

**Bionano Devices : Protein-based Memory**

**Speakers:** Professor V. Renugopalakrishnan (Renu) / Harvard Medical School, Boston, MA 02114

**Venue:** EA#06-03 (Seminar Room)

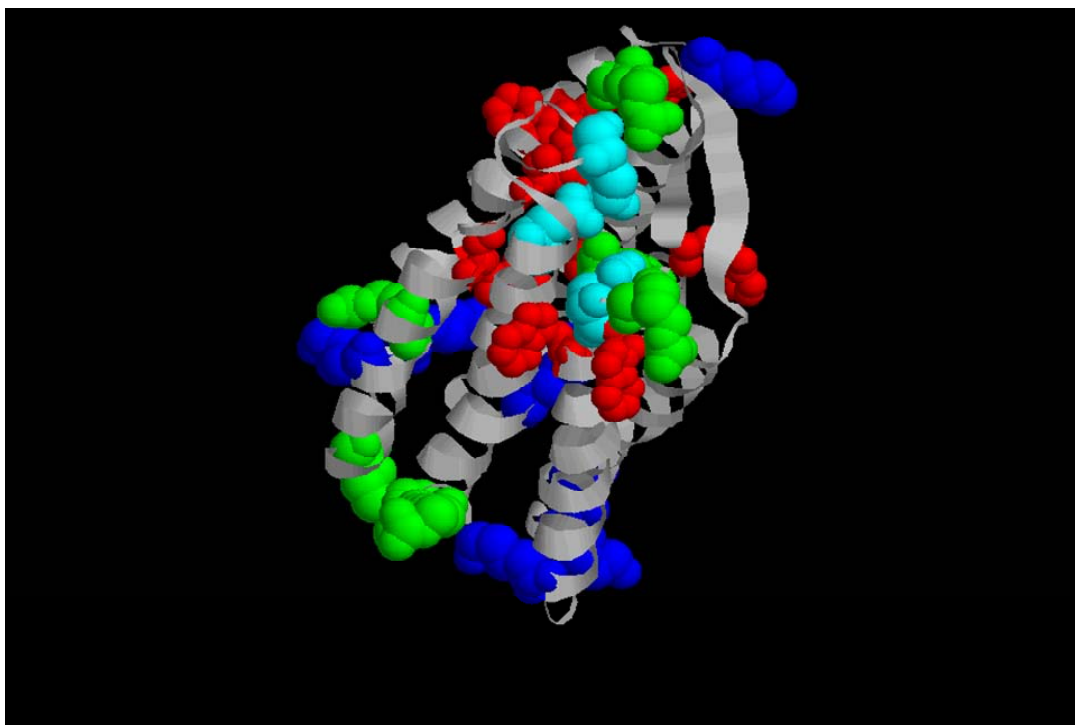
**Date:** 20 February 2006 (Monday)

**Time:** 2.30pm to 3.30pm



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**Abstract:**



**Structure of [E9Q/E194Q/E204Q] bR**

Soviet researchers, especially late Academician Yuri Anatoliovych Ovchinnikov were the first to explore the potential of bacteriorhodopsin (bR) as a logic gate. Dr. Renugopalakrishnan's many visits to the former to Soviet Union and the close contacts with Academician Ovchinnikov were responsible for initiating research in bR at Harvard Medical School in 80's and 90's. Our initial focus was on thermal stabilization of bR [1,2] without losing its unique photochemistry by stabilizing the photointermediates and enhancing their life times. Due to the unprecedented thermal stability of the genetically engineered bR designed by rational site-directed mutagenesis with physical dimensions in the nanoscale, it is believed that the protein-based devices might become future data storage systems of choice as the aerial densities go beyond 10 Terabit/in<sup>2</sup> mark and has the potential to reach 50 Terabit/in<sup>2</sup>. bR mutants developed in our laboratories (Renugopalakrishnan et al., 2003 [3]; Renugopalakrishnan et al., US Patents [4]) exhibit excellent physical and optical properties that make them ideal candidates for a storage material. Their naturally evolved properties, along with their genetically engineered variants, make them superior to any magnetic material used in present day memory devices. For example, the bR mutants with < 3 nm in dimension have demonstrated a long-term stability with a shelf life of 10 years at room temperature. In comparison, magnetic grains used in the best hard-drives today become highly unstable if the average grain size is reduced < 3 nm. Among other advantages of bR medium is its unprecedented recyclability and durability including resistance to microbial degradation. Finally, the bR media has demonstrated a faster time response, as compared to the magnetic disks, pico seconds range versus nano seconds range, respectively. The faster time response makes the bR media superior with respect to the data transfer rate. However, before the protein-based data storage can be finally implemented, suitable methods for immobilizing bR mutants on anchoring platforms including SW CNT (Tatke et al., ref. 5), protein on printed grids by microcontact printing, and mechanisms for writing and

reading information using Apertureless Scanning Near-Field Optical Microscopy (ASNOM) and its eventual miniaturization for consumer electronic applications are being investigated. Protein-lithography of bR on suitable anchoring platforms and mechanisms of writing and reading from the protein-based media, subject of a major US European joint research effort, will be discussed.

[1] V. Renugopalakrishnan et al., **J. Nanoscience and Nanotechnology 5, 1759-1767 2005**

[2] V. Renugopalakrishnan et al., **Proc. Royal Society. London, 2006**

[3] V. Renugopalakrishnan et al. **Int. J. Quantum Chem. 95, 627-631, 2003.**

[4] V. Renugopalakrishnan, Pingzuo Li, Design of a Bacteriorhodopsin, bR 192, with seven point mutations and its expression in *P. Pastoris*: Stabilization of the M and O photo intermediates with enhanced lifetimes, **US Provisional Patent (pending).**

[5] S.S. Tatke, V. Renugopalakrishnan, M. Prabhakaran, **Nanotechnology 15, S684-S690, 2004**

[6] V. Renugopalakrishnan, Pingzuo Li, Design of a Bacteriorhodopsin, bR 192, with seven point mutations and its expression in *P. Pastoris*: Stabilization of the M and O photo intermediates with enhanced lifetimes, **US Provisional Patent (pending).**

[7] S.S. Tatke, V. Renugopalakrishnan, M. Prabhakaran, **Nanotechnology 15, S684-S690, 2004**

Nanotubes, Springer, Heidelberg, Germany, 2006

V. Krishnamurthy and V. Renugopalakrishnan

Proteins Structure, Function, and Design, Kluwer Academic Publishers, The Netherlands, 1991, V. Renugopalakrishna, I. C. P. Smith, P. R. Carrey, A. C. Storer, and S.-G. Huang

Bionanotechnology : Proteins to Nanodevices, Springer, The Netherlands, V. Renugopalakrishnan and Randolph V. Lewis, 2006

Coordinating Editor, Journal of Bionanosciences

A selection out of approx 200 publications is condensed below :

#### **Recent Publications :**

Expression of Recombinant Proteins in *Pichia Pastoris*. Pingzuo Li, Xiu-Gao Gong Vincent Suzara , Nejat Düzgünes, and V. Renugopalakrishnan **Applied Biochem. & Biotech (submitted)**.

Thermal Denaturation of a Recombinant Mouse Amelogenin : CD and DSC Studies\* Motohisa Oobatake, Tomoko Yamasaki, James P. Simmer and V. Renugopalakrishnan, **Protein Structure, Function, Bioinformatics** 62,461-469, 2006.

Inelastic Neutron Scattering and Molecular Dynamics Simulations of Horse Heart Cytochrome c: Comparison of Experiment and Theory. C. S. Verma, V. Renugopalakrishnan, M. Prabhakaran, Sachin H. Gursahani, L. Vulpescu, J. A. Smith and Ramon Juarez Garduno. **Proc. Natl. Acad. Sci. USA** (review).

Interfacing Biological Macromolecules with Carbon Nanotubes and Silicon Surfaces: A Computer Modeling and Dynamic Simulation study. S.S.Tatke, V. Renugopalakrishnan, and M. Prabhakaran, **Nanotechnology**, 15, S684-S690, 2004.

Retroengineering bacteriorhodopsins: Design of smart proteins by bionanotechnology. Renugopalakrishnan, V.; Strzelczyk, A.; Li, Pingzuo; Mokhnatyuk, A. A.; Gursahani, S. H.; Nagaraju, M., Prabhakaran, M.; Arjomandi, H.; Lakka, S.L. **Int. Journal of Quantum Chemistry** 95, 627-631,2003.

**Cytochrome –c from horse heart: The effect of temperature and pressures from molecular dynamics simulations and normal mode analysis.** M. Prabhakaran, S.H . Gursahani, C. S. Verma, R. Garduno-Juarez, and V. Renugopalakrishnan, **J.Phys.Chem.Solids**, 65, 1615-1622, 2004

Electrostatics of Cytochrome-c Assemblies, V. Renugopalakrishnan, M. Oritz-Lombardia, and C. S. Verma, **J. Mol. Modeling** 11,265-270, 2005

A 27-mer tandem repeat polypeptide in bovine amelogenin: Synthesis and CD spectra. Renugopalakrishnan, V. **Journal of Peptide Science** 8,139-143,2002.

**Peptide NH - ND Exchange : FT-IR study of a hydrophobic protein recombinant amelogenin reveals a tight secondary structure.** V. Renugopalakrishnan, O.P.Lamba, J.P. Simmer, and R.Garduno-Juarez, **J.Biol.Chem.**(submitted)

**Rational design of thermally stable proteins: Relevance to Bionanotechnology.** V. Renugopalakrishnan, R. Garduno-Juarez, G. Narasimhan, C.S. Verma, X. Wei, Pingzuo Li. **J. Nanosc. Nanotech.** 5,1759-1767,2005

Bacteriorhodopsin Energy Landscape : Current Status V. Renugopalakrishnan, “**Specifically Interacting Molecular Materials: Modeling and Design**”, Challenges and Advances in Computational Chemistry and Physics, Ed. J. Leszczynski, Springer, Heidelberg, Germany, 2006

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