Quantum Tunneling NEMS Devices for Bio-Medical Applications

Marek T. Michalewicz[1]
Anthony Sasse[1,2]
Zygmunt Rymuza[3]

[1] Quantum Precision Instruments Asia Private Limited, Singapore
[2] Monash University, Melbourne, Australia
[3] Technical University of Warsaw, Warsaw, Poland

Quantum Precision Instruments Asia Private Limited

A nanotechnology enabling company developing Nano Electro-Mechanical (NEMS) sensors, wireless smart sensor networks *and* atomic precision metrology nanoTrek® devices especially useful in:

- medical diagnostics and biotechnology,
- security, defence and military,
- aviation, maritime and navigation,
- manufacturing and microelectronics applications,
- nanotechnology and scientific industries and
- consumer products.

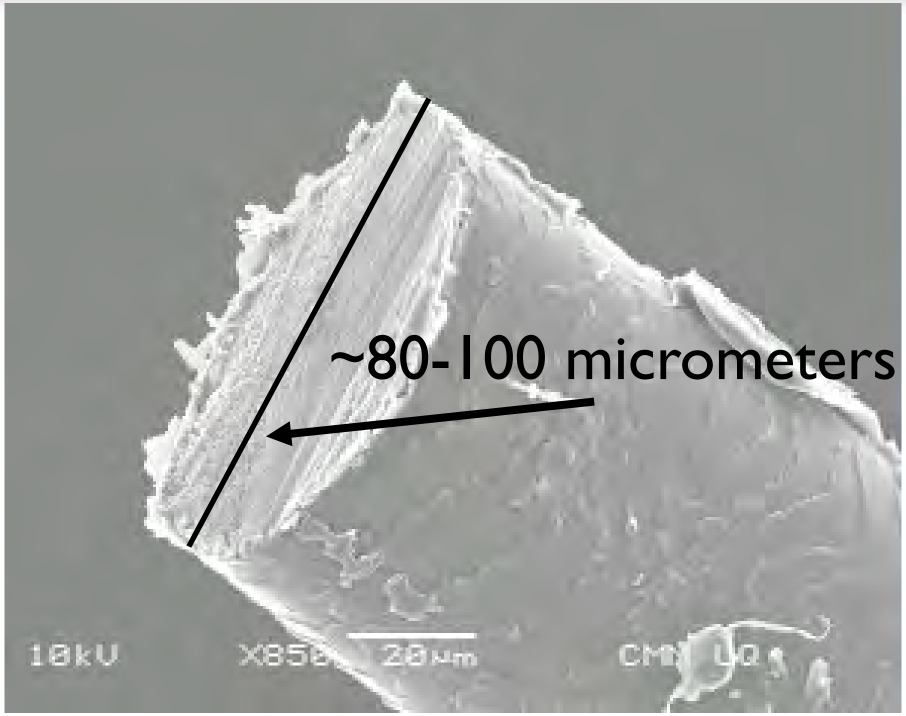
What is quantum tunneling?

Tunneling of particles (electrons, protons, alpha particles) is an exclusively quantum phenomena arising out of the particle-wave duality. It can only be explained by laws of quantum physics. In the quantum realm particles like an electron can penetrate energy barriers higher then the energy of a particle, and appear on the "other side" in a "ghost-like" manner.

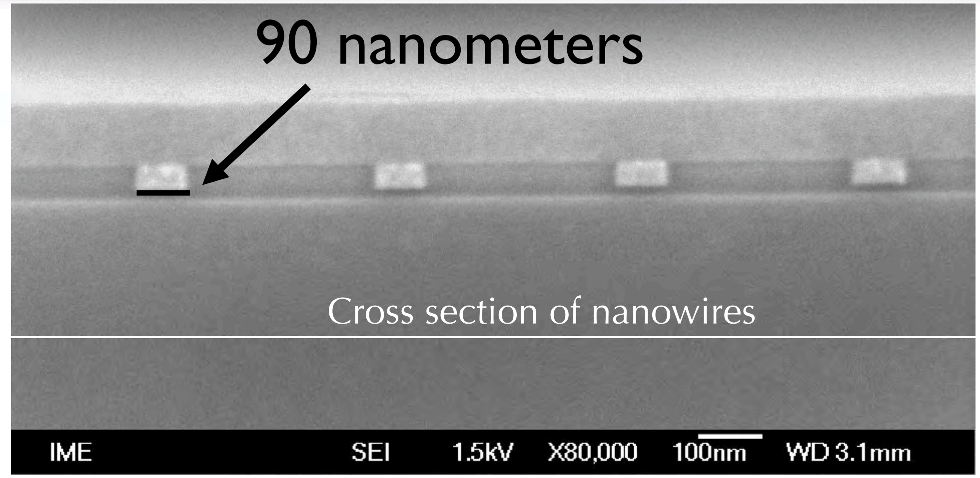
Nobel Prizes in Physics awarded for contributions related to quantum tunneling effect:

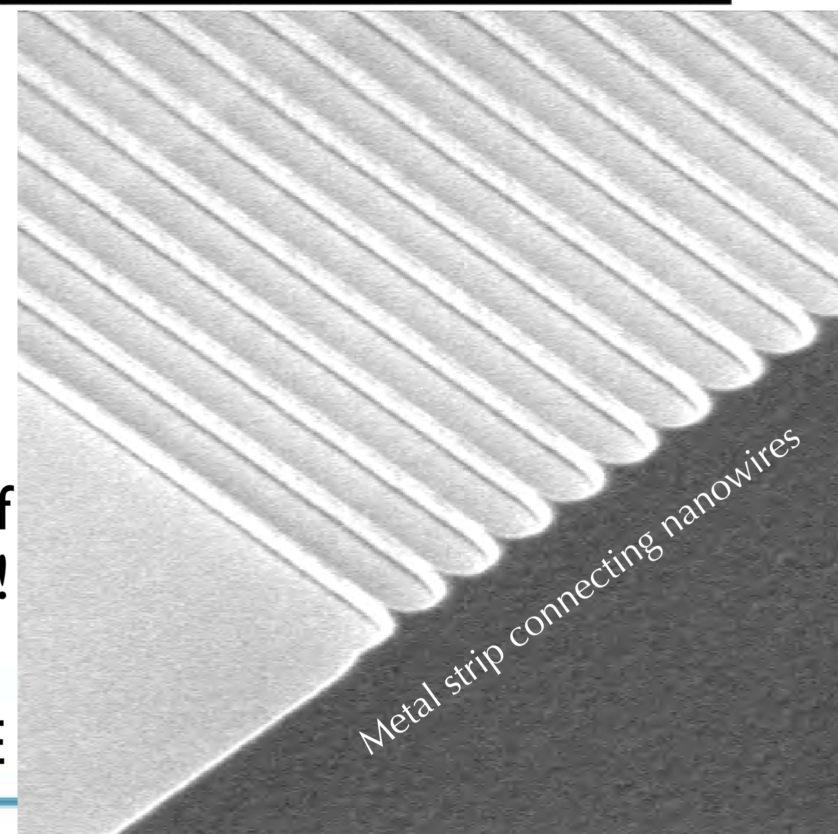
- L.-V. de Broglie (1927, particle-wave duality)
- H.A. Bethe (1967, energy production in the Sun and stars)
- B. D. Josephson (1973, theoretical predictions of the properties of a supercurrent through tunnel barrier, Josephson effects)
- L. Esaki and I. Giaever (1973, experimental discoveries regarding tunneling phenomena in semiconductors and superconductors, respectively)
- G. Binnig and H. Rohrer (1986, design of the scanning tunneling microscope).

Is what we do *nanotechnology*?



Electron Microscope Image
of human hair



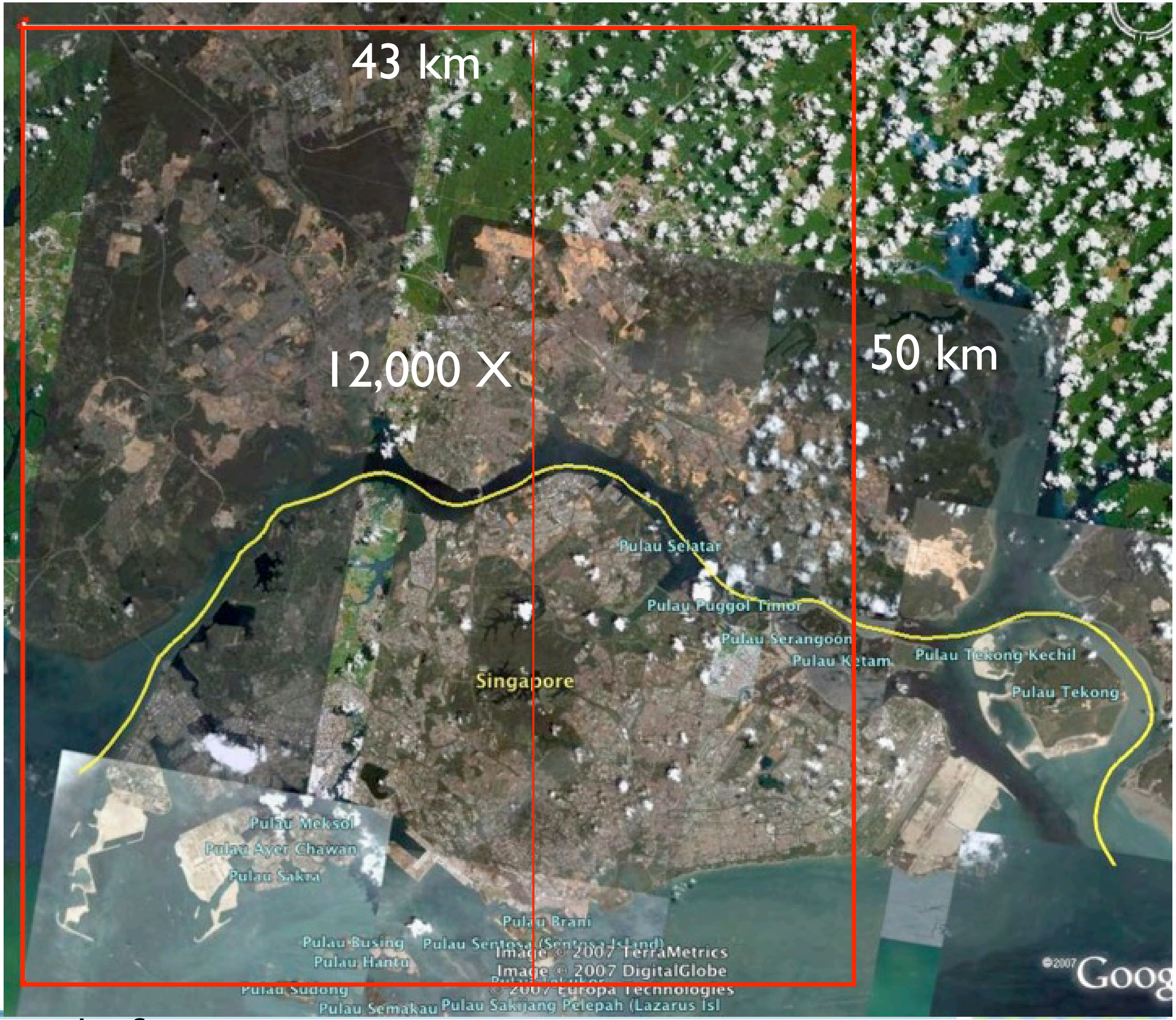


Each nanowire is ~1/1000th width of
of human hair!

Prototype nanoTrek® devices fabricated at IME

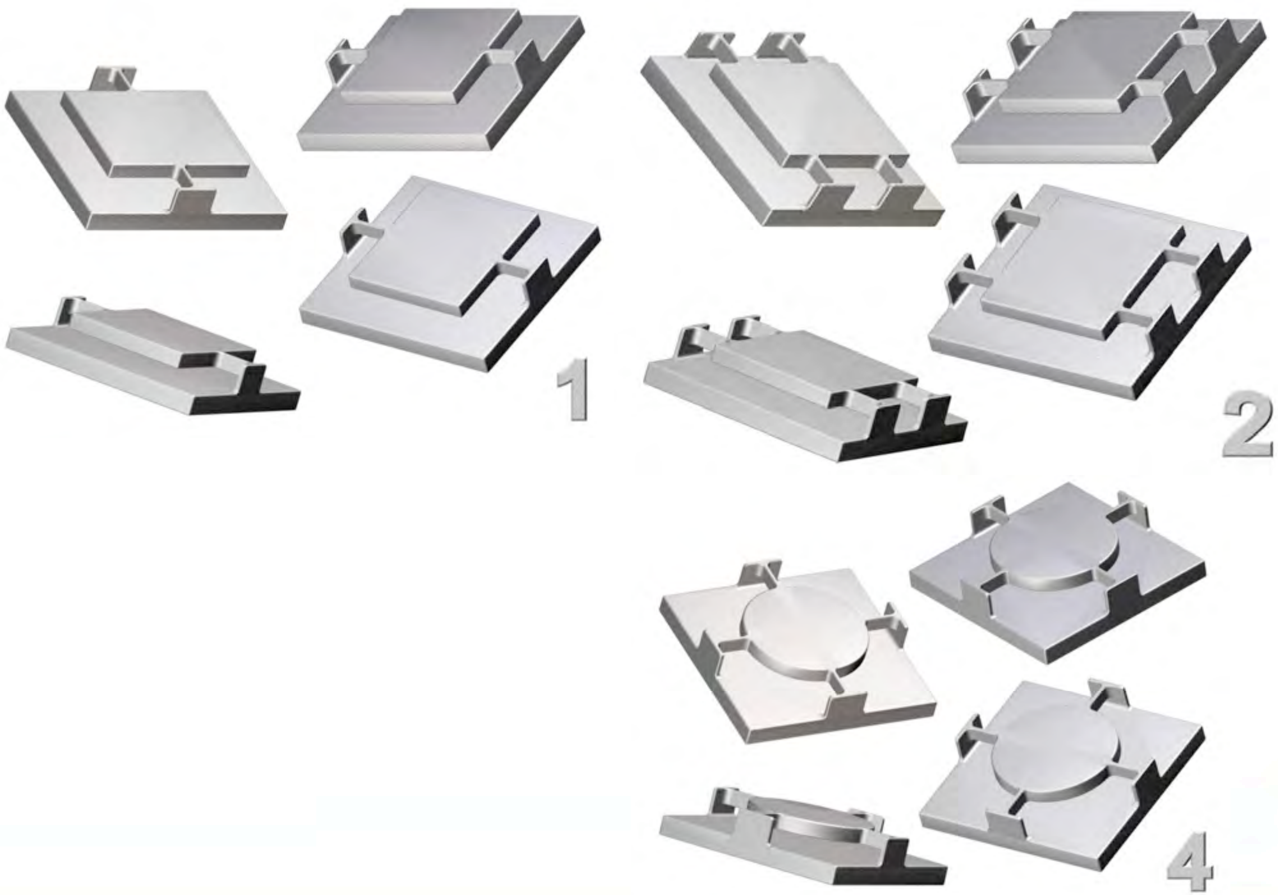
nanoTrek® devices - scale analogy

Imagine a straight path 1 meter wide running the entire length of 50 km, and another one, separated by 3 meters, and another one… Imagine 12,000 such 1m wide and 50 km long paths! Now, shrink this picture ten million times and you get an image of one of the hundreds of nanoTrek® devices



Quantum-π NEMS devices

Examples of Quantum-π NEMS device design, where the nanowires are manufactured in the top and bottom plates. The entire top square or round element will be only approx. 20 microns or 1/5th of a diameter of a human hair.



What can we measure?

Our NEMS sensors will be very useful in a range of bio-medical applications such as:

Measurand	Sensor
Motion (velocity, acceleration)	Accelerometers
Sound	Ultra sensitive microphones
Force (pressure)	Pressure meters
Flow	Flow Meters

Medical Tools and Technologies

1. Pressure sensors for "nearly non-invasive" medical monitoring

A. Post operative Intra-cardiac and Intra-Cranial monitoring

- Current technology requires placement of infection prone catheters (pipes) connecting the target site with an external pressure transducers, with only short term measurements possible (current limit 3-7 days).
- Long term implantable/leave behind sensors will revolutionise post-operative care

Medical Tools and Technologies

1. Pressure sensors for “nearly non-invasive” medical monitoring

- Multiple sites eg: left atrium, left ventricle, Pulmonary artery, Superior Vena Cava, Aorta, radial artery.
- Basal versus Superior Cranial pressures
- Will enable highly accurate diagnosis and allow optimization of medical care,
- Detect adverse events earlier

Medical Tools and Technologies

1. Pressure sensors for “nearly non-invasive” medical monitoring

B. Blood Pressure monitoring

- ✦ Peri-arterial Nanotrek device will provide constant measurement long-term accurate data allowing optimization of medical therapy, instead of Sphygmomanometers
- ✦ Blood pressure monitors - pictures showing they have not changed in over a 150 years. external/nanotrek internal, continuous 24/7 monitoring

C. Other sites

- Glaucoma = Intra-Ocular Pressure
- Renal Artery Stenosis
- Peripheral Vascular disease (Carotids, limbs)
- Abdominal Aortic Aneurysm (where transmural pressure/tension will predict timing of rupture)
- Vertebral disc pressure
- Bladder

Medical Tools and Technologies

1. Pressure sensors for “nearly non-invasive” medical monitoring

- Associated Flow meters will allow Pressure/ Flow analysis
- Nanotech devices will be easily incorporated into the large variety of Stents currently being inserted.

  Examples include: coronary artery, Abdominal Aorta, peripheral arteries such as carotid and limbs, and stents are being developed for Bronchii (Airways).
- Motion localization (eyes in sleep, limb paralysis)

Medical Tools and Technologies

2. Flow Meters – Vascular

- Critical Blood Flow scenarios: coronary, renal, carotid–pre, peri, post operative.
- Vascular spasms- cerebral: Sub-Arachnoid Haemorrhages
- Neo-natal Cardiac Malformations

Medical Tools and Technologies

2. Flow Meters – Airflow

Acute: Asthma, Sleep Apnoea

Chronic: Chronic Obstructive Pulmonary Disease = COPD

All applications could be realized as *wearable, patient based network, internally placed, or externally worn, in association with a low power wireless network such as Passive Radiofrequency technology, to allow continuous or intermittent computer based monitoring in a home, step-down facility or hospital environment.*

Medical Tools and Technologies

3. Ultra sensitive microphones

- Ultra sensitive microphones networks
  – *hyper sensitive networks of many sensors* for ultrasound tests
- Structure/Function of organs.
  – Neonatology: organs can be observed for normal development
  – Organ Transplant Monitoring, for loss of function, such as in Cardiac Transplantation the progress of the left ventricle and atria.
  – Ordinary organs will be able to be closely observed, such as in Cardiac failure, and more precise treatments tailored as a result.

Small Molecule Drug Discovery & Development

Ternary & Quaternary protein structure determination

nanoTrek® would allow the most precise detection of angular positioning - this is very important in low-angle diffraction detectors for positioning, detection and interpretation of signal; in bio-medical context it translates to highly accurate diffraction studies of ternary and quaternary structures of proteins.

Quantum-π facilities in Singapore

Quantum-π office and lab space at NUS Business Incubator

Collaborations:

A*STAR (Agency for Science Technology & Research)

IMRE: Institute of Materials Research & Engineering
IME: Institute of Microelectronics
DSI: Data Storage Institute
SIMTech: Singapore Institute of Manufacturing Technology

SPRING: (Standards, Productivity and Innovation Board) Singapore

SSLS: Singapore Synchrotron Light Source

Dr Anthony Sasse, M.B.B.S. (Uni of Melb), F.R.A.C.P.

- Specialist Respiratory Physician,
- Fellow of the Royal Australian College of Physicians,
- Accreditation in Sleep Disorders,
- Extensive experience in Intensive Care,
- Director of Intensive Care at Latrobe Regional Hospital 1993-2000,
- Runs a 5 bed Sleep Disorders Unit in Melbourne and Gippsland, Australia,
- Inventor of granted patents (USA, UK etc) in Non-Invasive Passive Radiofrequency monitoring with human and animal applications,
- Has published experimental animal research in treatments for Sleep Apnoea,
- Senior Lecturer at Monash University,
- Maintains a significant private practice in Sleep and Respiratory

Prof Zygmunt Rymuza, PhD, DSc

Professor at the Institute of Micromechanics and Photonics, Warsaw University of Technology, Poland

Leader of the microtribology and micro/nanotechnology research group.

His research is focussed mainly on nanomechanics and micro/nanotribology of ultrathin films and MEMS/nanotechnology materials and miniature tribosystems embodied in mechatronic devices. He is author of the monographs "Tribology of Miniature Systems" (Elsevier Science Publishers, Amsterdam 1989) and "Tribology of Anti-Friction Polymers" (published in Polish by WNT, Warsaw 1986) and over 250 technical papers published in many international and Polish journals and presented at conferences. He is a member of the board of The Polish Tribology Society.

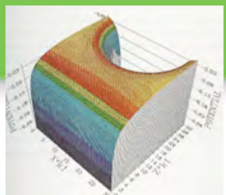
Dr Marek T. Michalewicz, Founder and CEO

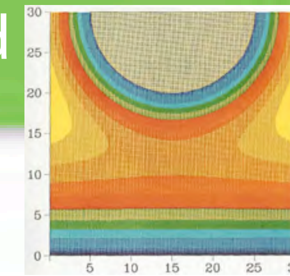
PhD (Physics), Institute of Advanced Studies, Australian National University, Canberra
MSc (Physics), LaTrobe University, Melbourne
University of Wroclaw, Poland (4 years, Physics)
University of Minnesota, Minneapolis, USA (Research Associate, 2 years)
17 years research experience following a PhD degree
22 years experience of scientific and commercial computing
Scientific consultant in the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Supercomputing and High Performance Computing (10 y)

1997-2000 Principal Research Scientist at the CSIRO Mathematical and Information Sciences High Performance Computing

Edited two books on Computational Life Sciences & Medicine and authored over 35 scientific papers and book chapters and some 45 conference presentations in 12 countries
Fellow of The Australian Institute of Physics
Member of The American Physical Society
Senior Associate Foresight Institute (for Nanotechnology)

Dr Marek T. Michalewicz
Physics, Computation and Nanotechnology research record





1984-1987 - studies of the tunnelling potential in the Scanning Tunnelling Microscope (STM)
1986 April - visit to H. Rohrer's group at the IBM Laboratory in Zurich

Studies of surface plasmons on metallic quantum dots of 20-600 nm radius on buckyball C_{60}.

Theoretical identification of four molecular surface plasmons on C_{60}

Extensive experience with Cray–2, Cray Y–MP, Cray C90, Cray J90, NEC SX-4 and SX-5 vector-parallel supercomputers and Cray T3D, MasPar and Compaq alpha massively parallel supercomputers.

Massively parallel algorithm in the study of disordered condensed matter: O(1) parallel scaling, electronic structure solved for a sample of ~500,000 atoms (TiO2) on SIMD computer (<u>MasPar 16,000 Processors</u>)

1995 - defined the Grand Challenge problem in Computational Nanoelectronics at the 1st Asian Supercomputer Conference in Taipei, Taiwan

1996 - honorable mention - the Bell prize for supercomputing research

1998 - the fastest application on SX-4 with 32 CPU in the World: created program that scaled linearly, O(N), run with a speed of 43 GFLOPS/s on NEC SX-4 vector -parallel supercomputer with 32 processors (~67% theoretical peak speed) and computed electronic densities of states for multi-million atom samples in mere minutes. The largest test computation performed was for the electronic density of states (DOS) for the TiO2 sample consisting of 7,623,000 atoms.

Mathematically, this was equivalent to obtaining a spectrum of an n x n Hermitian operator (Hamiltonian) where n = 38,115,000
1990 –2000 investigated morphology and size dependent electronic properties of nanoparticles of rutile (TiO2). The largest sample studied had dimensions of 48nm x 50nm x 32nm.