NanoSaclay
Laboratoire d'Excellence en Nanosciences et Nanotechnologies

Visit of Prof. Massimiliano Di Ventra to Labex NanoSaclay, March 16-27

Massimiliano Di Ventra obtained his undergraduate degree in Physics summa cum laude from the University of Trieste (Italy) in 1991 and did his PhD studies at the Ecole Polytechnique Federale de Lausanne (Switzerland) in 1993-1997. He has been Research Assistant Professor at Vanderbilt University and Visiting Scientist at IBM T.J. Watson Research Center before joining the Physics Department of Virginia Tech in 2000 as Assistant Professor. He was promoted to Associate Professor in 2003 and moved to the Physics Department of the University of California, San Diego, in 2004 where he was promoted to Full Professor in 2006. Di Ventra's research interests are in the **theory of electronic and transport properties of nanoscale systems, non-equilibrium statistical mechanics, DNA sequencing/polymer dynamics in nanopores, and memory effects in nanostructures for applications in unconventional computing and biophysics**. He has been invited to deliver more than 190 talks worldwide on these topics. He serves on the editorial board of several scientific journals and has won numerous awards and honors, including the NSF Early CAREER Award, the Ralph E. Powe Junior Faculty Enhancement Award, fellowship in the Institute of Physics and the American Physical Society. He has published more than 140 papers in refereed journals (13 of these are listed as ISI Essential Science Indicators highly-cited papers of the period 2003-2013), co-edited the textbook Introduction to Nanoscale Science and Technology (Springer, 2004) for undergraduate students, and he is single author of the graduate-level textbook Electrical Transport in Nanoscale Systems (Cambridge University Press, 2008).

If you want to meet Massimiliano Di Ventra, please contact Dr. Damien Querlioz (damien.querlioz@u-psud.fr) and Dr. Julie Grollier (julie.grollier@thalesgroup.com).

TENTATIVE PROGRAM

Tutorial on Memcomputing

Tues March 17 & Wed March 18, IEF, room 44, 11am

Coffee and cookies will be served at 10:45am, the tutorial starts at 11am

Memcomputing: a brain-inspired computing paradigm to compute *with* and *in* memory

I will discuss a novel computing paradigm we named *memcomputing* [1] inspired by the operation of our own brain. Memcomputing — computing using memory circuit elements or memelements [2] — satisfies important physical requirements: (i) it is intrinsically massively parallel, (ii) its information-storing and computing units are physically the same, and (iii) it does not rely on active elements as the main tools of operation. I will then introduce the notion of *universal memcomputing machines* (UMMs) as a class of general-purpose computing machines based on systems with memory. We have shown [3] that the memory properties of UMMs endow them with *universal computing power*--they are Turing-complete--, *intrinsic parallelism*, *functional polymorphism*, and *information overhead*, namely their collective states can support exponential data compression directly in memory. We have proved that UMMs can solve NP-complete problems in polynomial time, and as an example I will provide the polynomial-time solution of the subset-sum problem when implemented in hardware. Even though we have not proved NP=P, the practical implementation of these UMMs would represent a paradigm shift from present von Neumann architectures bringing us closer to brain-like neural computation. In fact, I will discuss a practical CMOS-compatible realization of this computing paradigm that uses memcapacitors and we have named Dynamic Computing Random Access Memory (DCRAM) [4].

[1] M. Di Ventra and Y.V. Pershin, **Computing: the Parallel Approach,** *Nature Physics*, **9**, 200 (2013).
[2] M. Di Ventra, Y.V. Pershin, and L.O. Chua, **Circuit Elements with Memory: Memristors, Memcapacitors, and Meminductors**, *Proc. IEEE*, **97**, 1717 (2009).
[3] F. L. Traversa and M. Di Ventra, **Universal Memcomputing Machines**, arXiv:1405.0931.
[4] F. L. Traversa, F. Bonani, Y.V. Pershin and M. Di Ventra, **Dynamic Computing Random Access Memory**, Nanotechnology (in press).

Seminar : Quantum sequencing: reading the genetic code with quantum mechanics

Monday March 23, NANOINNOV/CEA, Amphi, 11am

Personalized or precision medicine refers to the ability of tailoring drugs to the specific genome of each individual [1]. It is however not yet feasible due the high cost and slow speed of present DNA sequencing methods. I will discuss a sequencing protocol we have suggested

that requires the measurement of the distributions of transverse currents during the translocation of single-stranded DNA into nanochannels [2-5]. I will show that such a sequencing approach can reach unprecedented speeds, without requiring any chemical preparation, amplification or labeling thus opening up the possibility for personalized medicine. I will also discuss recent experiments that support these theoretical predictions and are a step forward toward making personalized medicine a reality [6].

References

1. M. Zwolak, M. Di Ventra, *Rev. Mod. Phys*. 2008, **80**, 141.
2. M. Zwolak and M. Di Ventra, *Nano Lett*. **5**, 421 (2005).
3. J. Lagerqvist, M. Zwolak, and M. Di Ventra, *Nano Lett.,* 2006 **6**, 779.
4. J. Lagerqvist, M. Zwolak, and M. Di Ventra, *Biophys. J.* 2007, **93**, 2384.
5. M. Krems, M. Zwolak, Y.V. Pershin, and M. Di Ventra, *Biophys. J.* 2009, **97**, 1990.
6. T. Ohshiro, K. Matsubara, M. Tsutsui, M. Furuhashi, M. Taniguchi and T. Kawai, *Nature: Scientific Reports*, 2012, 2, 501.

Seminar : Quantum analogies in ionic transport through nanopores

Thursday March 26, IEF, room 44, 11am

Ionic transport in nanopores or nanochannels is key to many cellular processes and is now being explored as a method for DNA/polymer sequencing and detection [1]. Although apparently simple in its scope, the study of ionic dynamics in confined geometries such as nanopores - when the microscopic details of the surrounding environment are properly taken into account - has revealed interesting new phenomena that have an almost one-to-one correspondence with the quantum regime. The picture that emerges is that ions can form two `quasi-particle' states, one in which they surround themselves with other ions of opposite charge – ionic atmosphere - and one in which semi-bound water molecules form layers at different distances from the ions - hydration layers. While the first quasi-particle state has less relevance in experiments of ionic flow in nanochannels that are presently pursued, the second state gives rise to two additional effects. In the first, which is a single quasi-particle effect, the ionic conductance through a nanopore of given radius is predicted to be “quantized” as a function of pore radius, with the corresponding “quantization units” not related to universal constants - like the Plank constant, *h*, and the elementary charge *e*, but rather to the radii of the hydration layers [2,3]. The second effect instead involves the many-body interaction among ionic quasi-particles of the same sign, and occurs when the pore has a finite capacitance to accommodate ions so that there is a threshold concentration beyond which ions of the same sign are not energetically allowed to enter the pore [4]. This effect is the equivalent of the Coulomb blockade effect one encounters in mesoscopic and nanoscopic systems of finite capacitance set out of equilibrium. Like the same effect in the electron transport case, the ionic counterpart appears only in the “quantum” regime, namely when the hydration layers forming the ionic quasi-particles need to break in order to pass through at least one of the openings of the pore. I will discuss these phenomena and the conditions under which they may be detected. Along the way, I make the analogy with the electronic quantum transport case, pointing out both the similarities and differences. Since nanopores are being considered for a host of technological applications in DNA sequencing and detection, we expect these phenomena will become very much relevant in this field and their understanding paramount to progress [5].

[1] M. Zwolak, M. Di Ventra, *Rev. Mod. Phys*. 2008, **80**, 141.
[2] M. Zwolak, J. Lagerqvist, M. Di Ventra, *Phys. Rev. Lett.* **103**, 128102 (2009).
[3] M. Zwolak, J. Wilson, M. Di Ventra, *Journal of Physics: Condensed Matter* **22**, 454126 (2010).
[4] M. Krems and M. Di Ventra, *Journal of Physics: Condensed Matter* **25** (6), 065101 (2013).
[5] A. Meyertholen and M. Di Ventra, arXiv:1305.7450

CURRICULUM VITAE

2006 - Full Professor, University of California, San Diego.
2004 - 2006 Associate Professor, University of California, San Diego.
2003 - Associate Professor, Virginia Tech.
2000 - 2002 Assistant Professor, Virginia Tech.
1998 - 2000 Visiting Scientist, IBM T.J. Watson Research Center.
1999 - 2000 Research Assistant Professor, Vanderbilt University.
1997 - 1999 Research Associate, Vanderbilt University.
1993 - 1997 Ph.D. in Physics, Ecole Polytechnique Federale de Lausanne (Switzerland).
1992 - 1993 Military Service.
1991 "Laurea" (Diploma) in Physics 110/110 cum laude, University of Trieste.

AWARDS/HONORS

Plenary Lecture, Sanibel Symposium, St. Augustine, FL (2/2003)
Fellow, Institute of Physics (2002)
NSF Early CAREER Award (2002)
Plenary Lecture, Nano and Giga Challenges in Microelectronics, Moscow (9/2002)
New Century Technology Council Innovation Award (2002)
Ralph E. Powe Junior Faculty Enhancement Award (2001)
University of Trieste Fellowship for Research Abroad (1993)
National Institute for the Physics of Matter (INFM) Fellowship (1991)
Diploma in Physics cum laude, University of Trieste (1991).
Editorial Board, Computational Science and Discovery
Editorial Board, International Journal of Modern Physics B
Editorial Board, Modern Physics Letters B
Editorial Board, International Journal of Nanoscience (2001-2007)
Editorial Board, Journal of Computational and Theoretical Nanoscience (2003-2006)
Editorial Board, Journal of Nanoscience and Nanotechnology (2004-2005)