# Marin Alexe

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## *Personal Information*:

Born: November 11, 1960, Romania
Romanian citizen, married, one child
Spoken languages: Romanian (native), English, German

## *Education:*

Ph.D. in Physics, Institute of Atomic Physics, Bucharest, Romania, 1995
Dipl.- Ing. in Physics, University of Bucharest, 1985

## *Employment history:*

1998-present permanent research staff at Max Planck Institute of Microstructure Physics
1996-1998 Post-doctoral research fellow at Max Planck Institute of Microstructure Physics
1988-1996 Research staff, Institute of Physics and Technology of Materials, Bucharest
1985-1988 Physicist, Special Steel Plant, Targoviste, Romania

## *Visiting Positions*

Visiting research fellow at University of Cambridge, UK, 2002

## *Research interest*

*Nanoscience & nanotechnology, ferroelectric nanostructures and ultra-thin films.*

Nano-fabrication technologies; novel physical phenomena in electronic, magnetic, and photonic materials with shrinking dimensions. Size effects in nanoscale ferroelectric materials. Physics and and nano-engineering of thin film devices (multi-layers and , multi-functional thin film devices, sensors, micro-actuators, non-volatile memories, DRAMs) ; Crystalline Oxides on Semiconductors; Functional metal oxide thin film deposition and processing for microelectronic, optical and high frequency applications

*Nanoengineering of functional oxides.*

Epitaxial ferroelectric and conductive oxides, nanoscale fabrication of functional oxide structures including nanowires, nanotubes, and nanostructures; compositional and interface engineering of ferroelectric and functional structures, self-assembled oxide nanostructures

*Physics and engineering of complex oxide thin films and nanostructures*

Thin film growth and characterization of multi-functional metal oxide thin film with ferroelectric, conductive, semiconducting properties; growth mechanisms and defect

engineering, structure-property-processing interrelationships; transport phenomena in correlated systems,

*Nanoscale Characterization*:

Physics at the nanoscale using scanning probes; Applications of scanning force microscopy to study domains and domain switching ferroelectric thin films and nanoscale structures; scaling studies using piezoelectric force microscopy

*Information Technologies*

Non-volatile information storage technologies: ferroelectric random access memories; integrated optical devices for information processing and storage; "smart" thin film for sensors and actuators; Physics and technology of MOS devices including MFS devices and non-volatile memories; Interfaces (oxides-semiconductor) and interface properties; Integration of functional oxides in Si and GaAs technologies and processes.

## *Membership in scientific or coordination committees*

Member of the International Advisory Board of *"European Meeting on Ferroelectricity"* (EMF)

Member of the International Advisory Board of *"European Conference on Applications of Polar Dielectrics"* (ECAPD)

Member of the International Advisory Board of *"International Symposium on Integrated Ferroelectrics"* (ISIF-2007)

Program Chair of *"International Symposium on Integrated Ferroelectrics"* (ISIF-2008)

Organizer and co-organizer of four different Symposia of the European Materials Research Society (E-MRS) 2003-2006

Co-organizer of the symposium on *Ferroelectric thin films* of the Materials Research Society (MRS) Fall Meeting Boston, 2005

Co-organizer of the symposium on *Functional Materials* of the Materials Research Society (MRS) Spring Meeting San Francisco, 2006

Member of the Coordination Committee of the Max-Planck-Institute of Microstructure Physics

## *Publication summary:*

Over 140 papers and reviews published in journals that include Nature Materials, Advanced Materials, Nanotechnology, Physical Review Letters, Applied Physics Letters, Physical Review, Journal of Applied Physics, Ferroelectrics, Integrated Ferroelectrics, Electronic letters, etc.

Presented over 30 Invited talks at International Conferences, Symposia and Workshops

## *Books:*

"*Nanoscale characterization of ferroelectric materials*", M. Alexe and A. Gruvermann Eds., Springer Verlag, Heidelberg, 2004

"*Basics and Applications of Direct Wafer Bonding*", M. Alexe and U. Gösele Eds., Springer Verlag, Heidelberg, 2004
"*Nanoscale Ferroelectrics*" To be published by Springer Verlag, 2008

ISI citation report: Published papers: 132; Total citations: 1326; ***h-index: 21***

## *Patents:*

- *Composite Pyroelectric Material with high Pyroelectric Coefficient*, C. Constantin, L. Pintilie, L. Ribco, and M. Alexe, Pat. No. RO109482/28-02-1995
- *Process for Producing Thin Conductive Layers of $BaPbO_3$*, M. Alexe, Pat No. RO116136/2000-10-30
- *A Nanotube Based Cantilever Arm, a Method of Operating and Manufacturing a Nanotube Based Cantilever Arm, and a Storage Device and a Photonic Crystal Based on an Array of Nanotube Based Cantilever Arms*, M. Alexe, Y. Luo, I. Szafraniak, R. Wehrspohn, M. Steinhart, Pat No. EP1439546/2004-07-21
- *Method for the Production of a Porous Material with a Periodic Pore Arrangement*, Wehrspohn Ralf; Gosele Ulrich M; Nielsch Kornelius; Choi Jinsub; Reiche Manfred; Alexe Marin, Pat. No. US2005252787
- *A Nanowire-Based Memory Capacitor and Memory Cell and Methods for Fabricating Them*, M. Alexe and U. Gösele, Patent Pending

## *Professional affiliation:*

Material Research Society
American Institute of Physics
Institute of Physics - IOP

## *Funding history:*

Author of several granted EU projects, co-author and Principal Investigator of EU and German (BMBF and SFB) Projects, author of a VW Foundation Project, and two industrial projects; more than 75% success rate of the project applications.

– *"Bonding technology for monolithic integration of GaAs optoelectronic devices on Si substrates for Chip-to-Chip optical interconnections"* – BONTEC. Esprit-EU project, 1998-2000, 200 k€ granted, status: **finished**. Parteners: MPI-Halle, IMEL-NCSR Demokritos Athens and University of Crete, Greece.

– *"GaAs bonding to high thermally conductive AlN substrates"*. NORTEL Ltd. Canada, 2000-2001, 50k $ granted, Status: **finished**.

– *"Nano-imprint Lithography for nanosize structures of functional materials"*, BMBF Project, 2001-2003, 500k DEM **finished**, Partners: Uni-Wuppertal, Electronic Vision Group GmbH, Microresist Technology GmbH, MPI-Halle

– *"Integration of very high-k dielectrics with silicon CMOS technology"*- INVEST, EU-IST Project, 2001-2004, 200k€ **finished**,. Partners: MPI-Halle, IMEC-Leuven, IBM-Zurich, NCSR Demokritos Athens, OAR-Oxford, TU-Clausthal, Riber S.A- France, INFM-Milano, Philips-Leuven,

– "*Single-crystalline thin films by direct wafer bonding and hydrogen implantation*"-BONDFILM, Marie Curie Host Fellowship, 2000-2004, 300k € **finished**.

- *"Nanosize ferroelectrics structures via chemical solution routes"* – Project Group in the European COST Action 528 "Chemical solution deposition of thin films", Partners: MPI-Halle (coordinator), RWTH-Aachen, TU-Dresden, Cambridge University - UK, Cranfield University – UK, and EPFL – Switzerland, Status: **finished**.
- *"Nanosized Ferroelectric Hybrids"*, VW Stiftung Project 2001-2004, 200 k€, Parteners:FZ Jülich, MPI-Halle, RWTH Aachen, FhG Erlangen, Uni Liège (Belgium), Status: **finished**.
- *"Waferbonding and Active Passive Integration Technology and Implementation"*, -WAPITI, EU-IST Poject 2004-2007, 200 k€, Parteners:IFH Berlin,University of Cambridge, National and Kapodestrian University of Athens, EV Group Austria, IMT Bucharest, Status: **in progress**.
- *"Nanosized Ferroelectric Hybrids-II"*, VW Stiftung Project 2005-2008, 350 k€, Parteners:FZ Jülich, MPI-Halle, RWTH Aachen, FhG Erlangen, Uni Liège (Belgium), Status: **in progress**.
- *"Funktionalität Oxidischer Grenzflächen (Functional oxide interfaces)"*, Focused Research Area (SFB) no. 762, 2008-2011, 400 k€, partners, Martin-Luther University Halle, University of Leipzig, University of Magdeburg, Status: **in progress**.

## *Professional Experience:*

- 1985-1988 physicist at the Special Steel Plant, Targoviste, Romania
  - thick film deposition by plasma spraying onto steel roles (400 mm diameter, 2800 mm length), IR thermometry, and ultrasonic defectoscopy

- 1988-1993 Research staff at Institute of Physics and Technology of Materials, Bucharest

  - Fabrication and characterization of ferroelectric and pyroelectric ceramics (mainly perovskite oxides) used for piezoelectric transducers and infrared detection, including night vision.
  - Design of and fabrication pyroelectric detectors and linear arrays based on PZT ceramics and TGS single-crystal
  - Semiconductor and oxide thin film deposition and characterization.

- 1993-1996 Senior research staff at Institute of Physics and Technology of Materials

  - Leading and managing the thin film group
  - Set-up chemical solution deposition facilities for ferroelectric and functional oxide thin film deposition
  - Fabrication of force sensors and pressure gauges based on piezorezistive materials

- 1996-1998 Post-doctoral research fellow at the Max Planck Institute of Microstructure Physics, Halle (Saale), Germany

- 1998-present Research staff at the Max Planck Institute of Microstructure Physics, Halle (Saale), Germany

  - Setup facility for chemical solution and pulsed laser deposition of oxide thin films.
  - Setup electrical measurement systems for ferroelectric films and general semiconductor characterization to study transport (CV, IV, It, PE characteristics, including interface trap density measurements on metal-ferroelectric heterostructures, photoelectric characterization of ferroelectric films and MFS heterostructures.

- Electron beam lithography and direct writing of nano-size ferroelectric memory cells and piezoresponse scanning force microscopy investigation on ferroelectric thin films and nanosize ferroelectric structures
- Direct wafer bonding (DWB) of ferroelectric thin films (PZT, BiT and SBT) to silicon and complex semiconductor heterostructures including integration of GaAs epitaxial structures into CMOS technology by DWB for chip-to-chip optical interconnection; μ-ring resonators
- Single crystalline layer transfer by layer splitting by hydrogen implantation and direct wafer bonding (smart-cut)
- Structural (HRTEM) and electrical characterization (trap density) of high-k gate oxides.
- Nanofabrication of nanowires, nanotubes and nanostructures of functional materials.
- Charge storage in nanocrystalline silicon layers.
- Semiconductor properties of perovskite films for oxide electronics
- Growth and characterization of multiferroic epitaxial films

## *Scientific Leadership Profile*

Due to the particular historical environment my career has actually started only after my PhD defence, when I joined, as postdoctoral fellow, the newly established Max Planck Institute of Microstructure Physics in Halle (MPI–Halle). Like all other graduated student in the former communist Romania, I was compulsorily working in industry for three years after graduating in 1985. Only in 1988 it was possible to join the Institute of Materials Physics in Bucharest (now the National Institute of Materials Physics, NIMP). Until 1990 I have been forbidden to get enrolled in any PhD program because I was not member of the Communist Party. Soon after 1990 I have started my PhD while I was already managing a thin films group at NIMP. Early 1996, just after my PhD defence, I have joined MPI-Halle and during the next years I have developed together with Dr. Dietrich Hesse, at the initiative of the head of the department Prof. Goesele, the group on ferroelectric thin films, which meanwhile became one of the most significant group in the filed.

In 1997, at the eve of the new field of nanoscience and nanotechnology, I have addressed fabrication and characterization of ferroelectric nanostructures. Upon my best knowledge we have been the first group addressing nanoscale ferroelectrics. The paper on self-assembled ferroelectric nanosize capacitors was the first paper specifically addressing this topic.[1] Later on, after this pioneering work, I have achieved a milestone in the field by successful patterning of sub-100 nm lateral size ferroelectric structures by e-beam direct writing.[2] The importance of this work should be judged in the context: by that time in the field of ferroelectric non-volatile random access memories (FeRAM) a vital problem was the scaling down of the memory cell size in the submicrometer range. The risk of reaching the so-called superparaelectric state the at only sub-micron lateral sizes was high. This would have been extremely detrimental of the whole field of ferroelectrics. Patterning nanoscale structures and demonstrating that the ferroelectricity does not vanish at these sizes was a milestone from that point of view. This has been acknowledged by highlighting the paper in Nature.[3]

We have further developed self-assembly fabrication methods that have allows us to go with the sizes down to about 20 nm and thicknesses of few nm, keeping nevertheless a high crystalline quality and uniformity over large area. These epitaxial nanocrystalline structures have enabled Dr. Ming-Wen Chu to determine the direct relationship between extended defects, i.e. misfit dislocations, and ferroelectric properties showing that essentially there is no superparaelectric limit of ferroelectricity. [4] This work has was at the basis of a significant number of theoretical and experimental studies on influence of defects on ferroelectric properties, including a very recent study in cooperation with the scanning probe group at Oak Ridge National Laboratory on a the fundamental question of nucleation in the domain switching.[5] Recently we have developed a new method based on ultrathin nanoporous anodic alumina membranes to fabricate large area nanosized ferroelectric epitaxial capacitors. [6]

Also recently we have addressed the problem of defects and the influence of them in thin films. Based on detailed structural investigations, we gain a good understanding of defect in single crystalline epitaxial films and the role of these defects and have eventually been able to grow defect-free films. This enabled us the study of the intrinsic properties, including the semiconductor

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[1] *Self-patterning nano-electrodes on ferroelectric thin films for gigabit memory applications*. Alexe, M., et al., Appl. Phys. Lett. 73, 1592 (1998).

[2] *Patterning and switching of nanosize ferroelectric memory cells.* Alexe, M., et al. Applied Physics Letters 75, 1793 (1999)

[3] http://www.nature.com/news/1999/990930/full/news990930-1.html

[4] *Impact of misfit dislocations on the polarization instability of epitaxial nanostructured ferroelectric perovskites*.Chu, M. W., Szafraniak, I., Scholz, R., Harnagea, C., Hesse, D., Alexe, M. and Gosele, U. Nature Materials 3, 87 (2004).

[5] *Direct imaging of the spatial and energy distribution of nucleation centres in ferroelectric materials*. Jesse, S., Nature Materials 7, 209-215 (2008).

[6] *Individually addressable epitaxial ferroelectric nanocapacitor arrays with enar Tb inch$^{-2}$ density*. Woo Lee, et al, Nature Nanotechnology 3, 402 (2008).

properties, of PZT films. [7,8] A fruitful cooperation with the group of Prof. Matias Bargheer at the Max Born Institute-Berlin was based on these high quality films. Fundamental studies on ultra-fast phenomena in ferroelectrics and strongly correlated systems have been performed by femtosecond x-ray diffraction.[9]

We have also addressed fabrication and characterization of one dimensional systems, respectively ferroelectric micro- and nanoscale tubes. We have been the first showing a simple and elegant method to obtain nano-shell ferroelectric tubes. The first paper [10] on this topic has triggered significant number of follow-up studies in the field.

The field of low dimensional and nanoscale ferroelectrics, which I have pioneered, it is now an established field. It is present in all major conferences and symposia in ferroelectricity, many of them I have organized or chaired.

In the last ten years I have supervised and co-supervised a number of 5 students and more than 6 postdoctoral fellows, among them four Alexander von Humboldt fellows. All are now working as scientist in important companies in the microelectronic industy (SOITEC France, EVG, Seagate, Oerlikon) showing an important connection of my research with the real world, or in universities and/or research institutions (MIT-USA, Argonne Nat. Lab., CNRS-France). Among them I would list only Dr. Dinghua Bao now professor at the Sun Yat-Sen University, Guangzhou, China; Dr. Izabela Szafraniak, assistant professor at Poznan University of Technology; Dr. Jian Yu, assistant professor at Tongji University, Shanghai; to Dr. Virel Dragoi, Chief Scientist at Electronic Vision Group, Austria; Dr. Gwenäl LeRhun research staff at LETI-Grenoble, Dr. Wei Li and Dr. Burc Misirlioglu, research associates at Argonne National Lab. and Massachusetts Institute of Technology (MIT), USA, respectively.

I have published more than 140 papers and reviews in journals that include Nature Materials, Advanced Materials, Physical Review Letters, Applied Physics Letters, Physical Review, Journal of Applied Physics, Nanotechnology, Ferroelectrics, Integrated Ferroelectrics, Electronic letters, etc. I have three patents grated and one pending. I have edited two books in two different fields: nanoscale characterization and wafer bonding.

I have presented more than 30 invited talks at International Conferences, Symposia and Workshops

I am permanent member of the advisory board of three international conferences on ferroelectricity; I have organized and co-organized seven Symposia and conferences, among them four European Materials Research Society and three Materials Research Society-USA.

I was principal investigator in ten projects, among them four European projects.

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[7] *Intrinsic ferroelectric properties of strained tetragonal PbZr0.2Ti0.8O3 obtained on layer-by-layer grown, defect-free single-crystalline films.* Vrejoiu, I., et al., Advanced Materials 18, 1657 (2006).

[8] *Ferroelectric polarization-leakage current relation in high quality epitaxial Pb(Zr, Ti)$O_3$ films*. Pintilie, L., et al. Physical Review B 75 (2007)

[9] *Coupled ultrafast lattice and polarization dynamics in ferroelectric nanolayers*, Schmising CVK, et al., Phys. Rev. Lett. 98 257601 (2007)

[10] *Nanoshell tubes of ferroelectric lead zirconate titanate and barium titanate.* Luo, Y. et al. ,Appl. Phys. Lett. 83, 440(2003).

List of (co-) supervised PhD thesis:

1. Viorel Dragoi, *Study of semiconductor heterostructures fabricated by direct wafer bonding*. Bucharest University, 2000.
2. Catalin Harnagea, *Local piezoelectric response and domain structures in ferroelectric thin films investigated by voltage modulated force microscopy*. Martin-Luther-Universität Halle-Wittenberg, 2001.
3. Ionut Radu , *Layer transfer of semiconductors and complex oxides by helium and/or hydrogen implantation and wafer bonding*. Martin-Luther-Universität Halle-Wittenberg, 2003.
4. Alina Mihaela Visinoiu, *Growth mechanism and structure of epitaxial perovskite thin films and superlattices*. Martin-Luther-Universität Halle-Wittenberg, 2003.
5. Sung-Kyun Lee, *Growth, microstructure and ferroelectric properties of non-c-axis-oriented rare-earth-substituted bismuth titanate thin films and nanostructures*. Martin-Luther-Universität Halle-Wittenberg, 2005.
6. Ksenia Boldyreva, *Wachstum und Struktur-Eigenschafts-Beziehungen von epitaktischen antiferroelektrisch/ferroelektrischen Schichten oxidischen Multilagen*. Martin-Luther-Universität Halle-Wittenberg, 2008.

Top 10 publications:

1) *Individually addressable epitaxial ferroelectric nanocapacitor arrays with enar Tb inch$^{-2}$ density*. Woo Lee, H. Han, A, Lotnik, M.A. Schubert, S. Senz, M. Alexe, D. hesse, S. Baik, U. Gosele, Nature Nanotechnology 3, 402 (2008).
2) *Direct imaging of the spatial and energy distribution of nucleation centres in ferroelectric materials*. Jesse, S., B.J. Rodriguez, S. Choudhury, A.P. Baddorf, I. Vrejoiu, D. Hesse, M. Alexe, E.A. Eliseev, A.N. Morozovska, J. Zhang, L.-Q. Chen, and S.V. Kalinin, Nature Materials 7, 209-215 (2008).
3) *Atomic-scale study of electric dipoles near charged and uncharged domain walls in ferroelectric films*. Jia, C.L., S.B. Mi, K. Urban, I. Vrejoiu, M. Alexe, and D. Hesse, Nature Materials **7**, 57-61 (2008)
4) *Spatially Resolved Mapping of Polarization Switching Behavior in Nanoscale Ferroelectrics*, Rodriguez B.J., S. Jesse, M. Alexe, and S. V. Kalinin, Advanced Materials 20, 109 (2008)
5) *Coupled ultrafast lattice and polarization dynamics in ferroelectric nanolayers.* Schmising, C.V.K., M. Bargheer, M. Kiel, N. Zhavoronkov, M. Woerner, T. Elsaesser, I. Vrejoiu, D. Hesse, and M. Alexe, Physical Review Letters, 98, 257601 (2007).
6) *Intrinsic ferroelectric properties of strained tetragonal PbZr0.2Ti0.8O3 obtained on layer-by-layer grown, defect-free single-crystalline films.* Vrejoiu, I., Le Rhun, G., Pintilie, L., Hesse, D., Alexe, M. and Goesele, U. Advanced Materials (2006)
7) *Impact of misfit dislocations on the polarization instability of epitaxial nanostructured ferroelectric perovskites.* Chu, M. W., Szafraniak, I., Scholz, R., Harnagea, C., Hesse, D., Alexe, M. and Gosele, U. Nature Materials 3, 87-90 (2004).
8) *Ferroelectric epitaxial nanocrystals obtained by a self-patterning method.* Szafraniak, I., Harnagea, C., Scholz, R., Bhattacharyya, S., Hesse, D. and Alexe, M. Applied Physics Letters 83, 2211-2213 (2003).
9) *Nanoshell tubes of ferroelectric lead zirconate titanate and barium titanate.* Luo, Y., Szafraniak, I., Zakharov, N. D., Nagarajan, V., Steinhart, M., Wehrspohn, R. B., Wendorff, J. H., Ramesh, R. and Alexe, M. Applied Physics Letters 83, 440-442 (2003).
10) *Patterning and switching of nanosize ferroelectric memory cells.* Alexe, M., Harnagea, C., Hesse, D. & Gosele, U. Applied Physics Letters 75, 1793-1795 (1999)