of Abstracts of III International Optical Congress "Optics - XXI Century" & III International Conference "Basic Problems of Optics", Topical Meeting on Optoinformatics, Saint-Petersburg (Russia), p.48, 18th - 21st October 2004.
http://ysa.ifmo.ru/data/conferences/BPO-2004/Congress-2004_Program.pdf

16. H.P. Bezirganyan, H.H. Bezirganyan (Jr.), S.E. Bezirganyan and P.H. Bezirganyan (Jr.), Detection of weak X-ray Waves Scattered by the Crystal Subsurface Inclusions. //Book of Abstracts of XX Congress of the International Union of Crystallography (XX Congress IUCr), Florence (Italy), P.17.04.2, p. C448, 23rd - 31st August 2005, //*Acta Cryst*. A**61**, C448 (2005).
http://journals.iucr.org/a/issues/2005/a1/00/a33782/a33782.pdf

17. H.P. Bezirganyan, H.H. Bezirganyan (Jr.), S.E. Bezirganyan and P.H. Bezirganyan (Jr.), Data Readout by Sensing Changes in X-ray Reflectivity along Smooth Surface of the Ultrahigh-Density Digital Data Storage Media. //Book of Abstracts of 18th International Conference on X-Ray Optics and Microanalysis (XVIII ICXOM), Frascati, Rome (Italy), p.168, 25th - 30th September 2005.
http://www.lnf.infn.it/conference/icxom/

18. H.P. Bezirganyan, S.E. Bezirganyan, H.H. Bezirganyan (Jr.) and P.H. Bezirganyan (Jr.), Digital Data Read-out by Glancing Angle Incidence X-ray Reflection. //Book of Abstracts of 12th European Conference on X-Ray Spectrometry (EXRS 2006), Paris (France), P11-1, p.257, 19th - 23rd June 2006.
http://www.nucleide.org/exrs2006/

19. H.P. Bezirganyan, H.H. Bezirganyan (Jr.), S.E. Bezirganyan and P.H. Bezirganyan (Jr.), Specular Beam Suppression in case of Grazing-angle Incidence X-ray Backscattering Diffraction by the Single Crystal Wafer Covered with a Thin Non-Diffracting Layer. //Book of Abstracts of the 8th Biennial Conference on High-Resolution X-Ray Diffraction and Imaging (XTOP 2006), Baden-Baden / Karlsruhe (Germany), p.74, 17th - 23rd September 2006.
http://xtop2006.fzk.de/

20. H.P. Bezirganyan, S.E. Bezirganyan, P.H. Bezirganyan (Jr.) and H.H. Bezirganyan (Jr.), Digital Data Readout from X-ray Optical Memory Covered with Thin Cap Layer. Abstracts of 23rd Optical Data Storage Topical Meeting (ODS 2007) held in the Benson Hotel, Portland, Oregon (USA), p. MD7, 20th-23rd May 2007.
http://www.dmphotonics.com/Conferences/ODS%20Abstracts3.pdf

21. H.P. Bezirganyan, S.E. Bezirganyan, P.H. Bezirganyan (Jr.) and H.H. Bezirganyan (Jr.), Optimal Thickness of Non-diffracting Subsurface Mirrors of X-Ray Optical Memory. Abstracts of the 24th European Crystallographic Meeting (ECM24), Marrakech (Morocco), MS37 P02, p.

s253, 22nd-27th August 2007, Acta Cryst. A63, s253 (2007).
http://journals.iucr.org/a/issues/2007/a1/00/a38093/a38093.pdf

22. S.E. Bezirganyan, H.P. Bezirganyan, P.H. Bezirganyan (Jr.) and H.H. Bezirganyan (Jr.), Optimal Thickness of Non-diffracting Subsurface Mirrors of X-Ray Optical Memory. //Abstracts of the 5th IEEE East-West Design & Test Symposium (EWDTS 2007) held at Congress Hotel in Yerevan (Armenia), P22, 7th–10th September 2007.
http://www.bezirganyan.com/hakob/pdf/ewdtw07-program.pdf

23. H.P. Bezirganyan, S.E. Bezirganyan, P.H. Bezirganyan (Jr.) and H.H. Bezirganyan (Jr.). Grazing-angle incidence hard X-ray nanoscope. //Book of Abstracts of XXI Congress of the International Union of Crystallography (XXI Congress IUCr), Osaka (Japan), P01.07.39, pp. C182-183, 23rd-31st August 2008. //*Acta Cryst*. A64, C182-183 (2008).
http://journals.iucr.org/a/issues/2008/a1/00/a38781/a38781.pdf

24. H.P. Bezirganyan, S.E. Bezirganyan, P.H. Bezirganyan (Jr.) and H.H. Bezirganyan (Jr.), Fine distribution of hard x-ray wave field intensity inside ultra-high density digital data storage layer with nano-scale thickness during data read-out procedure from the x-ray optical memory (X-ROM) plate. //SPIE Symposium 7730, Optical Data Storage 2010 Topical Meeting held in UMC/Univ. of Colorado at Boulder, Boulder, Colorado (USA), p. 10, 23rd- 26th May, 2010.
http://spie.org/optical-data-storage.xml

"... Forthcoming Optical Data Storage media with the increasing digital data storage capacities necessarily require digital data read-out devices operating on the basis of Angström wavelength electromagnetic radiation that is on hard x-ray wavelength ..."