Sensors and Metrology Devices from Quantum-π:

from nanoTrek®
to tunneling photo-detector array

Marek T. Michalewicz, PhD
CEO & CTO
Poznan, 5 May 2008

Quantum Precision Instruments
Asia Private Limited, Singapore

Quantum Precision Instruments Asia Private Limited

A high-tech early stage company developing Nano Electro-Mechanical (NEMS) sensors, wireless sensor networks and atomic precision metrology nanoTrek® devices especially useful in:

- oil and gas industry,
- security, defense and military,
- medicine and biotechnology,
- aviation, maritime and navigation,
- precision manufacturing and microelectronics fabrication equipment, nanotechnology and scientific industries, and in
- consumer products.

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Motivation:

1. Critical appraisal of concepts
2. Invitation to engage in joint research
3. Suggestions and ideas for research
4. Open problems

Collaborators:

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9: Data Storage Institute, Singapore
10: Institute of Manufacturing Technology, Singapore
11: Birck Nanotechnology Laboratory, Purdue University, USA

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Prof. Boleslaw K. Szymanski	Professor of Computer Science, Director, Center for Pervasive Computing and Networking, Rensselaer Polytechnic Institute, Troy, NY, USA
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Quantum-π facilities in Singapore

Quantum-π is located
at NUS Business Incubator

Collaborations:

SSLS: Singapore Synchrotron Light Source

SPRING Singapore
Standards, Productivity and Innovation Board

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

Quantum tunneling

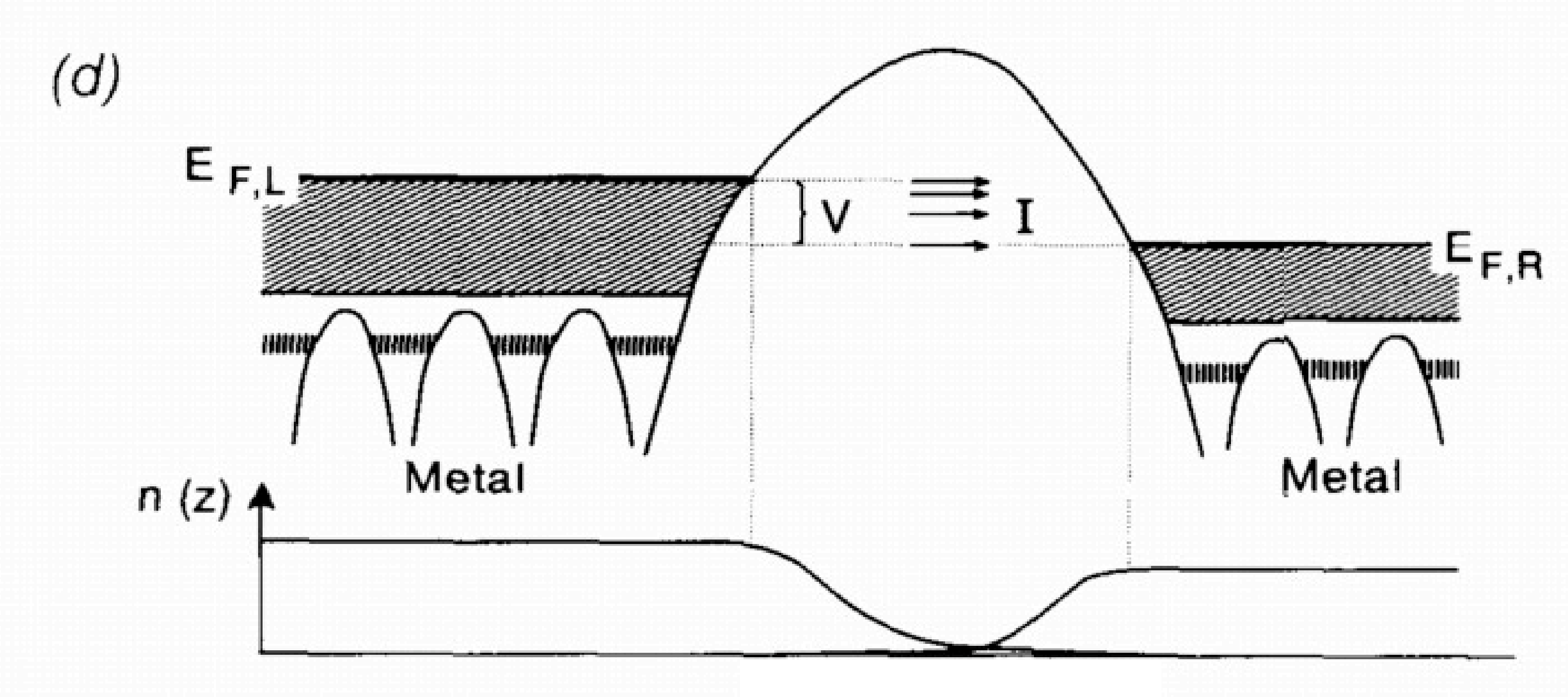
Tunneling of particles (electrons, protons, alpha particles) is an exclusively quantum phenomena arising out of the particle-wave duality. It can only be explained by laws of quantum physics. In the quantum realm particles like an electron can penetrate energy barriers higher then the energy of a particle,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

Quantum tunneling is a very well established natural phenomenon observed for example in energy production in the Sun and stars, alpha decay of heavy nucleus and used in many modern day devices such an Esaki tunnel diode, SQUID and the Scanning Tunneling Microscope.

Several Nobel Prizes in Physics were awarded for discoveries and 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).

Gerd Binnig and Heinrich Rohrer, IBM Zurich Lab
Scanning Tunneling Microscope, Nobel Prize in Physics 1986



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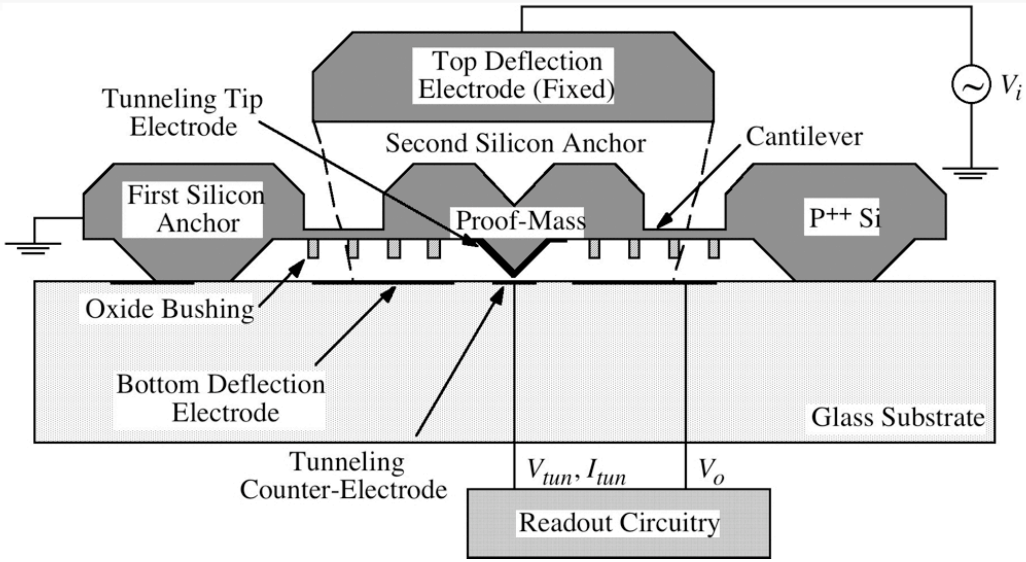
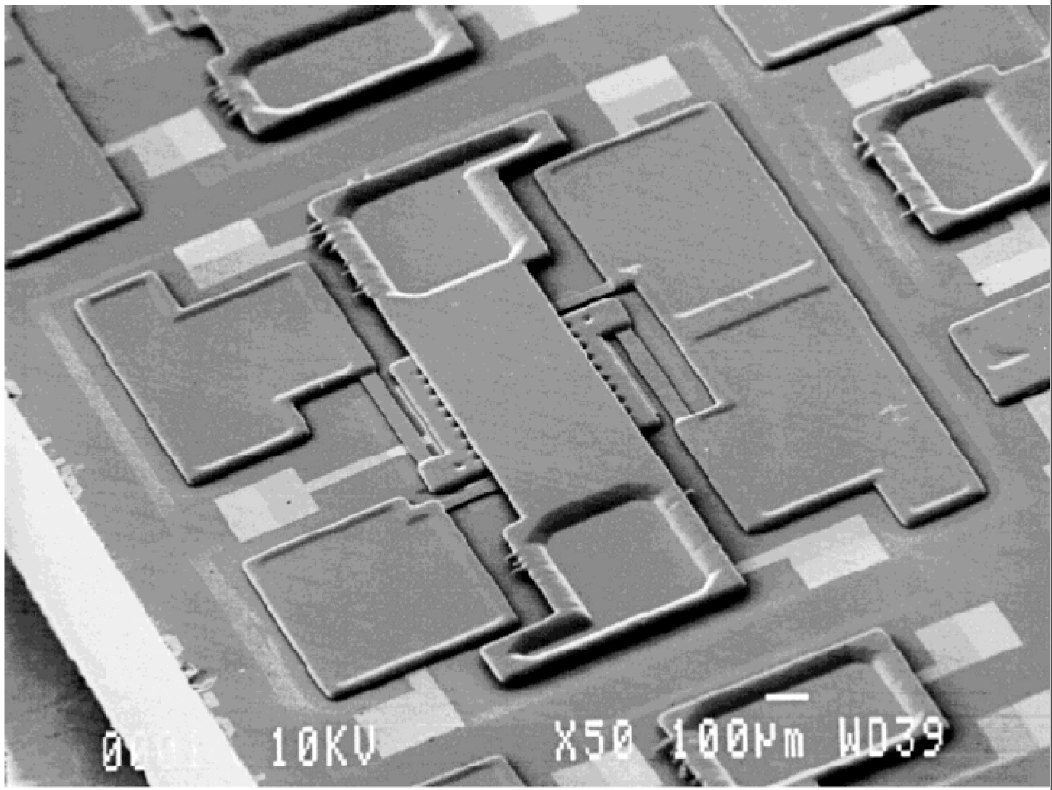
Chingwen Yeh
A Low-VoltageTunneling-Based Silicon Microaccelerometer



The general structure of the low-voltage tunneling-based accelerometer



The SEM photograph of a tunneling microaccelerometer fabricated using silicon-wafer-dissolved process and glass bonding. The picture shows the top electrode, and the perforated proof mass partially visible under this electrode

Devices and Concepts:

1. nanoTrek® - a quantum tunneling based linear encoder of position, motion and alignment
2. dynamic nanoTrek® – Nano Electro-Mechanical Systems (NEMS) sensors for measurements of vibration, acceleration, pressure, flow, etc.
3. new designs for the AFM cantilevers that do not require optical metrology to measure bending and torsions but utilize quantum tunnelling
4. 2-D tuneable diffraction gratings for atom beams, or a new type of an atom optics chip
5. quantum tunneling photo-detector cross-grid arrays

nanoTrek ®: Principle of operation

Demo 1

Principles: Understanding and Control

The System	Two arrays of long metallic strips overlie each other, separated by a thin uniform spacer of dielectric. Dimensions are on the scale of tens of nanometers.
The Signal	When a voltage is applied across the arrays, quantum tunneling of electrons across the spacer manifests as a measurable current.
The Challenge	The current is highly sensitive to the mutual overlap of the strips, both in relative lateral offset and relative angular orientation. We must compute and optimize the current in a local potential that is highly nonuniform.
The Payoff	A unique, well controlled, reproducible nanometrology.

Theoretical Description I
Tunneling Current as a Function of Overlap Area

The tunneling current by first-order perturbation theory [John Bardeen formula] is

$$I = e/h\, \Sigma M^2_{m\,,\,n}\, \delta(E_m - E_n)$$

where $M_{m,n}$ is the tunnelling matrix element between the states ψ_m in one quasi-1-D conductor and ψ_n in another one:

$$M_{m,n} = 1/2 \int dS\, (\psi^*_m \nabla \psi_n - \psi_n \nabla\, \psi^*_m)$$

note the above can be approximated by ~ 1/2 $A(\Theta) j_{mn}$, where $A(\Theta)$ is the area of conductors geometrical overlap. For wave functions in quasi-1-D conductors of square cross section that can "spill" on one side of a square the matrix element is

$$M_{m,n} = \kappa_z e^{-\kappa_z D} \int dS\;\; \gamma^*_1\, \gamma_2$$

where $\kappa_z = 2\pi/h(2m\phi)^{1/2}$, ϕ is the the work function and D is the vertical separation between the plates. The integral above is the function of overlap area and hence .... an angle of rotated plates. This function is linear for small angles.

8’ wafer fabricated at IME Singapore

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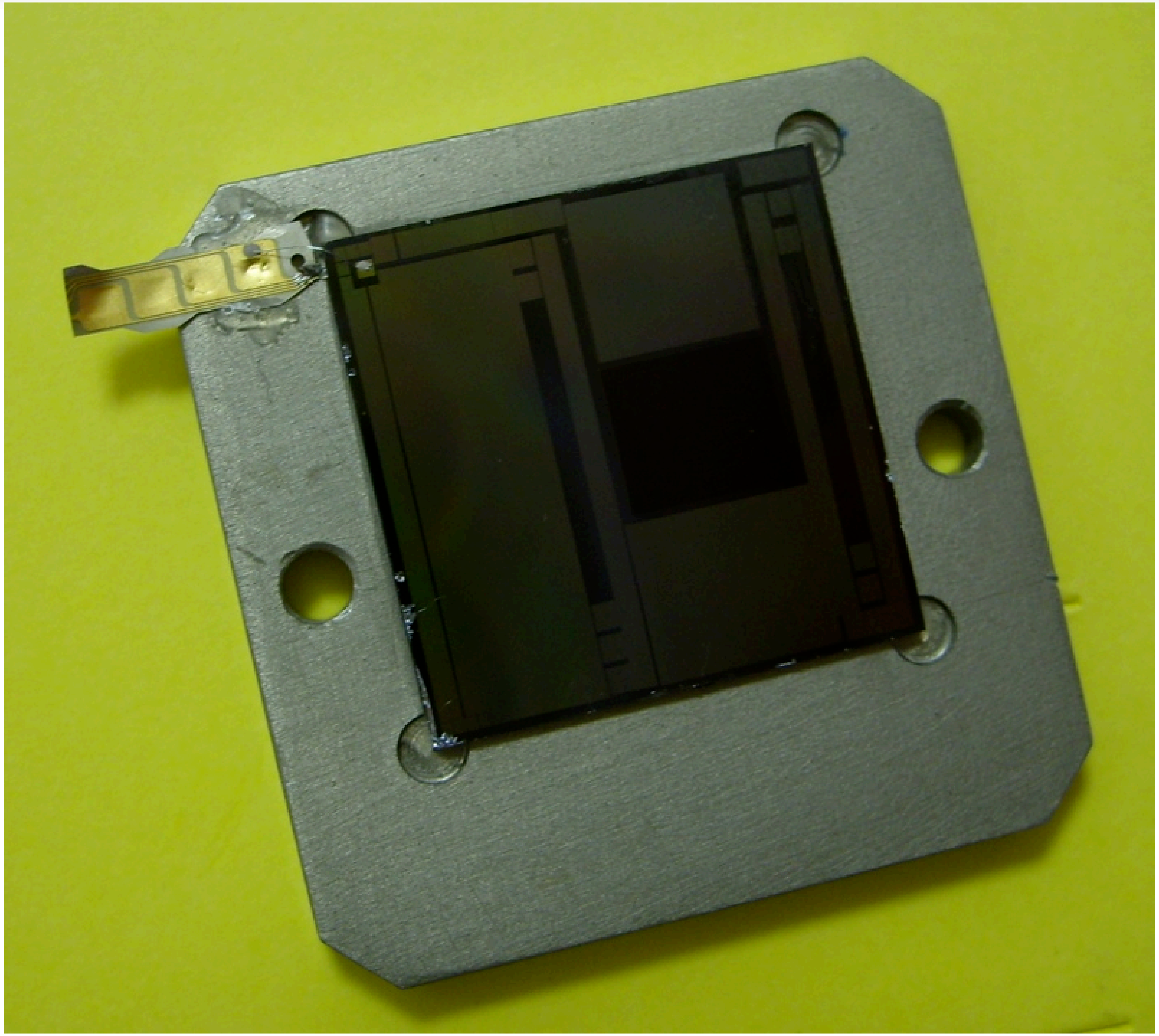
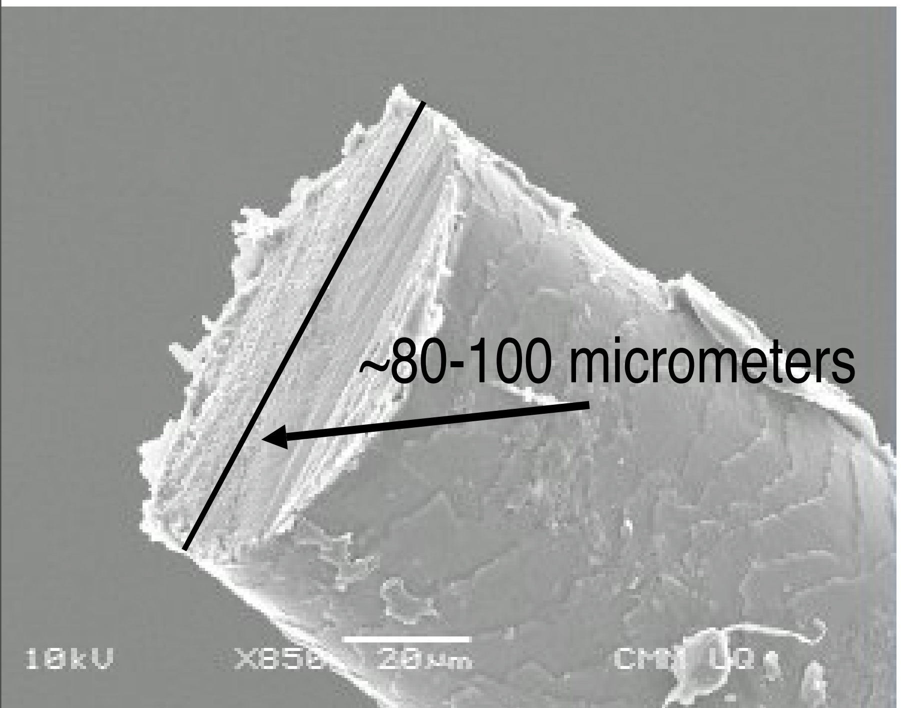
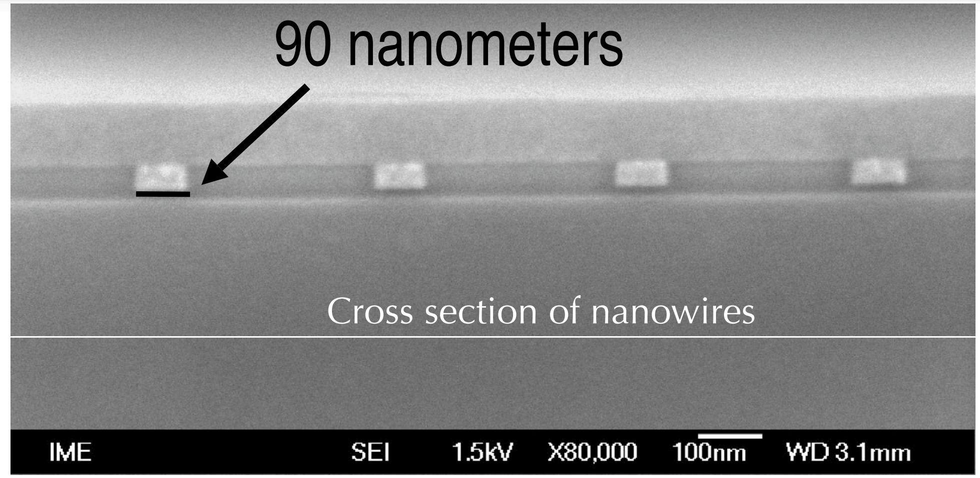
nanoTrek ® one plate set in a holder

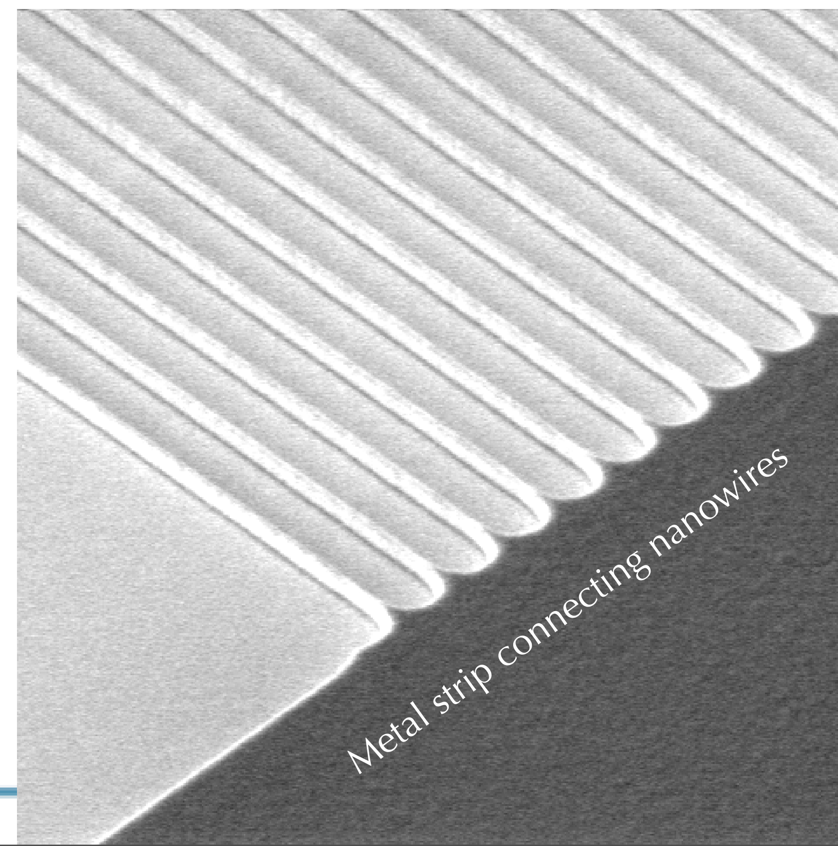


Prototype nanoTrek® devices fabricated at IME



Electron Microscope Image
of human hair

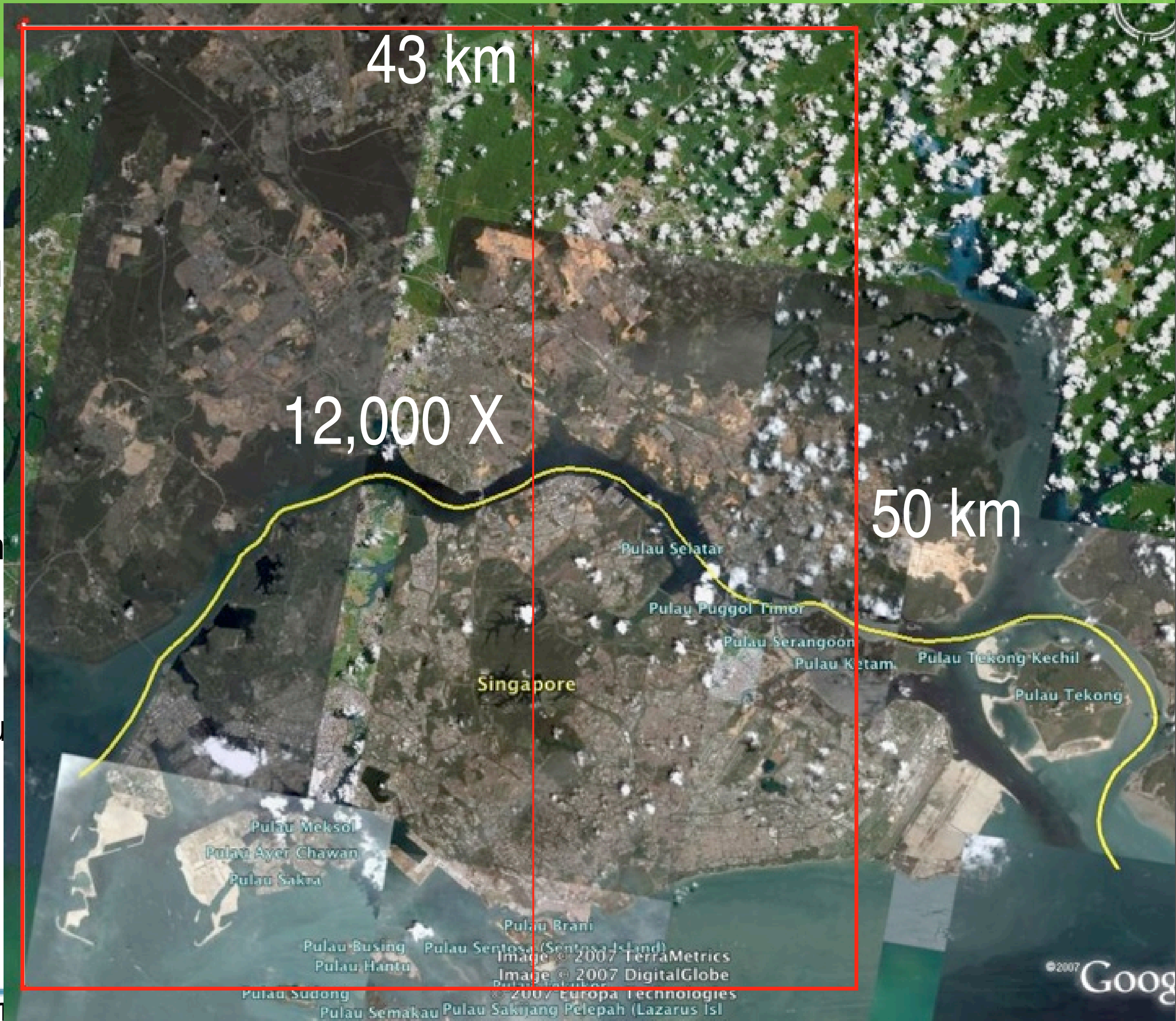




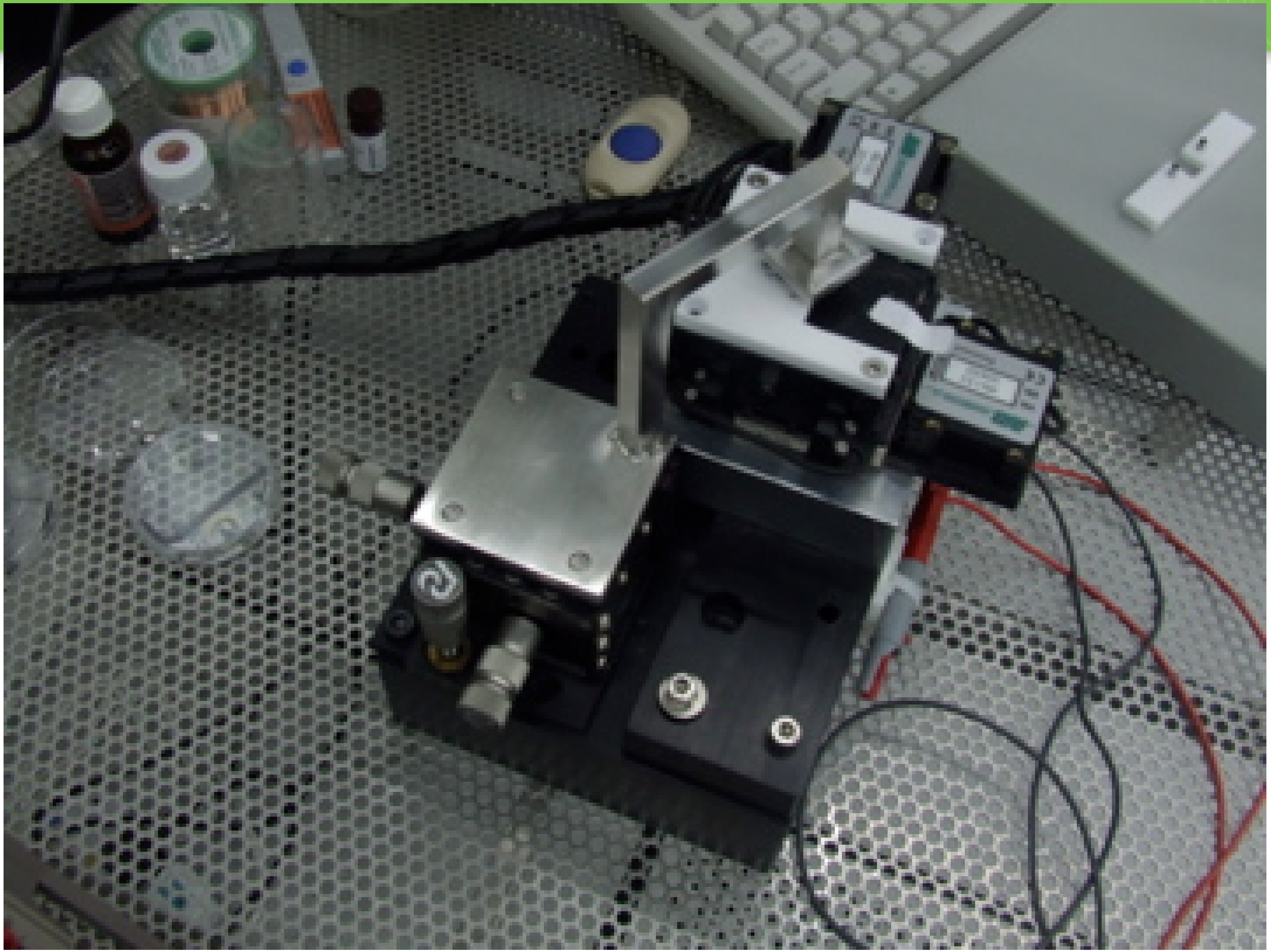
Each nanowire is ~1/1000th width of
of human hair!

nanoTrek® devices - scale analogy

Imagine a straight path 1 meter wide running the entire length of 50 km, and another one, separated by 2 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 experimental set-up at IMRE



Quantum-π experimental set-up at IMRE

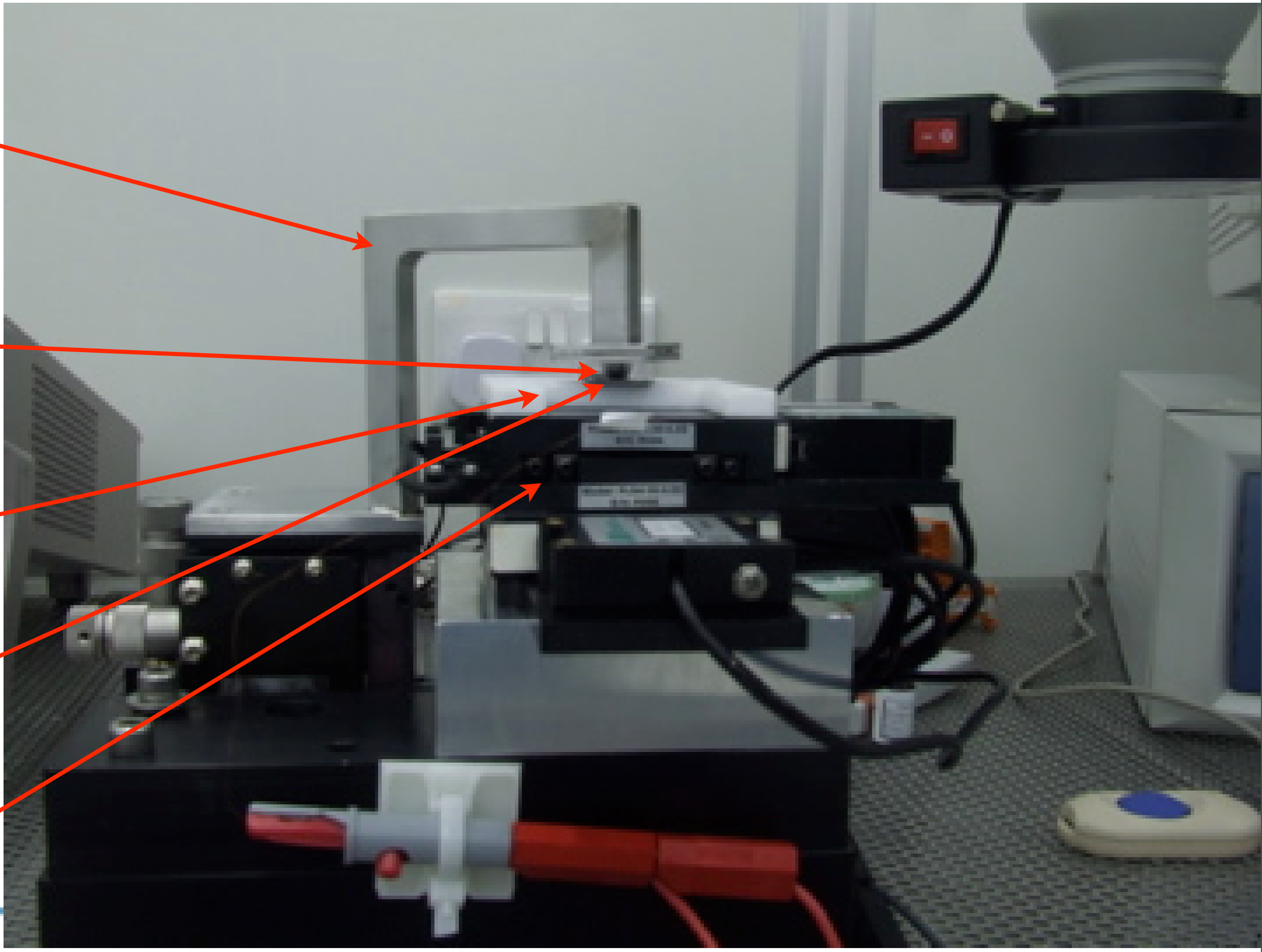
top plate fixture "gallows"

top nanoTrek plate is glued to ball-ended gallows

bottom nanoTrek plate is fixed to telfon holder

nanoTrek device

nanopositioner (Nanomotion)

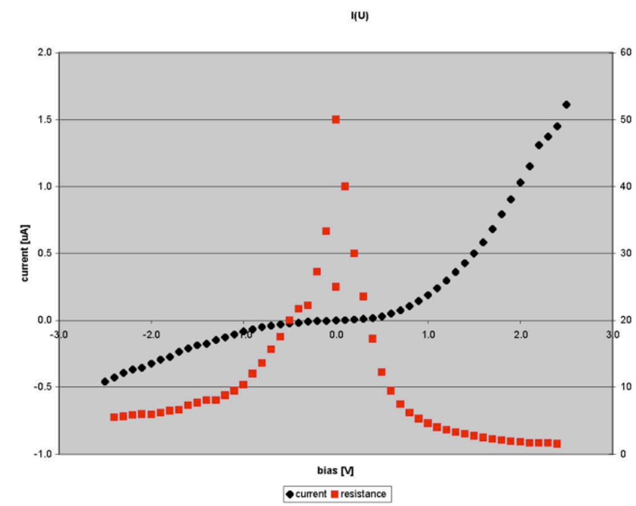


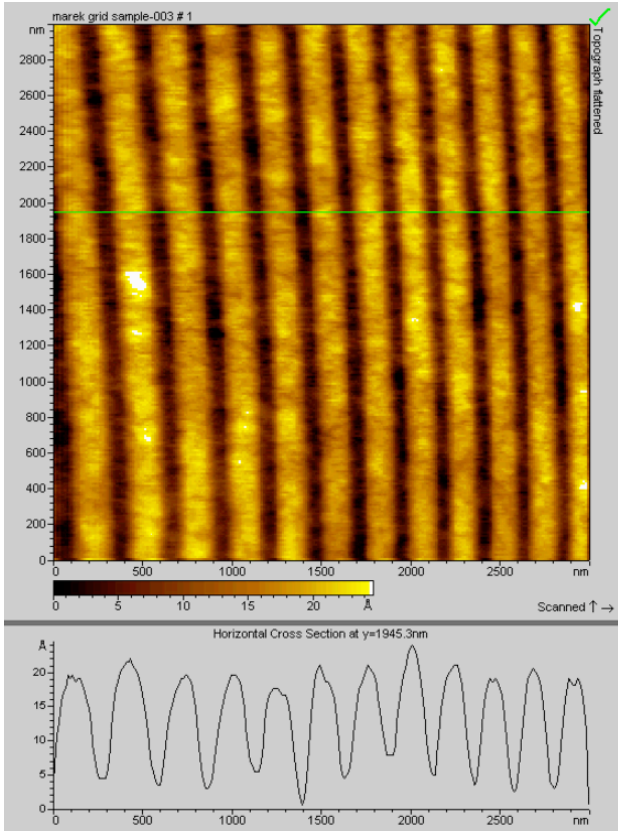
Product 1: Quantum Tunneling Linear Encoder of Position

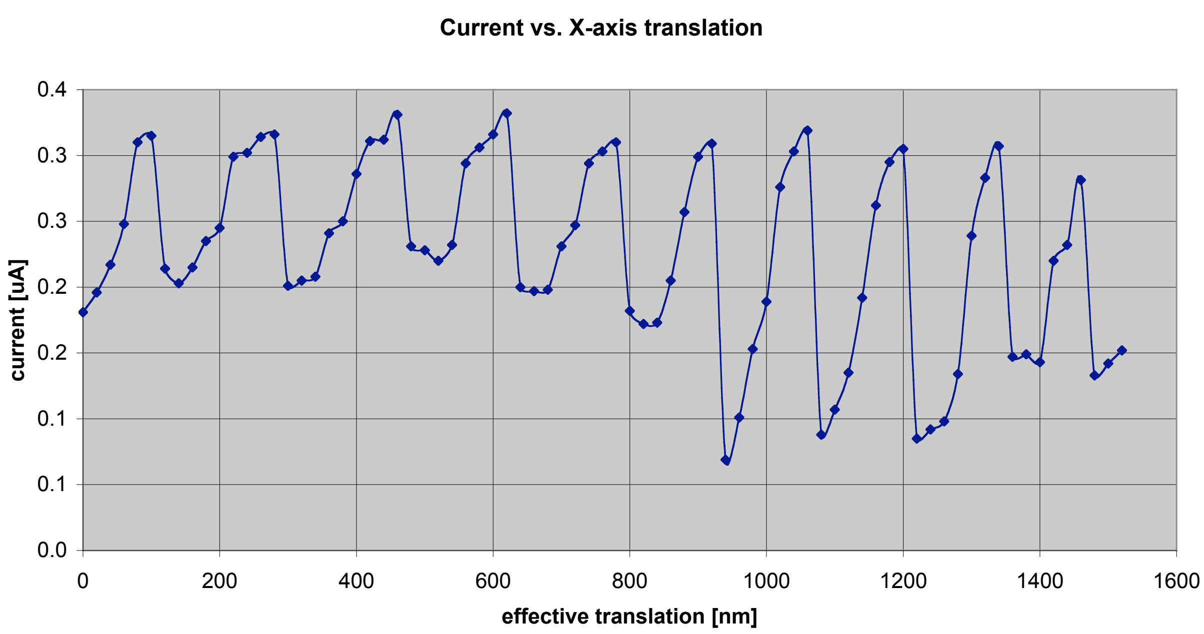
Unique metrology:

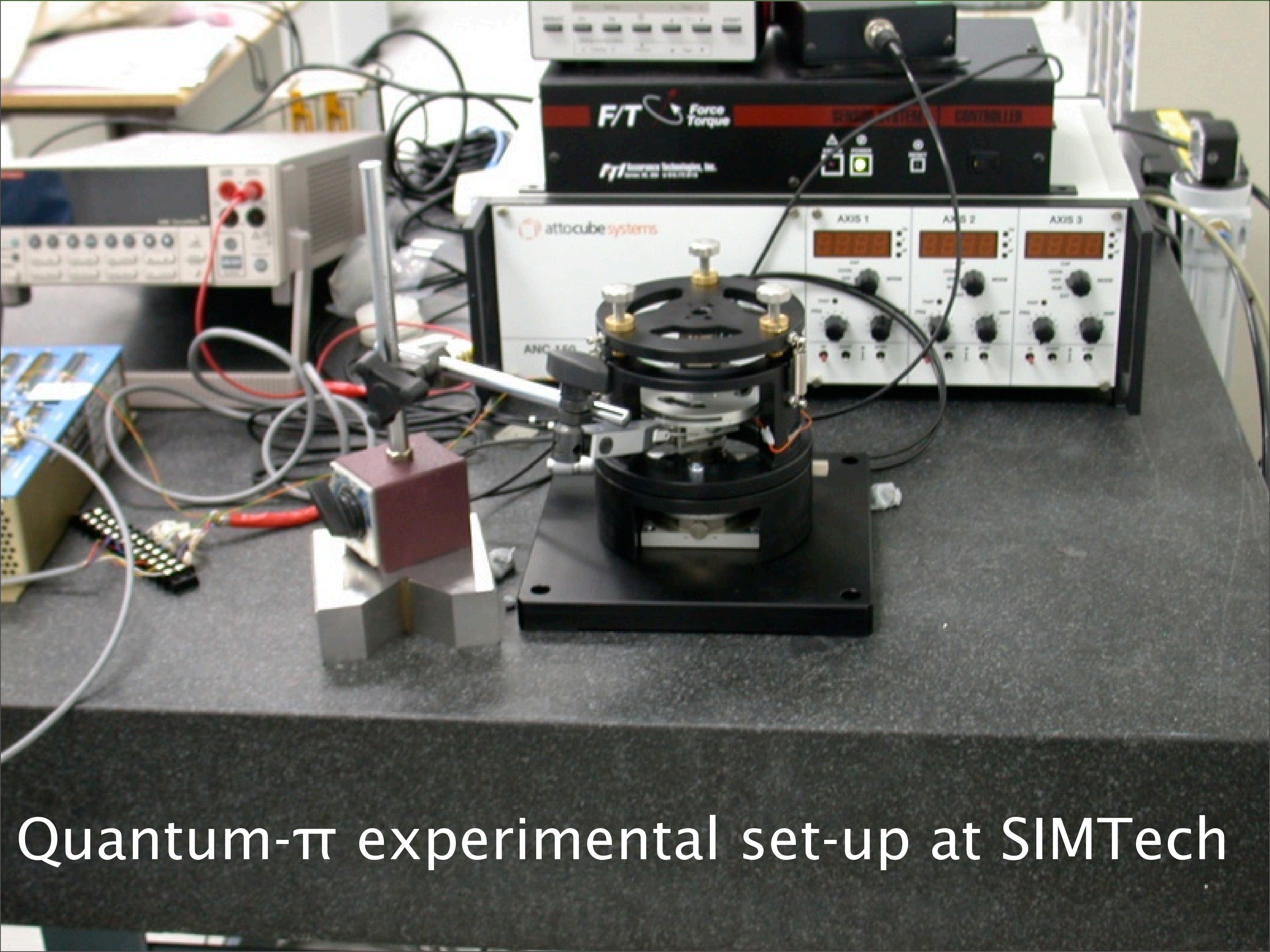
Target range: 20 cm

Target resolution: 0.1 pm
(with interpolation)

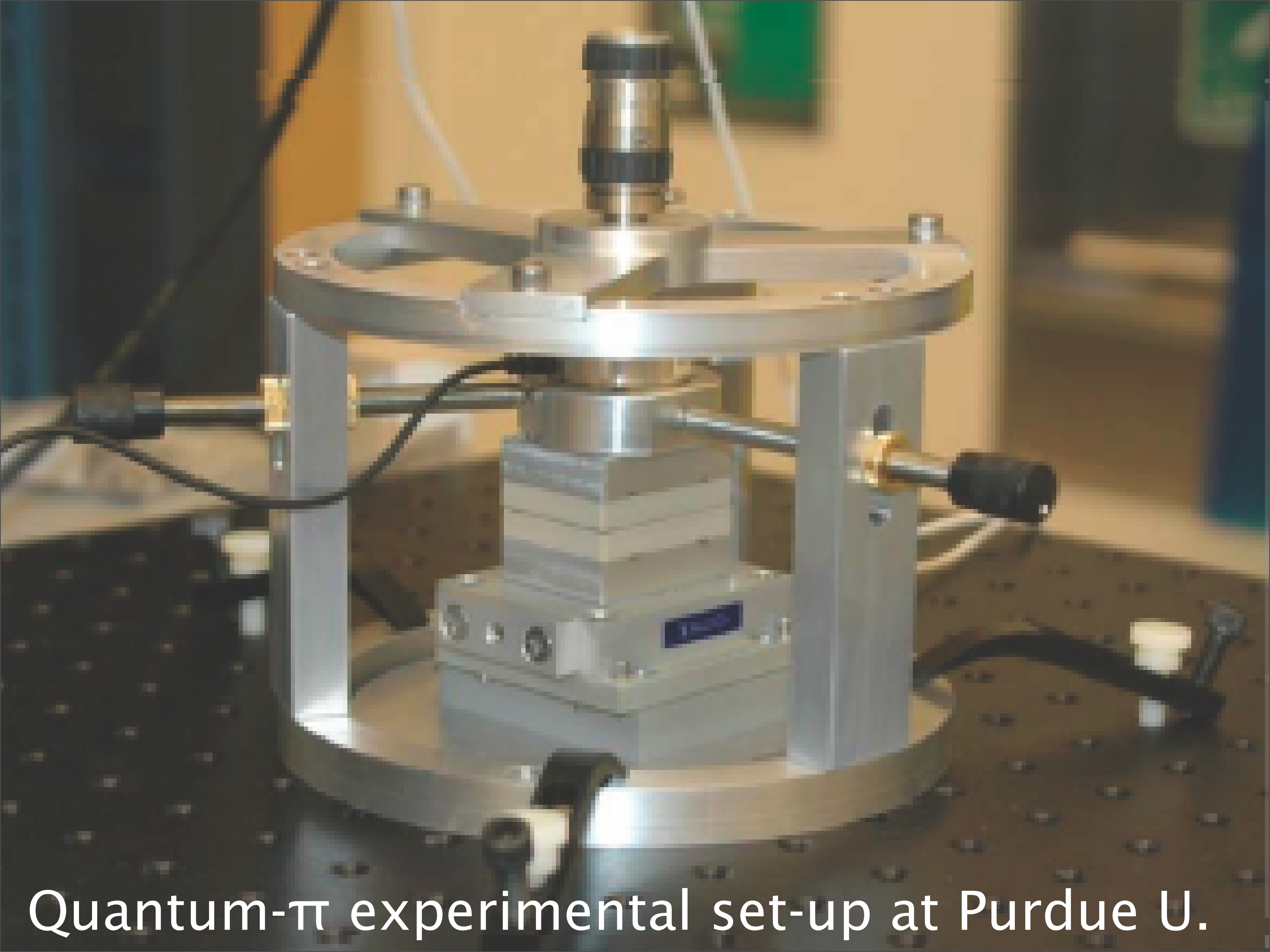






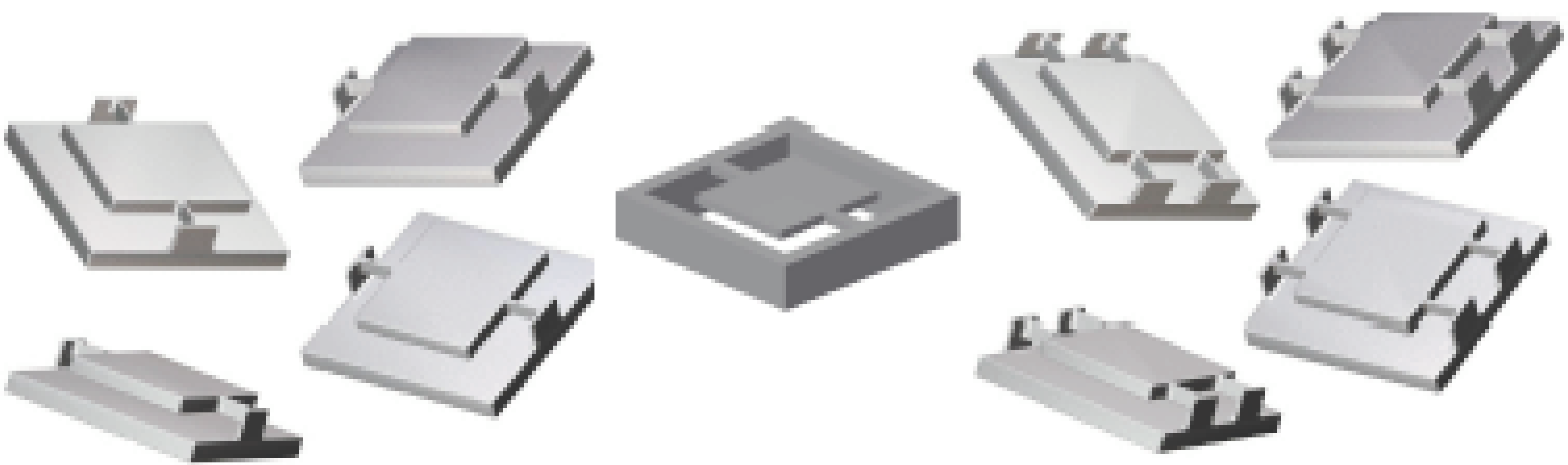


Quantum-π experimental set-up at SIMTech


Quantum-π experimental set-up at Purdue U.

Moire interference patterns

Dynamic nanoTrek® devices



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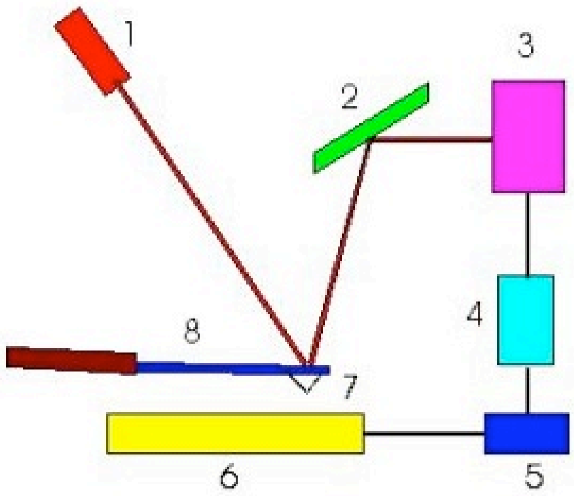
2-D Tuneable Diffraction Grating for Atoms and Molecules

Quantum-π Atom Chip

New Metrology of Cantilever Bending

AFM



1. Laser
2. Mirror
3. Photodetector
4. Amplifier
5. Register
6. Sample
7. Probe
8. Cantilever

An atomically sharp tip is scanned over a surface with feedback mechanisms to maintain the tip at a constant force (to obtain height information), or height (to obtain force information) above the sample. Tips are typically made from Si_3N_4 or Si, and extended down from the end of a cantilever. A diode laser is focused onto the back of the reflective cantilever. As the tip scans the surface of the sample, moving up and down with the contour of the surface, the laser beam is deflected into a dual element photodiode which measures the difference in light intensities between the upper and lower photodetectors, and then converts to voltage.

New Metrology of Cantilever Bending

"......
A complementary effort is based on atomic force microscopy (AFM) in which a sandwich immunoassay attaches magnetic beads to a microfabricated cantilever (R. Colton, NRL). In the laboratory the AFM technology is already 100 to 1,000 times more sensitive than conventional immunoassays...."

from: NATIONAL
NANOTECHNOLOGY
INITIATIVE:
Leading to the Next Industrial Revolution
A Report by the Interagency Working Group on
Nanoscience, Engineering and Technology
Committee on Technology
National Science and Technology Council
February 2000
Washington, D.C.

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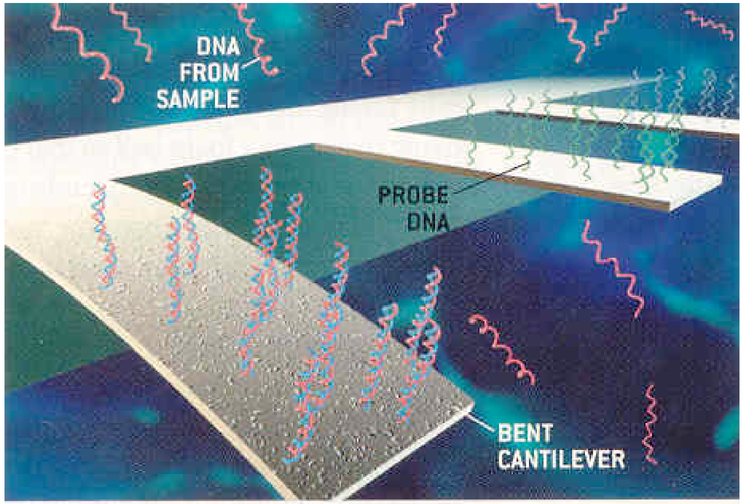
Cantilever DNA Sensor



www.ibm.com

- Probe DNA fragments are attached to cantilevers
- If complementary DNA fragments are in the analyte, they will bind and deflect the beam

New Metrology of Cantilever Bending

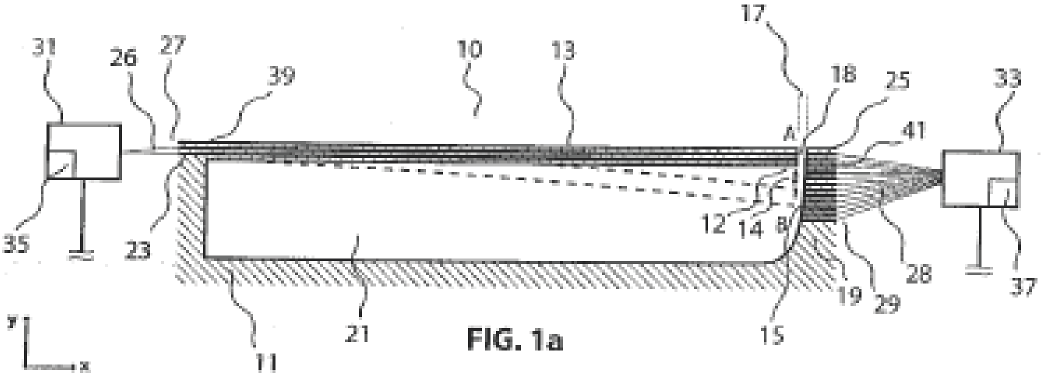


FIG. 1a

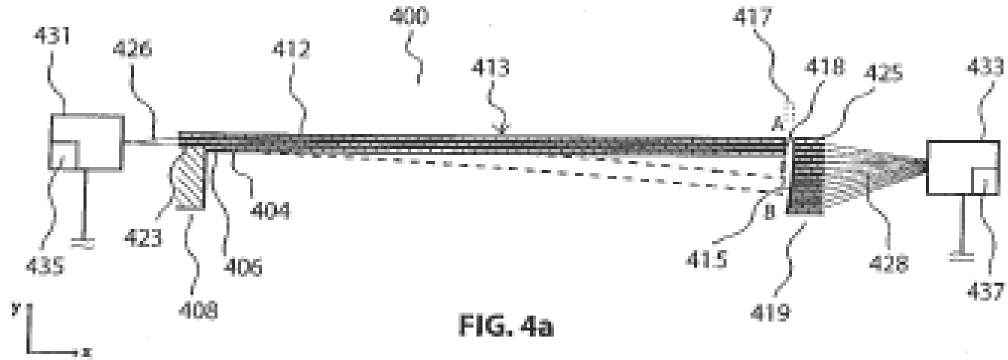


FIG. 4a

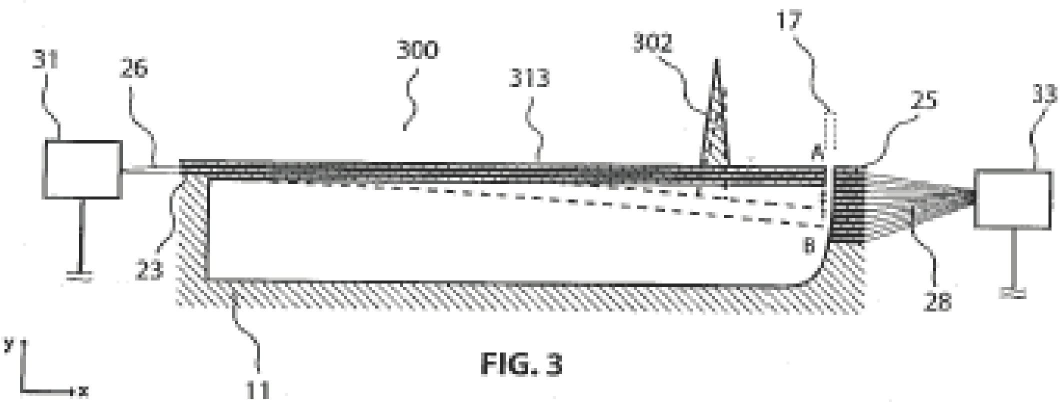


FIG. 3

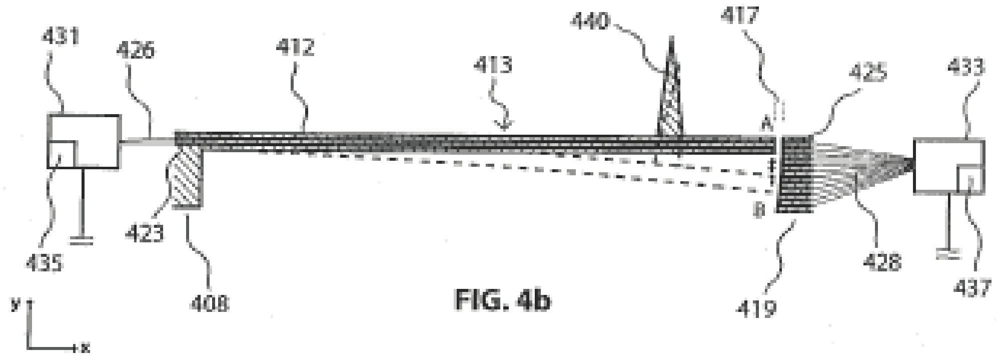


FIG. 4b

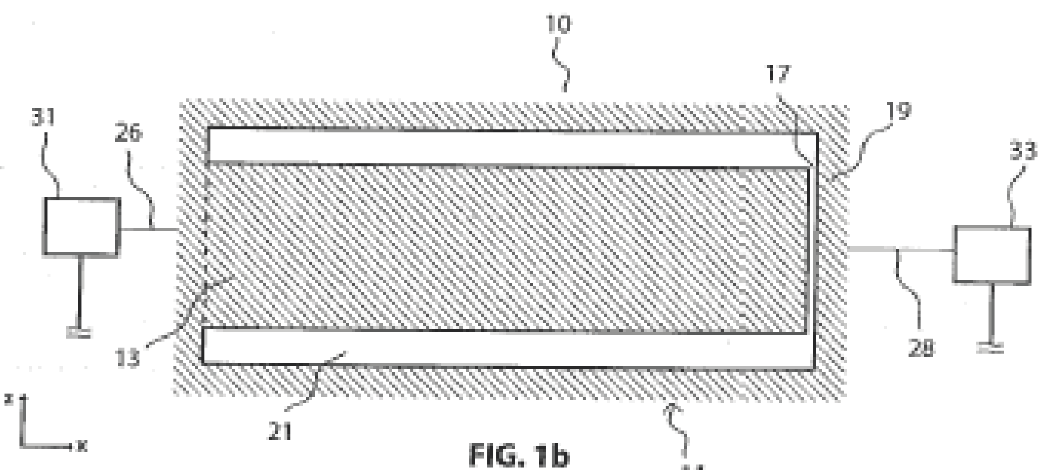


FIG. 1b

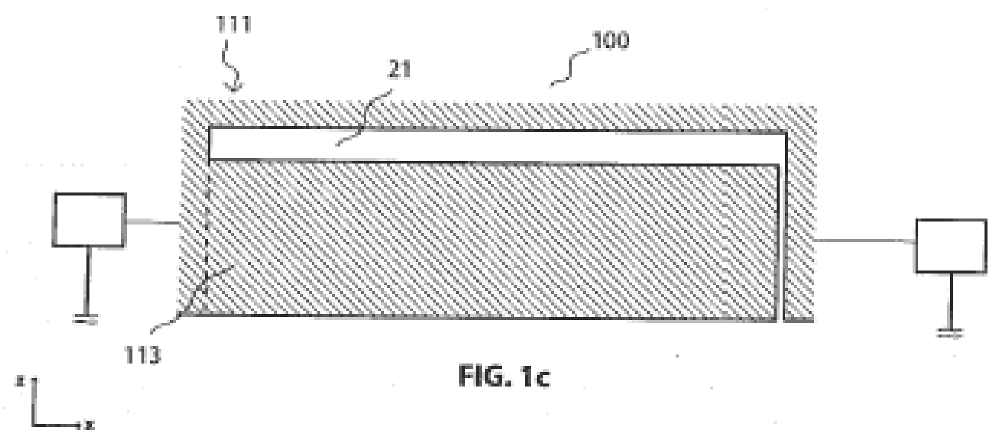
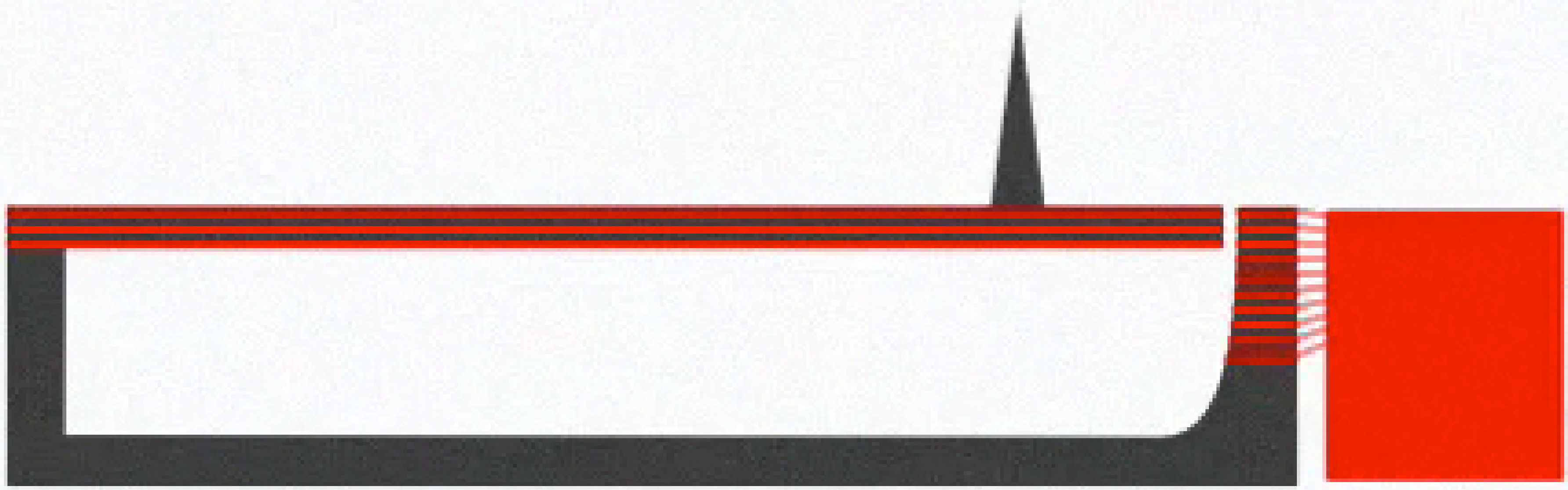


FIG. 1c



Tunneling Photosensitive Cross-Grid Array

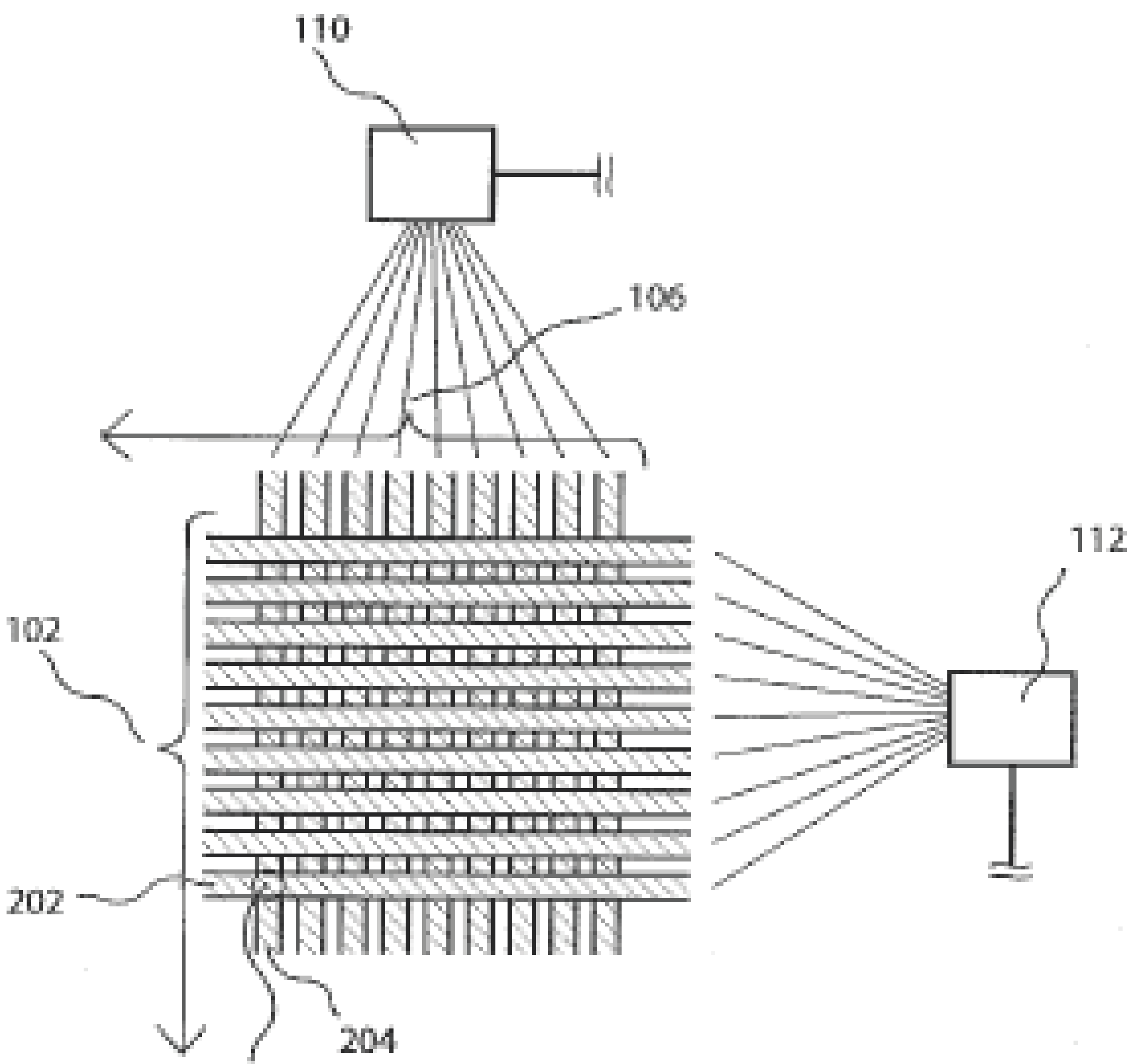
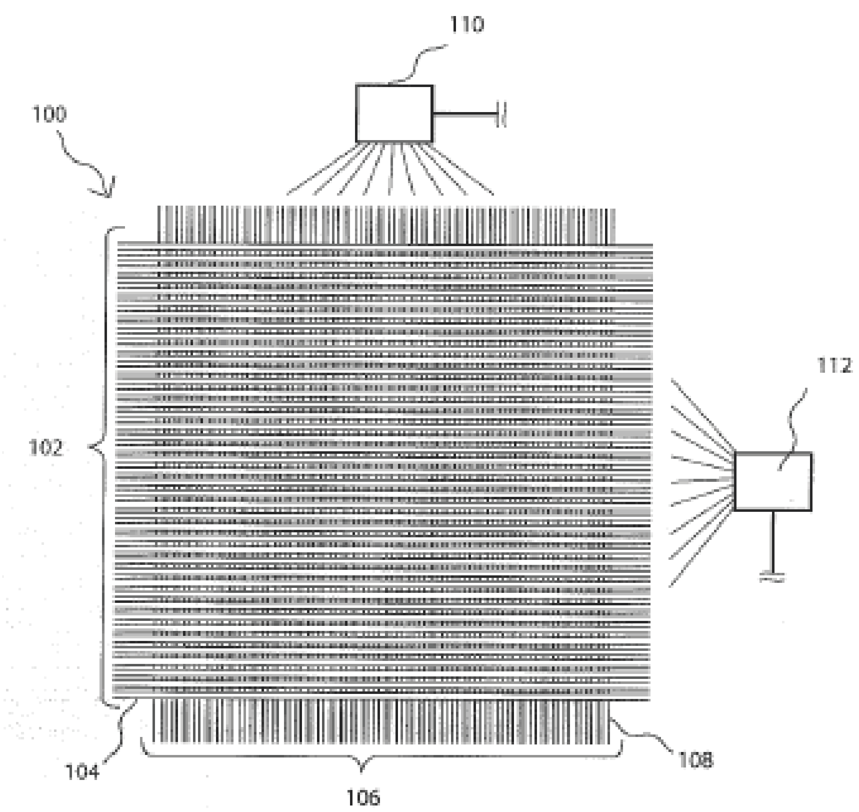
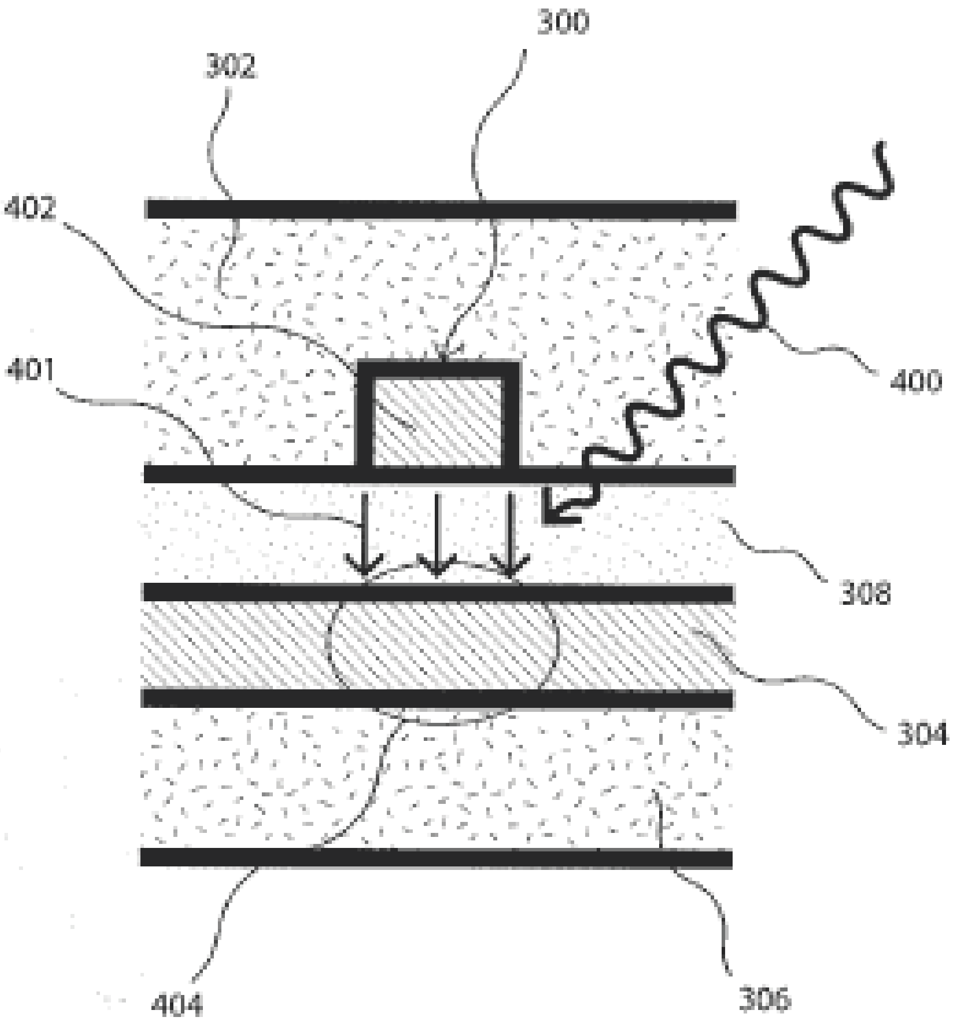
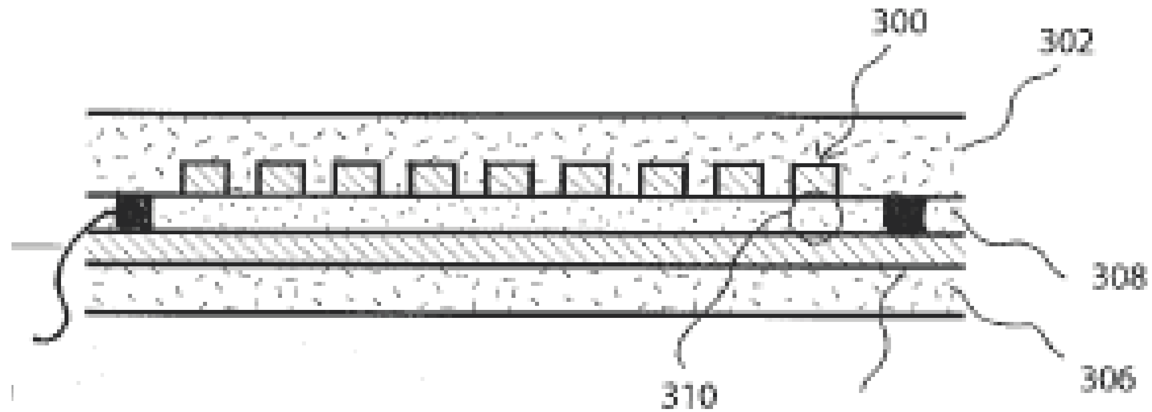


FIG. 2



Tunneling Photosensitive Cross-Grid Array





Tunneling Photosensitive Cross-Grid Array

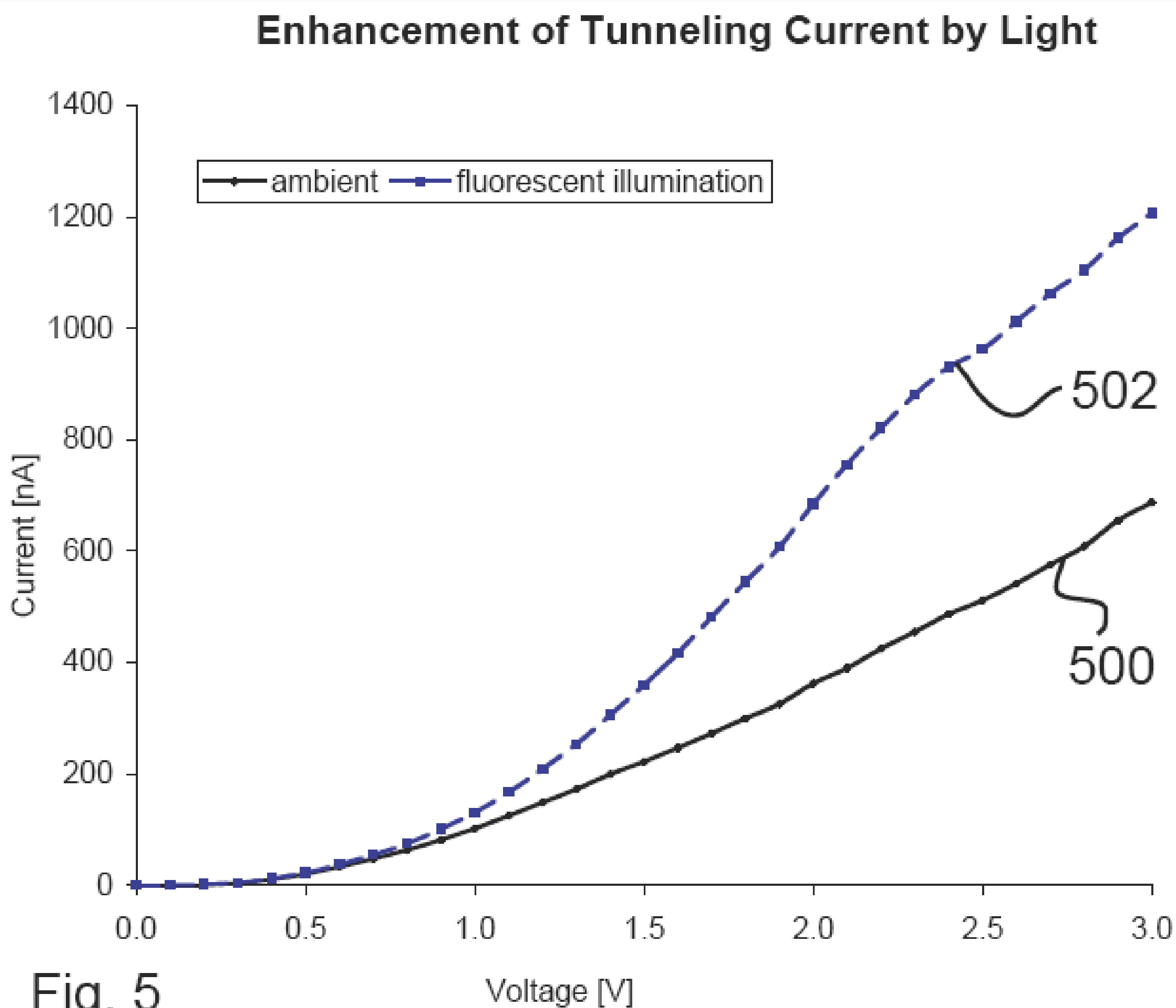


Fig. 5

Motivation:

1. Critical appraisal of concepts
2. Invitation to engage in joint research
3. Suggestions and ideas for research
4. Open problems

Future:

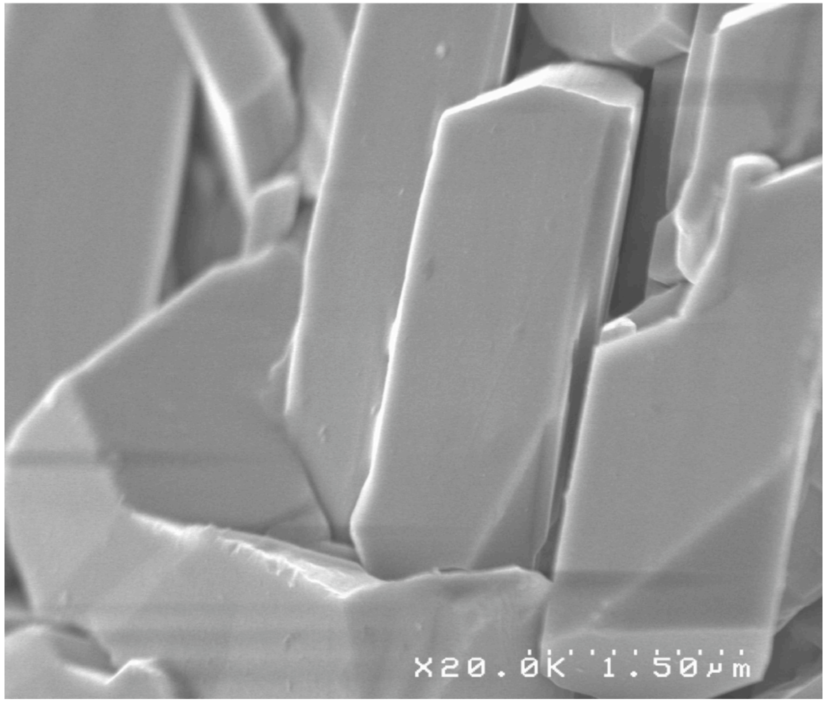
Ubiquitous, pervasive, omnipresent

embedded sensor networks

in 10-15 years time.

Company location and contact information

Dr Marek T. Michalewicz, Founder, CEO & CTO



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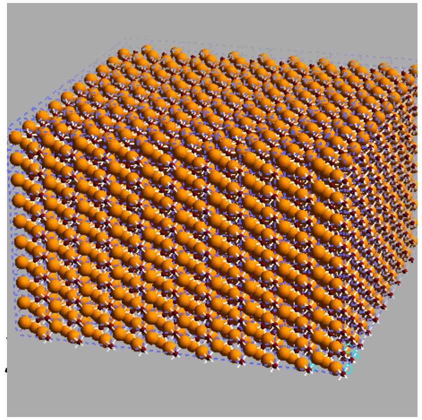
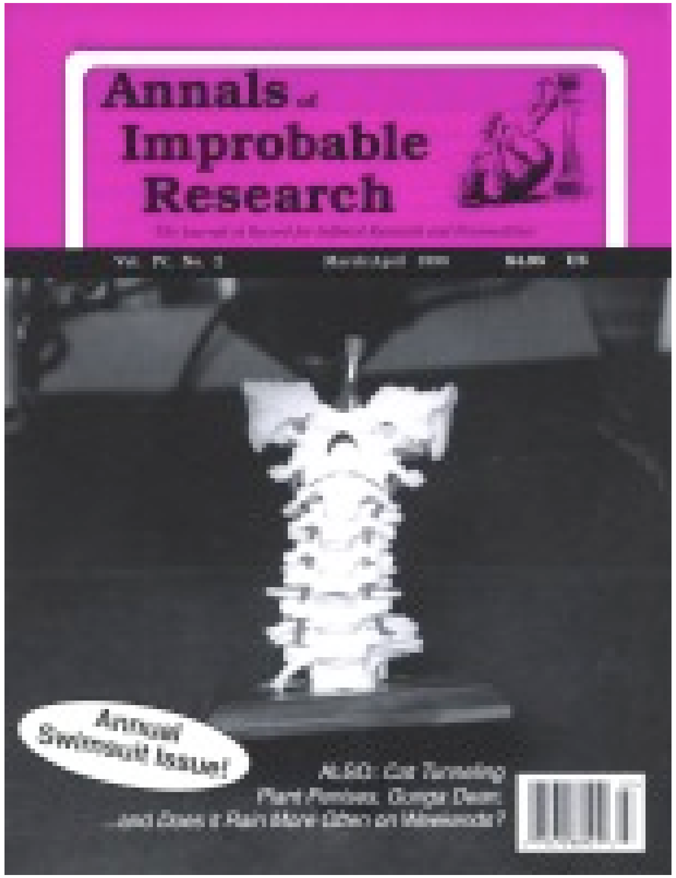
65 Chulia Street, #48–02 OCBC Centre, Singapore 04951



Post Script: Nanocar or “Where fantasy stops and reality begins?”



It started as a sheer scientific joke:

"Nano-cars: Enabling Technology for building Buckyball Pyramids",
M.T. Michalewicz, Annals of Improbable Research,
Vol. IV, No. 3 March/April 1998

Table of Contents for Volume 4, Issue 2, Mar/Apr 1998
Annual Swimsuit issue
Research:

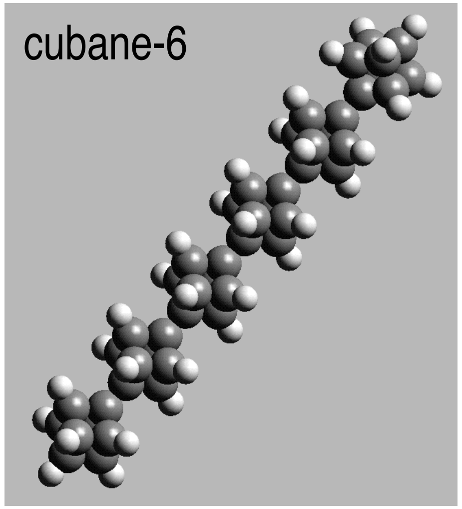
The History of the Universe in 200 Words or Less Translated Ten Times or More
Nano-Cars and Buckyball Pyramids
Penises in the Plant Kingdom
Cat Tunneling
Does It Rain More Often on the Weekends?

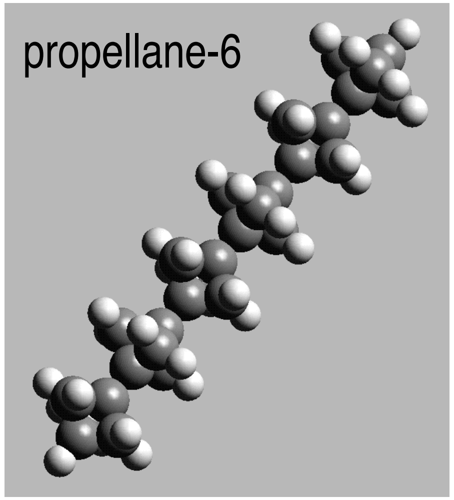
earlier also presented at:

"Nano-cars: Feynman's dream fulfilled or the ultimate challenge to Automotive Industry" Publication abstract: M T Michalewicz, The Fifth Foresight Conference on Molecular Nanotechnology, Palo Alto (1997) Nov 5-8

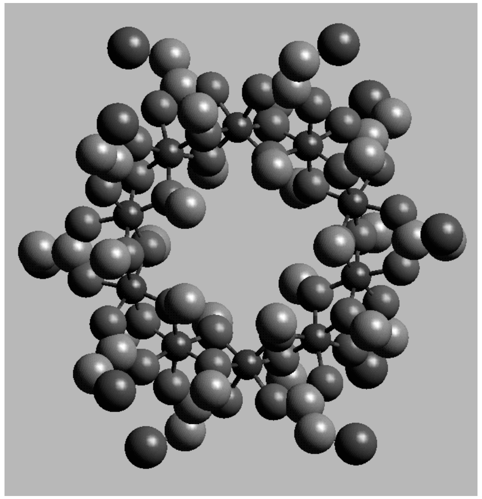
Post Script: Nanocar or “Where fantasy stops and reality begins?”

molecular tinkertoy components





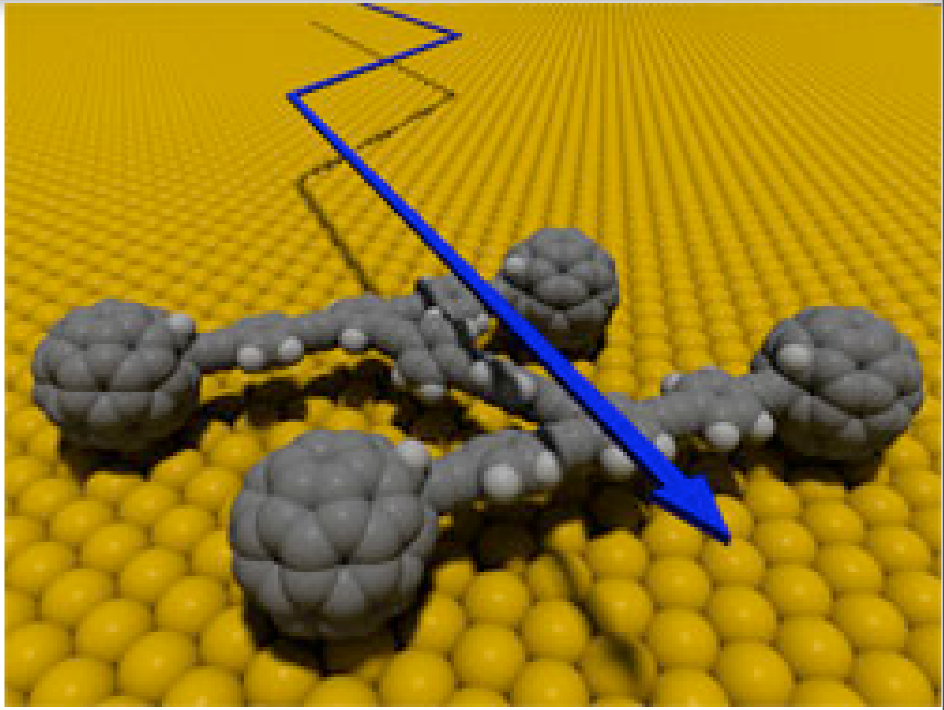
molecular ferric wheel



The concept of a nanocar built out of molecular "tinkertoys" was first hypothesized by Marek T. Michalewicz at The Fifth Foresight Conference on Molecular Nanotechnology, Palo Alto (1997 Nov 5-8) [2]. Subsequently an expanded version was published in Annals of Improbable Research, Vol. IV, No. 3 March/April 1998 [3]. These papers supposed to be a not-so-serious contribution to a fundamental debate on the limits of bottom-up Drexlerian nanotechnology and conceptual limits of how far mechanistic analogies advanced by Eric Drexler could be carried out. The important feature of this nanocar concept was the fact that all molecular component tinkertoys were known and synthetized molecules (alas some very exotic and only recently discovered, e.g. staffenes, and notably - ferric wheel, 1995), in contrast to some Drexlerian diamonoid structures that were only postulated and never synthesized; and the drive system that was embedded in a ferric wheel and driven by inhomogeneous or time-dependent magnetic field of a substrate - an "engine in a wheel" concept.

http://en.wikipedia.org/wiki/Nanocar

Post Script: Nanocar or “Where fantasy stops and reality begins?”



BUT..... 8 years later !!!

10/20/2005

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“Rice scientists build world's first single-molecule car
'Nanocar' with buckyball wheels paves way for other molecular machines.

Rice University scientists have constructed the world's smallest car -- a single molecule "nanocar" that contains a chassis, axles and four buckyball wheels.

The "nanocar" is described in a research paper that is available online and due to appear in an upcoming issue of the journal Nano Letters. ......”