Potentials and Progress in Quantum Technology for NASA Missions

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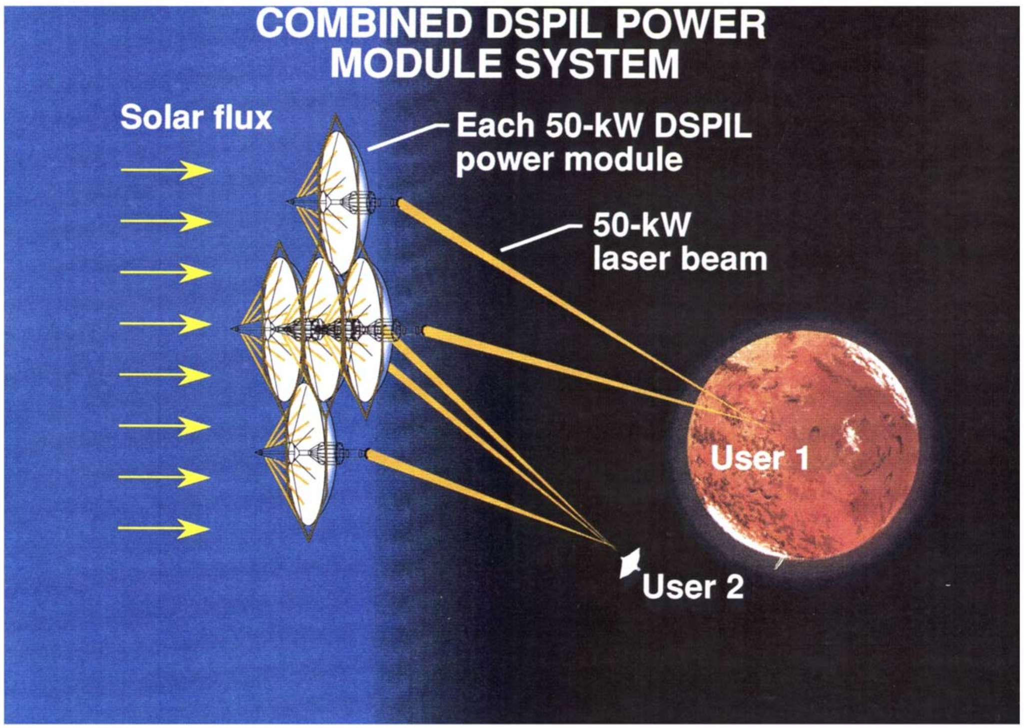
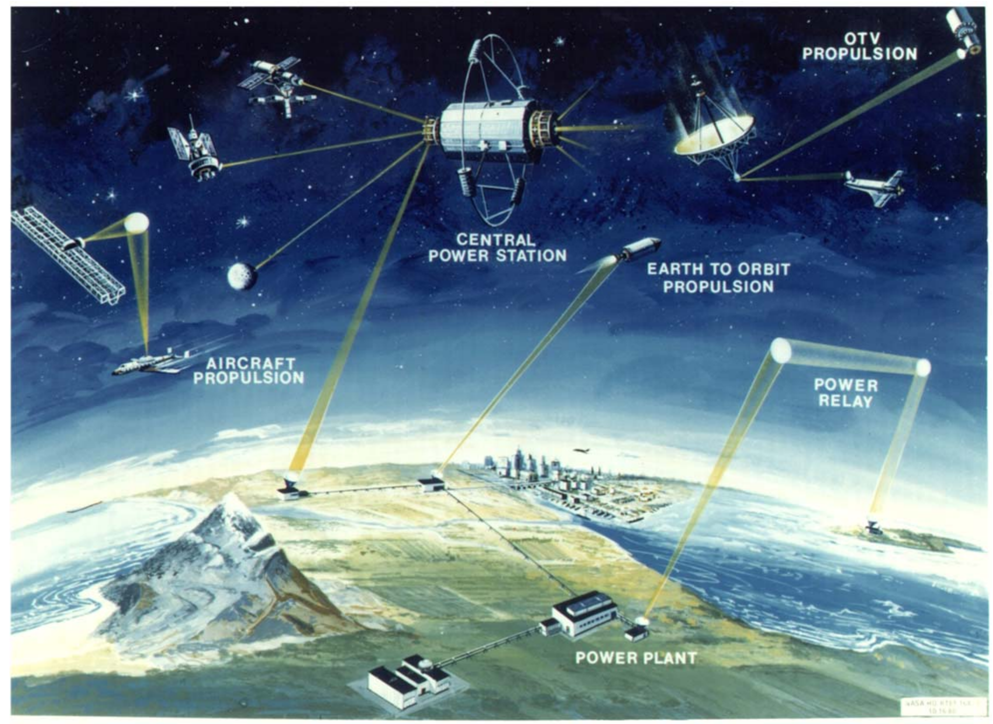
Challenges in NASA Missions

- Propulsion
  - High I_{sp} Fusion, MPD, Ion, Hall thrusters, etc.
  - High Thrust New propellants, Nuclear thermal
- Power
  - High Power Density NTAC, Nuclear Dry Cell, Portable Fusion Reactor, etc.
  - Wireless Power Transmission < 10 miles or > 10^5 miles
  - Long lasting without Refueling > years
- Telemetry
  - High Data Rate > GB/s
  - Processing Power > Peta-flops
- Probe & Sensors
  - Sensing Materials for DIR, FIR, EIR, DUV, VUV, Soft X-ray, X-ray, γ-ray, etc.
  - Magnetic, Electric, Gravity, Casimir-Polder Force, etc
  - Intelligent sensors

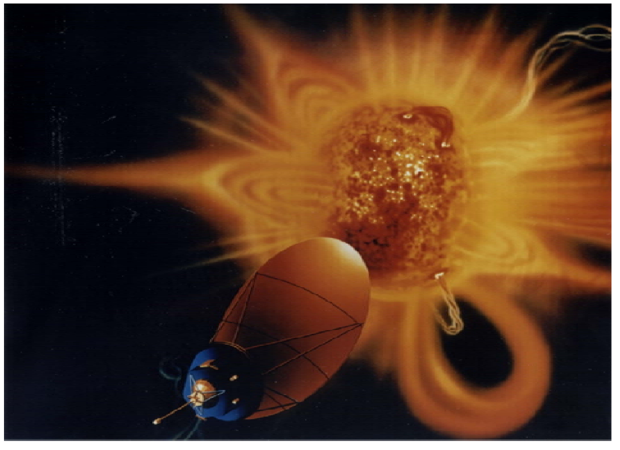
Power Satellite and Wireless Power in Space
- R&D in 80s -

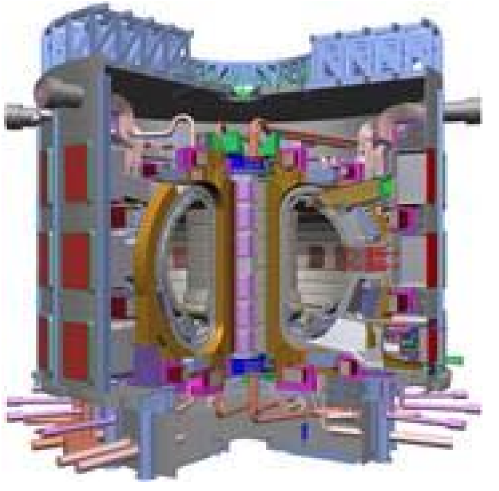


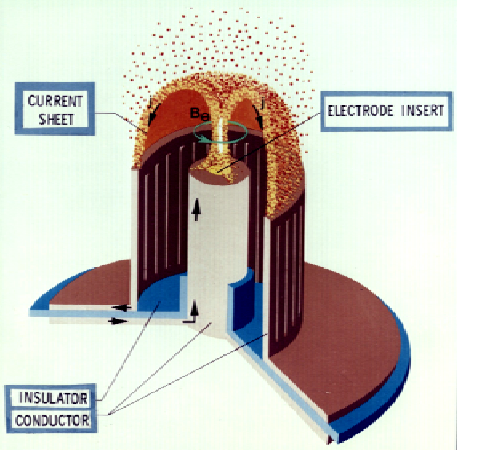


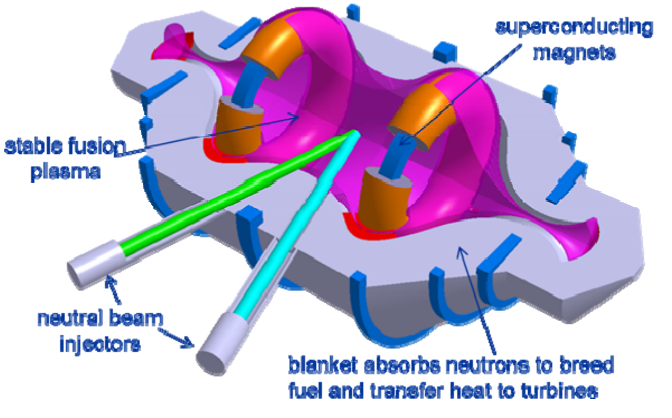
Lab demo with $t\text{-}C_4F_9I$:   50 W cw with < 1000 suns

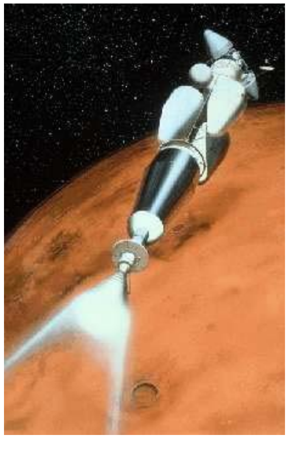
Fusion Reaction Power & Propulsion



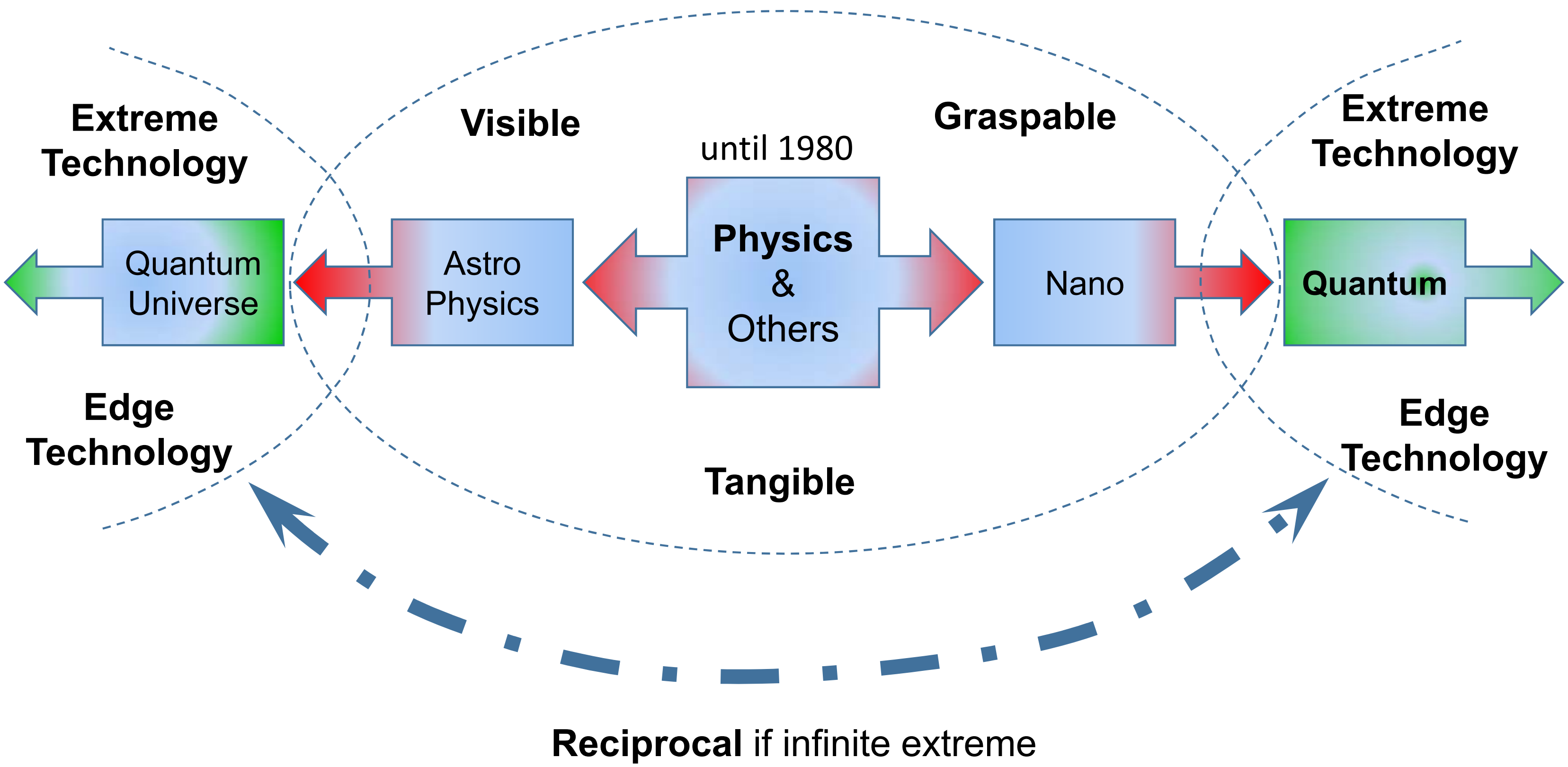




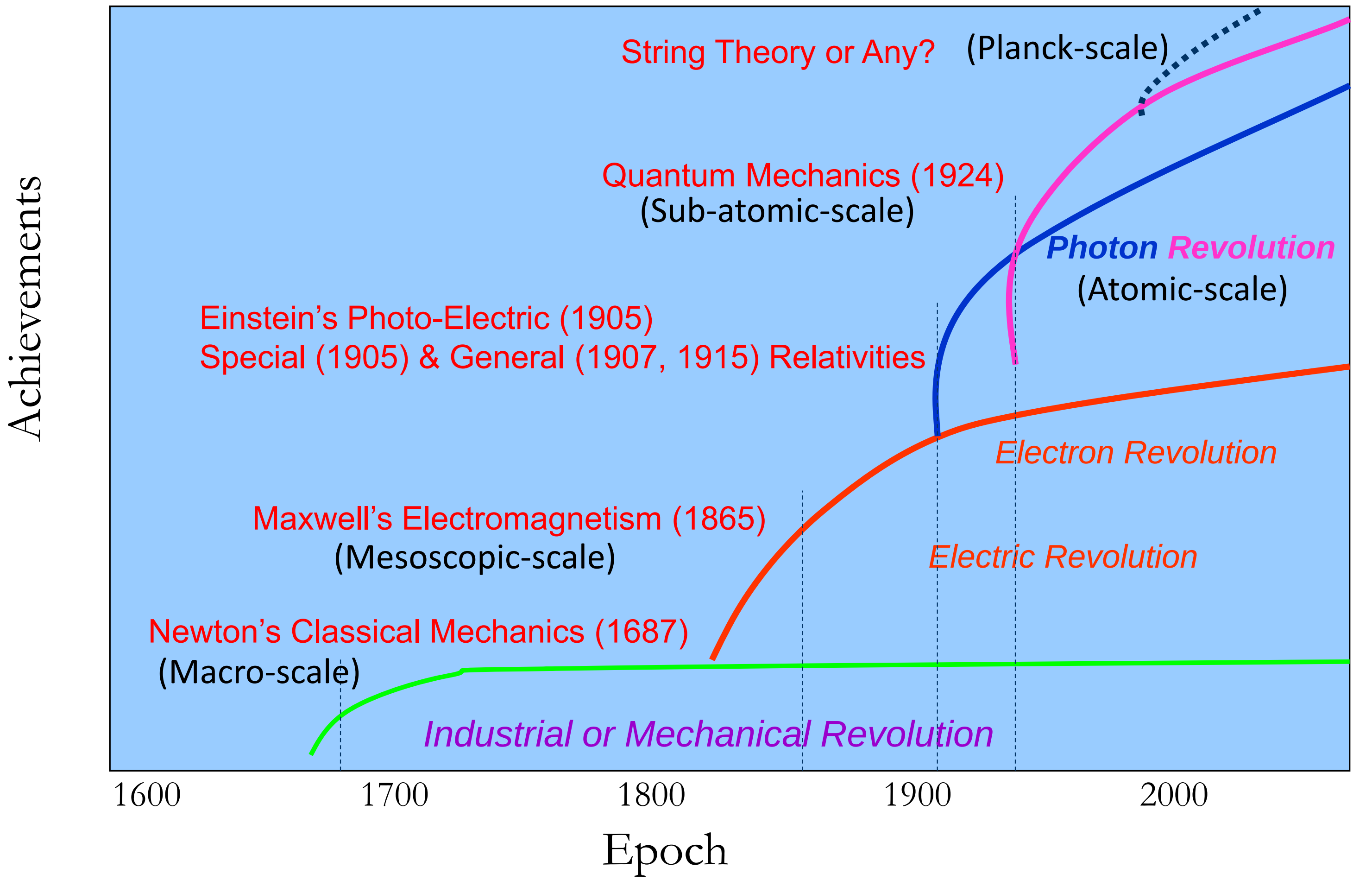




Why Are We Here?



Progress in Scientific Knowledge

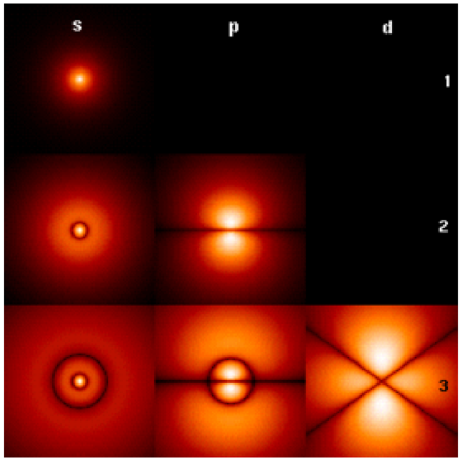


Definition of Quantum Technology (QT)

✓By Quantum Physics:

- Discreteness where continuity breaks down and so "probabilistic"
- Lack of deterministic causality
- Localism dictates
- Media: Fermion and Boson
- Duality means the Ambiguity between wave-particle
- Uncertainty Principle: Less measurable in momentum-space

Probability Space

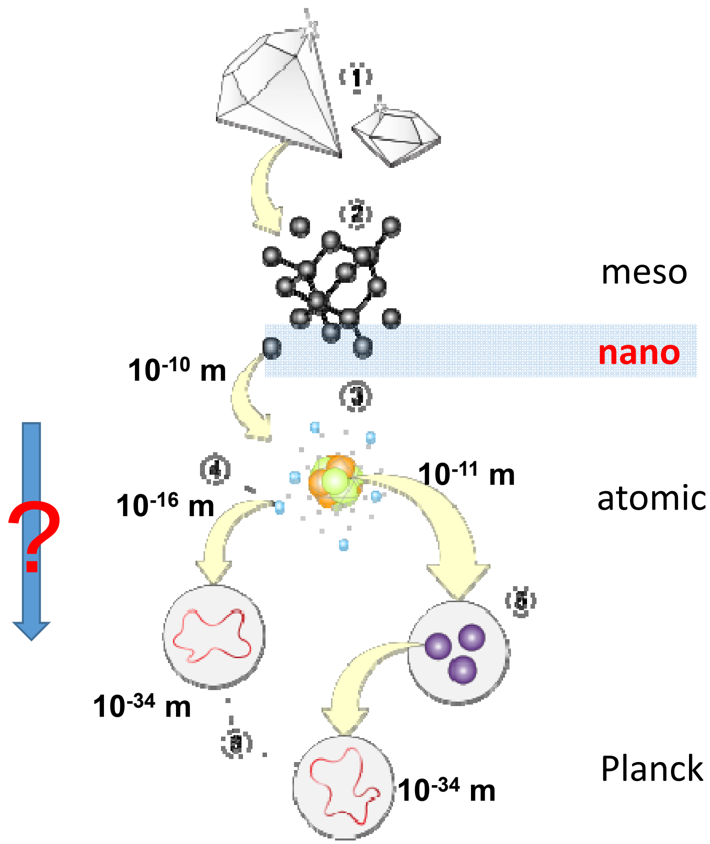


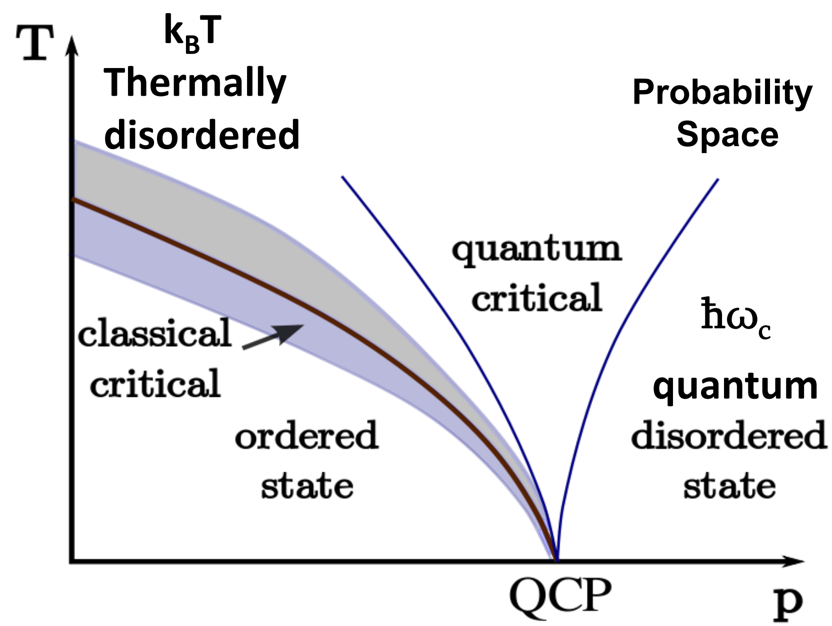
The QM underlies many fields, such as condensed matter physics, solid-state physics, atomic physics, molecular physics, computational physics, computational chemistry, quantum chemistry, particle physics, nuclear chemistry, and nuclear physics.

✓By Dimensional Scale:

- Is the advent of QT a natural consequence after the NT?
- Is anything beyond nano (10^{-9}) meter or nano-scale?
- Is it between the nano-scale and Planck scale (10^{-33} cm)?

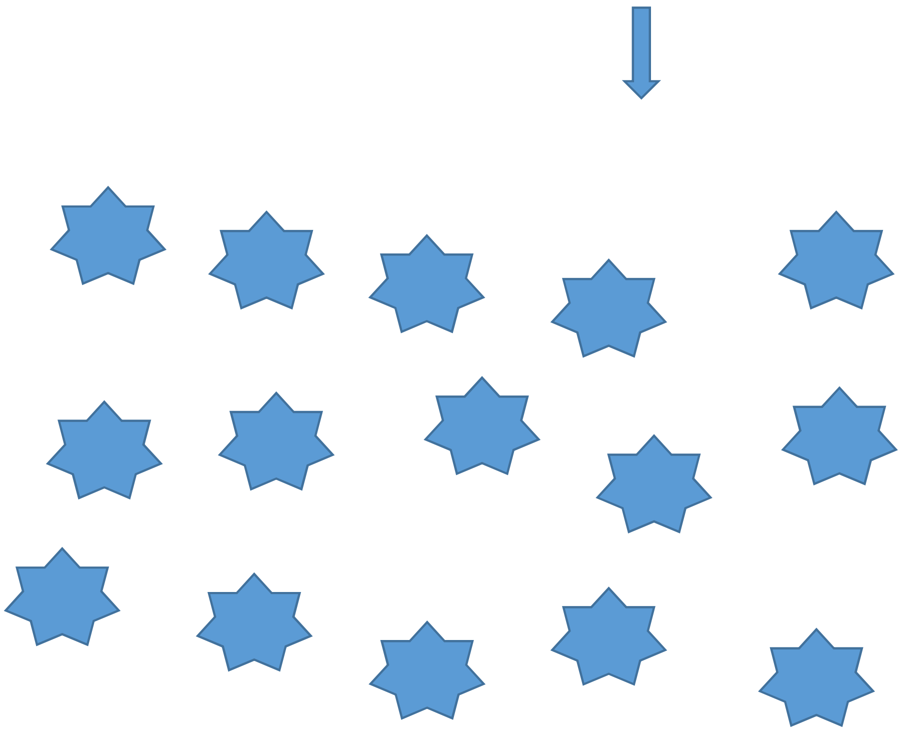
Quantum Technology – pico or femto scales?

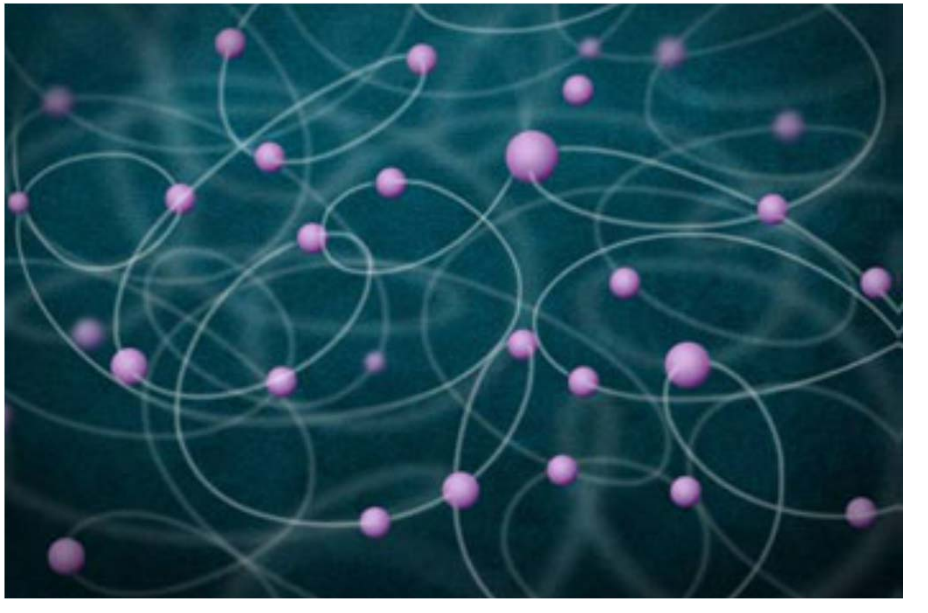




Quantum Entanglement of Atoms

(Nature March 26 Issue by Robert McConnell et al. of MIT)





Definition of Quantum Technology (QT)

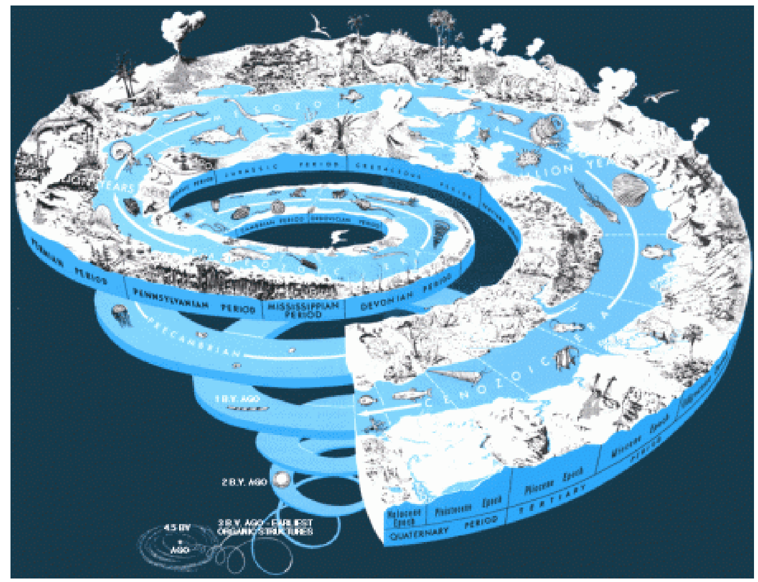
✓ By Time Scale:

- Does the spontaneity or transiency dictate in quantum domain?

  Within action, no “Nowness” but “Spontaneity” and “Transiency”. The spontaneity is related to ontological state while the transiency to quanta with causality.

- Is QT anything beyond pico (10^{-12}) or femto (10^{-15}) second? Time is no longer “independent variable”, but dependency to quanta (transiency).

- What is the state, including time less than Planck time (5.391×10^{-44} s)?



Einstein Theories of Time

Definition of Quantum Technology (QT)

QT is started from Quantum Mechanics, and gradually branched out to:

- Quantum Entanglement
- Quantum Tunneling
  - ✓ Quantum Electronics
  - ✓ Quantum Information
  - ✓ Quantum Simulator
  - ✓ Quantum Computing
  - ✓ Quantum Cryptography
  - ✓ Quantum Measurement and Metrology
  - ✓ Quantum Sensing
  - ✓ Quantum Optics and Atom Optics
  - ✓ Quantum Imaging
  - ✓ Quantum Cosmology – Quantum Gravity
  - ✓ Plasmonic modulation

- ✓ Quantum complex systems, networks and cellular automata
- ✓ Quantum electromechanical systems
- ✓ Quantum optomechanical systems
- ✓ Quantum machines, engineering and nanorobotics
- ✓ Quantum control theory
- ✓ Quantum thermodynamics
- ✓ Quantum metamaterials
- ✓ The effect of Casimir forces on micro- and nano-electromechanical systems
- ✓ Quantum biology
- ✓ Hybrid quantum systems
- ✓ Quantum Energetics

What possible with QT

- Back to the Past or go to the future by Q-Teleportation
- Concurrent Information Sharing thru Q-Information based on Q-Entanglement
- String (or M) Theory (?) within Planck's scale (10^{-33} cm)
- Time is independent or dependable variables; t_{domain}, t_{field}, or t_{energy}
- Superposition (Separation of fundamental reality) of Multiple possibilities
- Self-collapse of wave function: multiple to single eigenstate (by observation) by superposition
- Rydberg atoms (high dipole) for Q-computing
- Surface Dirac state – massless electron is a mirror image of electron (or called Dirac fermion)
- Activation Loading for quantum state modification
- Pumping High Power Density from Quantum Frame

Status and Facts of QT

Journals:

- EPJ Quantum Technology, as a Springer Open journal, Jan. 31, 2014

Conferences:

- There were 104 world-wide events on quantum technology in 2015 only.
- 1st NASA Quantum Future Technologies Conference, NASA Ames Research Center, Jan. 17-21, 2012
- Quantum Technology Blue Sky Team Workshop at NASA Langley, Nov. 17-18, 2015

Organizational Efforts:

- Quantum Technology Committee at NASA Langley in 1998
- Quantum Technology Initiative (> £100M) , England, 2014
- Quantum Technology Blue Sky Team at NASA Langley, 2015
- Quantum Manifesto for Europe, €1 bn in funding for “Flagship-scale Initiative”, March 17, 2016

QT – Done and Planned at NASA LaRC AEEM Lab

Done:

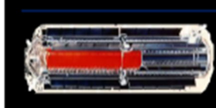
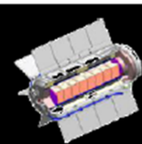
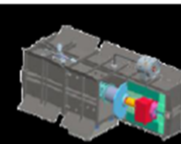
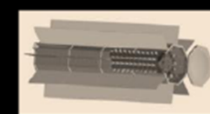
- Beam Steering by QCSE and KKR
- Quantum Apertures
- Light Scanning
- Spectral and Refractive Index Shifter
- Micro-Spectrometer (Fresnel Diffraction)
- Quantum-well PV
- Materials for Quantum cascade THz lasers

Planned:

- Nuclear Photo-Electron Avalanche Cell (NPEAC) Device
- Quantum state modifications

Power Sources for Deep Space Exploration

NASA Goal: **100 W/kg**

					
	GPHS-RTG Past	MMRTG Present	ASRG In Development	ARTG Future	TPV Future
Electric Output, BOM, W_e	285	125	~140-150	~280 to 420	~38-50
Heat Input, BOM, W_e	4500	2000	500	3000	250
RPS System Efficiency, BOM, %	6.3	6.3	~28-30	~9-14	~15-20
Total System Weight, kg	56	44.2	~19-21	~40	~7
Specific Power, W_e/kg	5.1	2.8	~7-8	~7-10	~6-7
Number of GPHS Modules	18	8	2	12	1
GPHS Module Weight, kg	25.7	12.9	3.2	19.3	1.6
^{238}Pu Weight, kg	7.6	3.5	0.88	5.3	0.44

QT - Nuclear Photo-Electron Avalanche Cell (NPEAC) Device

Potentials:

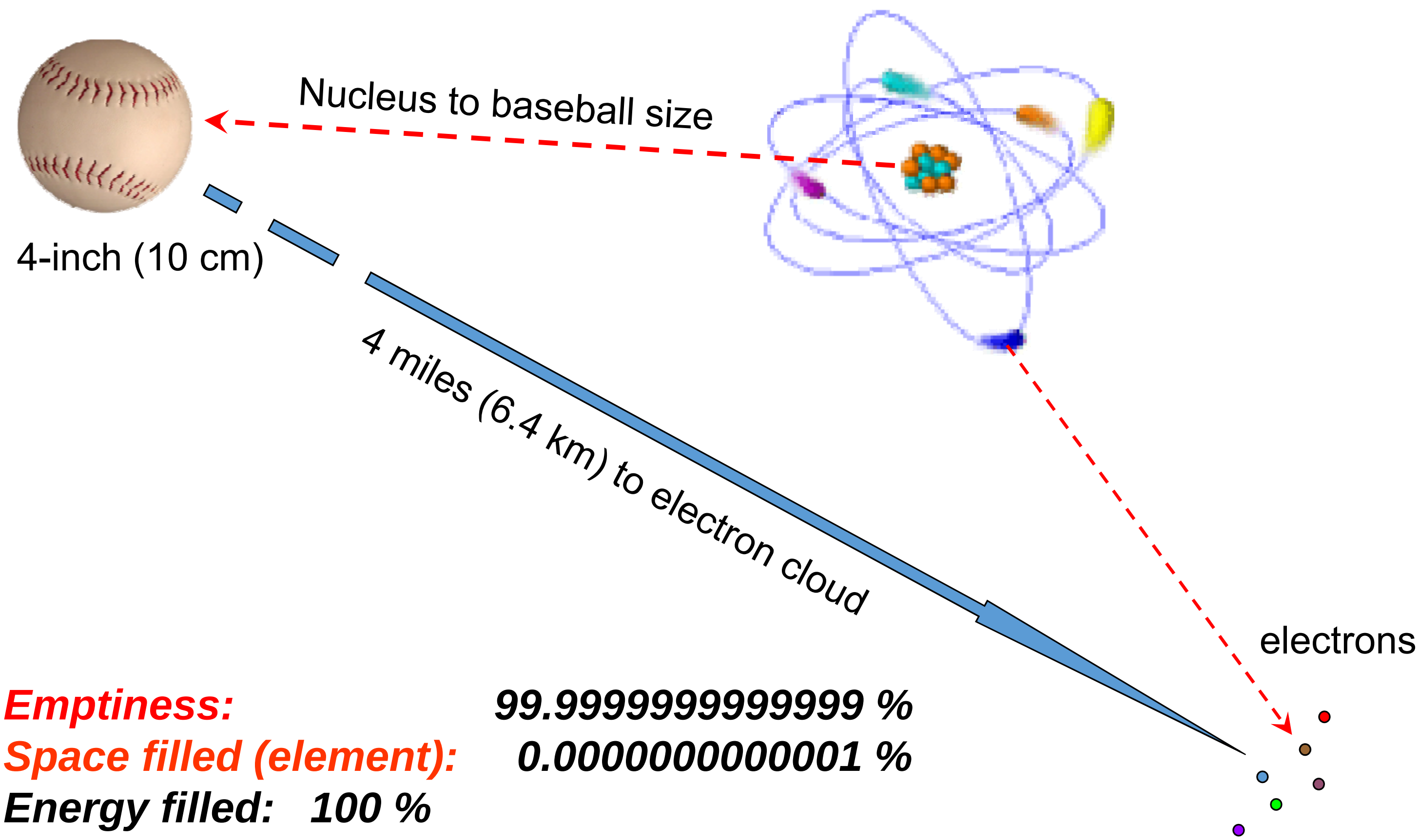
- Quantum level transitions (bound-to-free and free-to-free) of intra-bands
- Avalanche electrons through thermionic gap

Benefits:

- Electron avalanche by a huge number of electrons from Intra-bands
- High energy sources lead to high energy density systems
- Simple process: Thermionics of photo-electrons
- Long term operation with single loading of energy source over 30 years
- High power density, > 1 kW/cm^3

Energy in Quantum Domain

Energy Filled Universe



Emptiness: ***99.9999999999999 %***

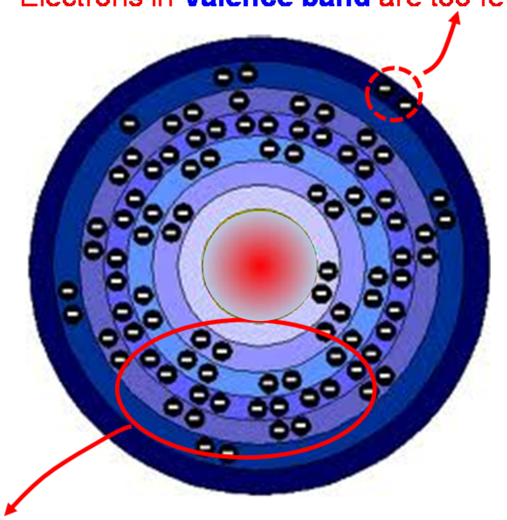
Space filled (element): ***0.0000000000001 %***

Energy filled: 100 %

Available Electrons as a Source for Energy Harvesting

Conventional Energy Conversion Cycles

Electrons in **Valence band** are too few, **3 C/cm³**



Electrons in **Intra-bands (IB)** are plenty, **10^5 C/cm³**

NPEAC Energy Conversion Cycles

Potential Well

- Valence Band ~ **3 C/cm³**
  (p-n Junction: Brillouin Limit)
- Intra Band ~ **10^5 C/cm³**

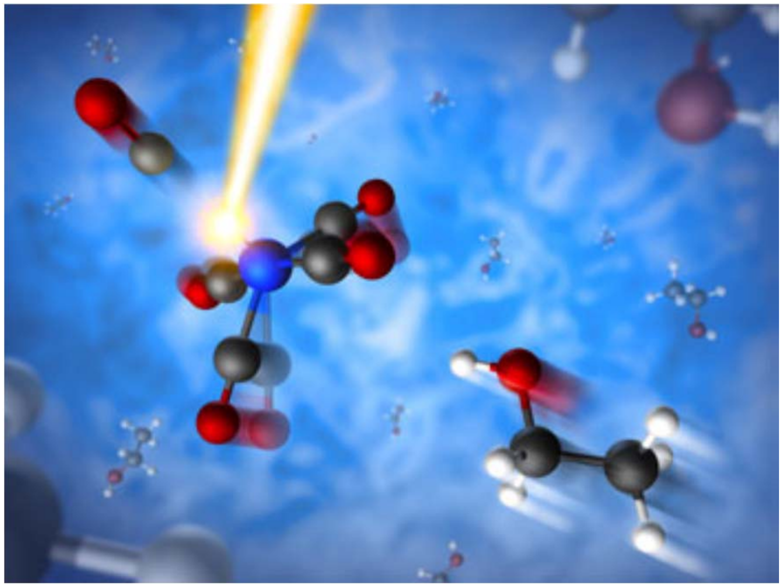
QT - Quantum State Modifications

Potentials:

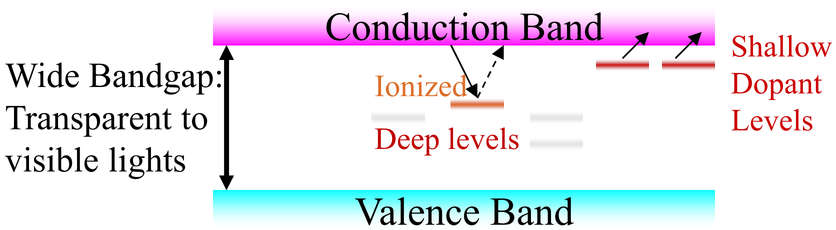
- Quantum state modifications possible by certain means

Benefits:

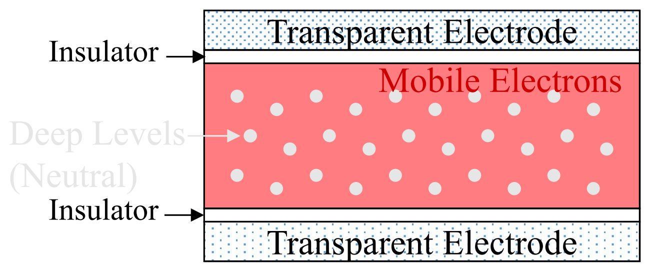
- New catalytic effects: lower activation energy leads to transition energy
- Alternatives to rare earth elements
- Quantum assembler, replicator, or self-cloning (non-Hamiltonian)



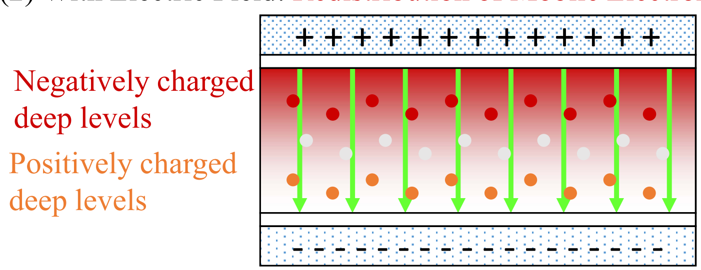
Smart Optics
Distribution of Carriers and Ionization of Deep Levels



(1) Without Electric Field



(2) With Electric Field: Redistribution of Mobile Electrons

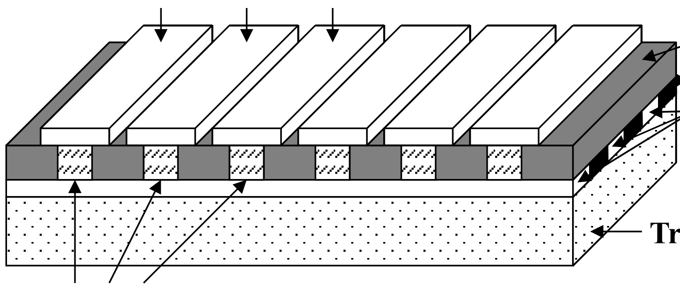


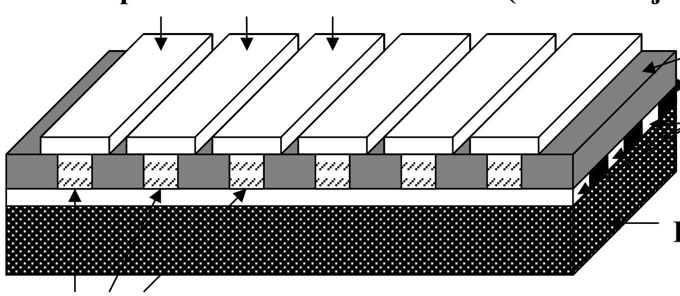
In the wide band-gap semiconductor, the visible lights penetrate the layer. Shallow dopant levels give mobile carriers to the conduction band or valence band. Due to the crystal imperfection, the existing deep levels can capture or emit the mobile charges. They can be ionized with the loss or capture of the carriers.

(1) Mobile electrons distributed uniformly in the media layer. Most of the deep levels are neutral in this state.

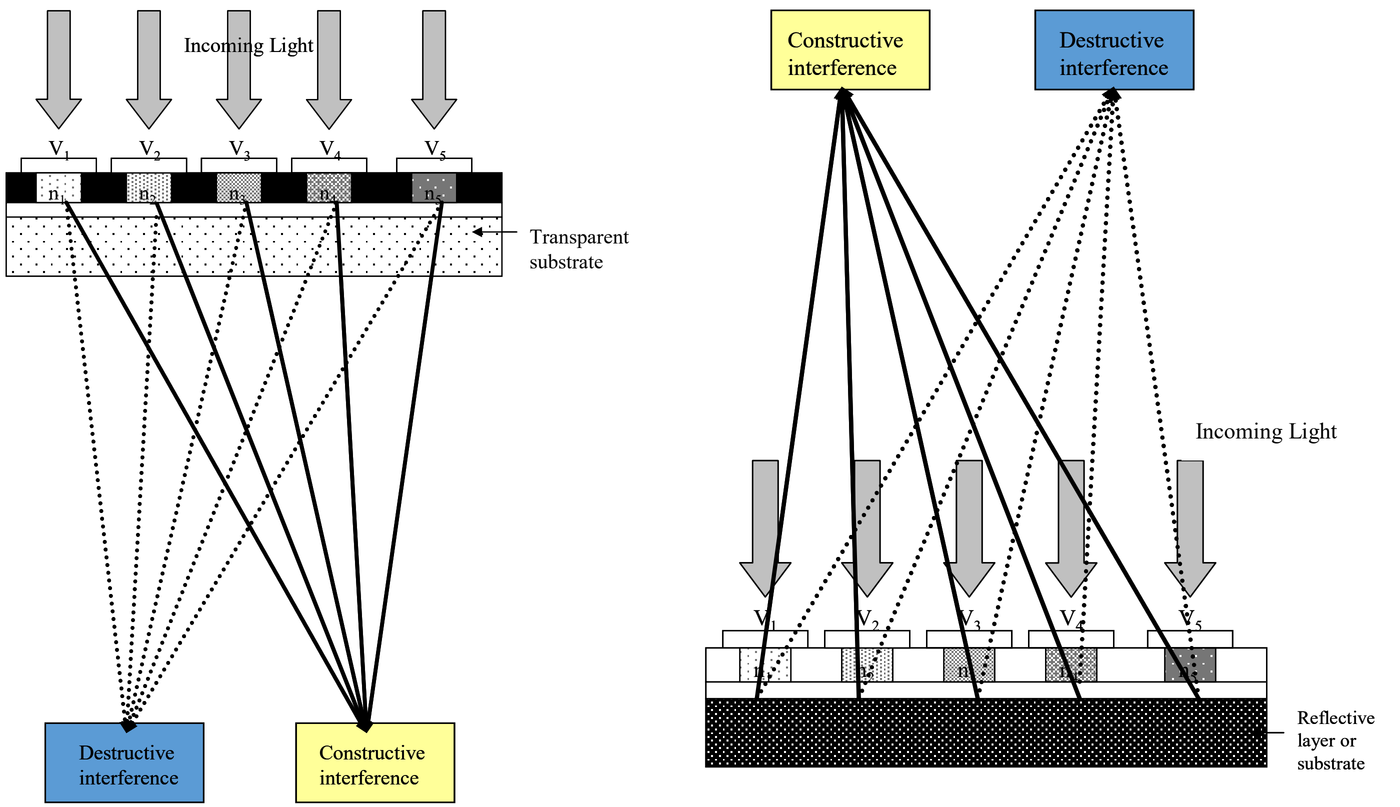
(2) With the strong electric field, the mobile carriers (electrons in the picture) are re-distributed and the deep levels are ionized and form new color centers. **They change the absorption coefficient and the index of refraction.**

Integrated Smart Optics Device Configuration



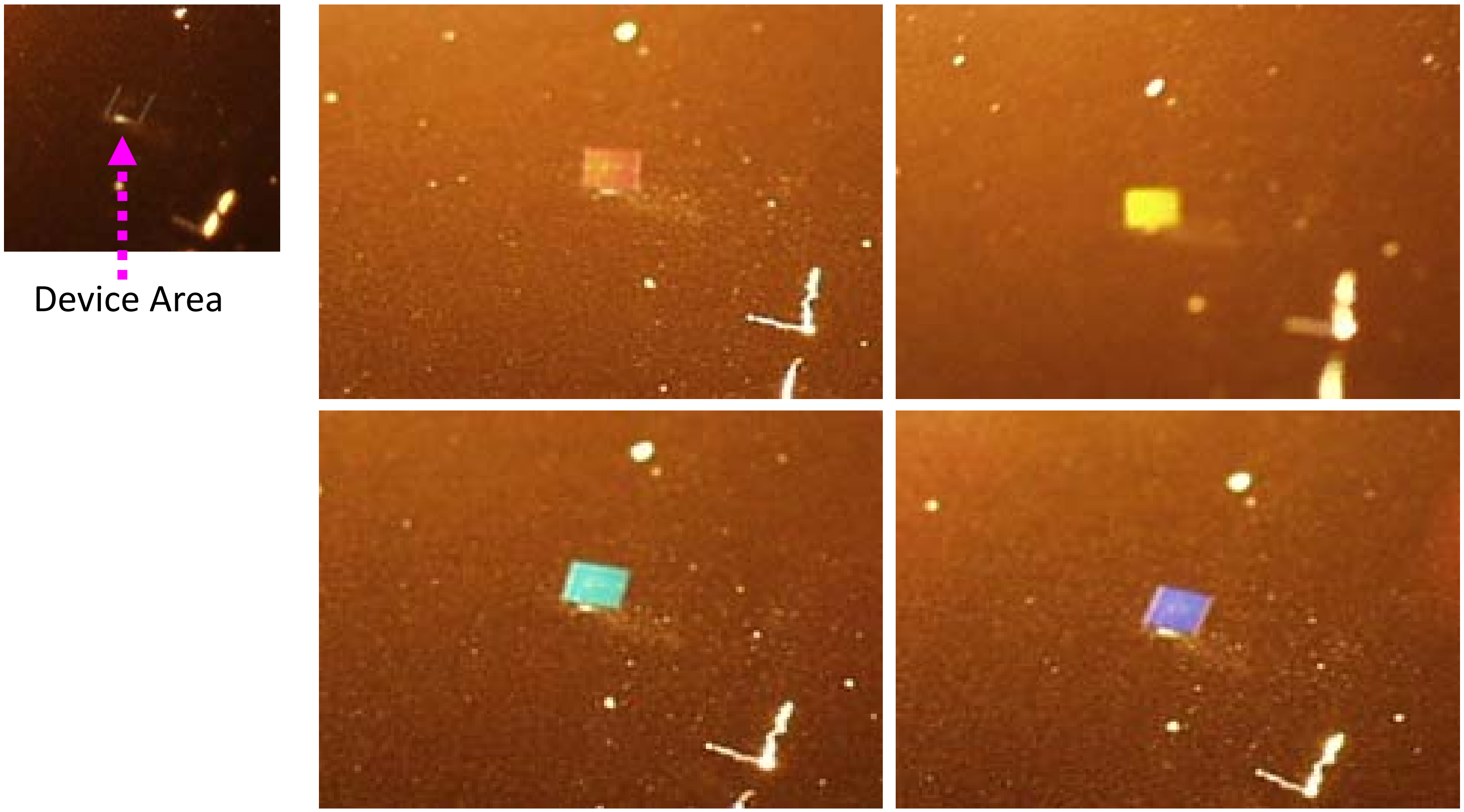


Integrated Smart Optics Device



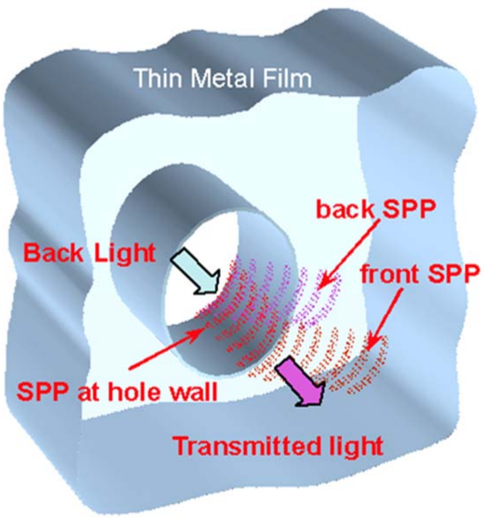
Different electric and/or magnetic field on each quantum hole device results in the different index of refraction. Therefore, the exit photons have different phases, depending on the applied electric and/or magnetic field.

Performance of Integrated Smart Optics Device



Our research goal is to make a device that can change the spectral response of light without changing the angle but changing the applied electric & magnetic field.

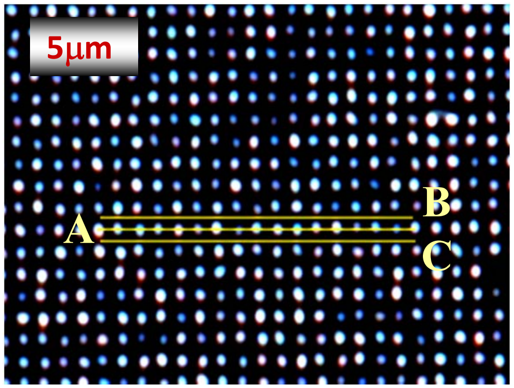
Plasmon Enhanced Transmission



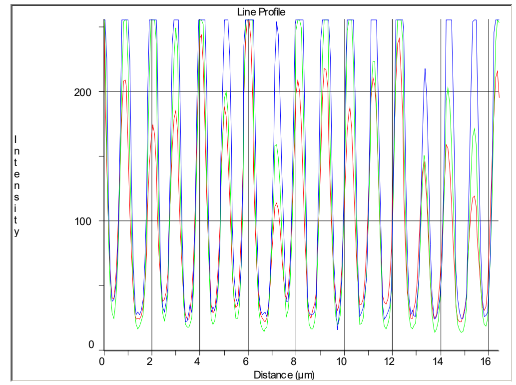
Transmission through a quantum aperture

- Metal surface has the collective movement of the electrons at the surface; it is called the surface plasmon, propagating on the surface only.
- The skin-depth of a good conductive metal is very shallow; a hundred nanometer of the metal film is enough to block the light penetration.
- The transmission of the photons through a hole smaller than $\lambda/4$ is controlled by the surface plasmons in the hole.
- The incident light generates the back surface plasmon. Surface plasmon propagates through the surface of the hole. In the front side, the surface plasmon radiates the light again.
- Other experiments indicate there is no enhanced transmission of a long wavelength light through tiny holes in Ge, where there is no plasmon. Only good conductor surface has plasmon.

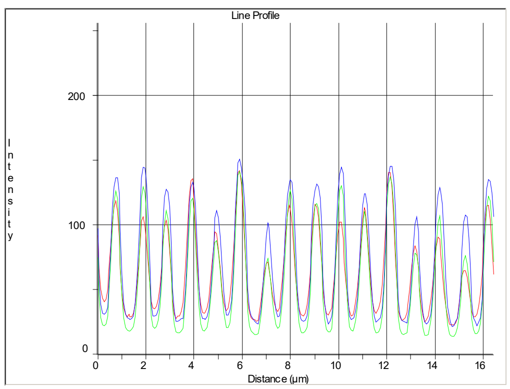
Microscopic Spectral Distribution From Individual Quantum Aperture with 200nm Diameter



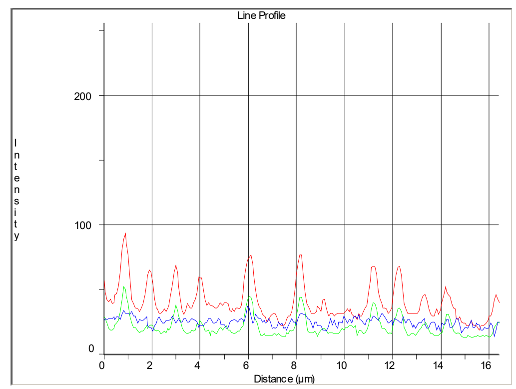
Transmitted Light



Center Line A: Strong Blue



Sum of Area between B and C: Close to White Light with Blue



Boundary Line B or C: Dark Red

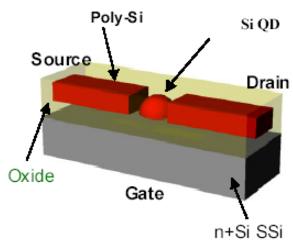
Applications of Quantum Apertures

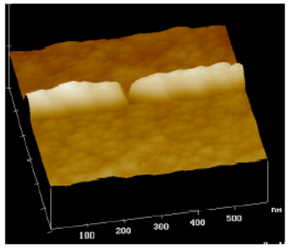
- On-off switching, dimming, and spectral selection of optical light transmitted through the array of holes
- Back-lighted flat-panel display*
- Optical diodes*
- Variable gratings and filters*
- Surface plasmon resonance (SPR) spectroscopy
- Optical window for sensors and probes
- Sub-wavelength photolithography
- Raman spectroscopy
- Monochromators
- Near-field scanning microscopes

Note: Proprietary information

Optical Diode Concept with FIGLV

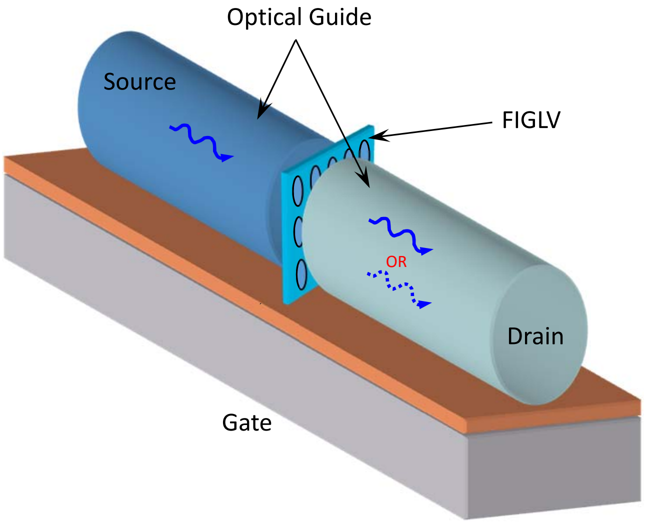
QD Diode Concept
(Cornell Univ)





Device geometry for electronic characterization of a single Si QD and an AFM cross-section of the electrodes (n++ Si) prior to the nanocrystal deposition.

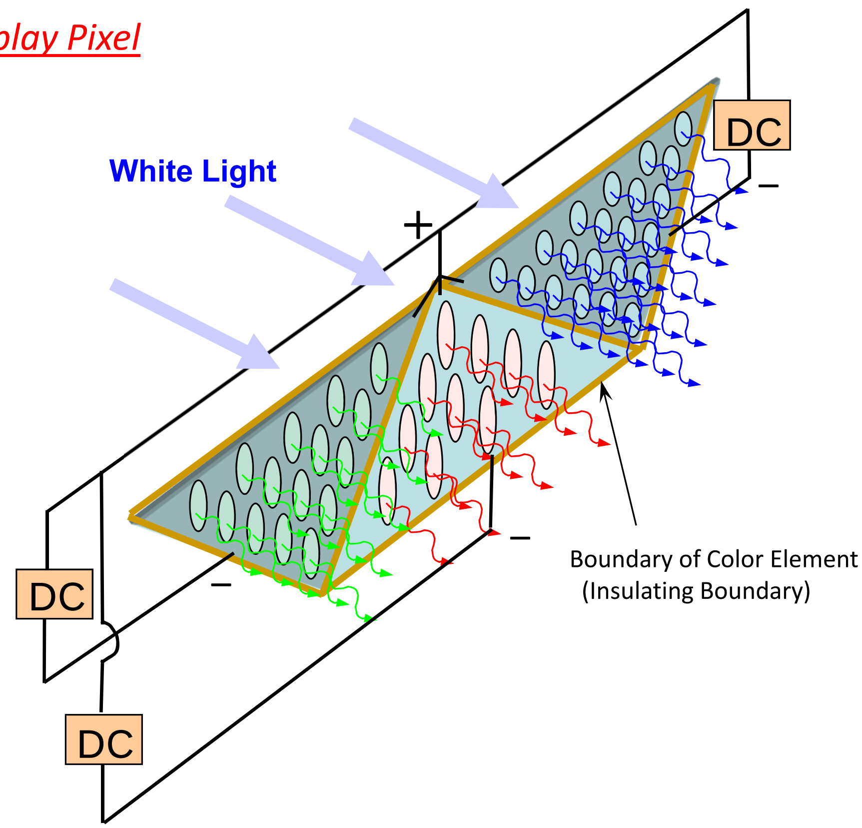
FIGLV Optical Diode Concept
(NASA Langley)



Note: Proprietary information

FIGLV for Display Applications

FIGLV Display Pixel

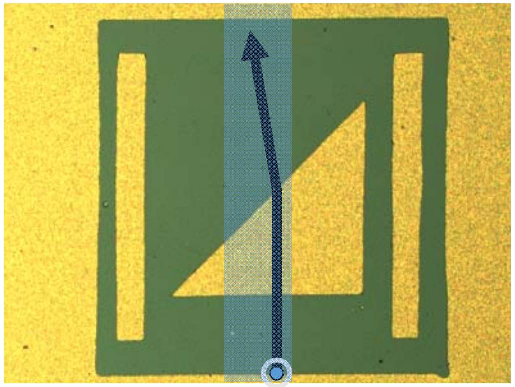


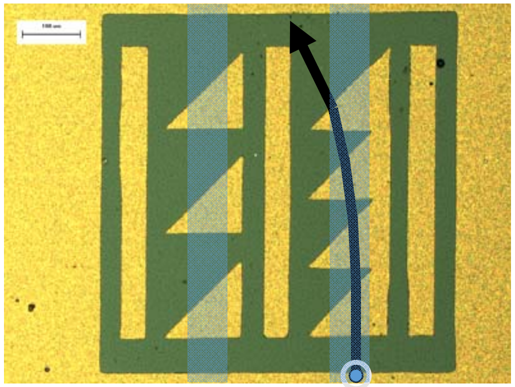
Note: Invention disclosed

Operation of Light Scanning Control Device (Ferroelectricity)

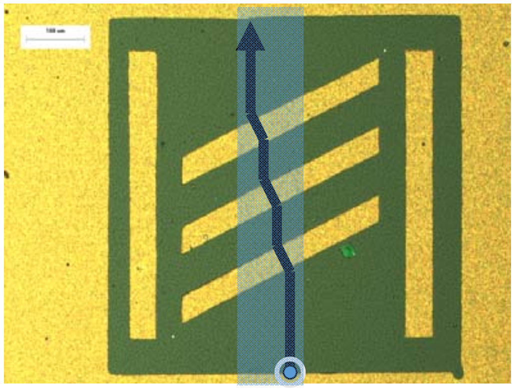
E-Beam Lithography

Single Beam Scanner



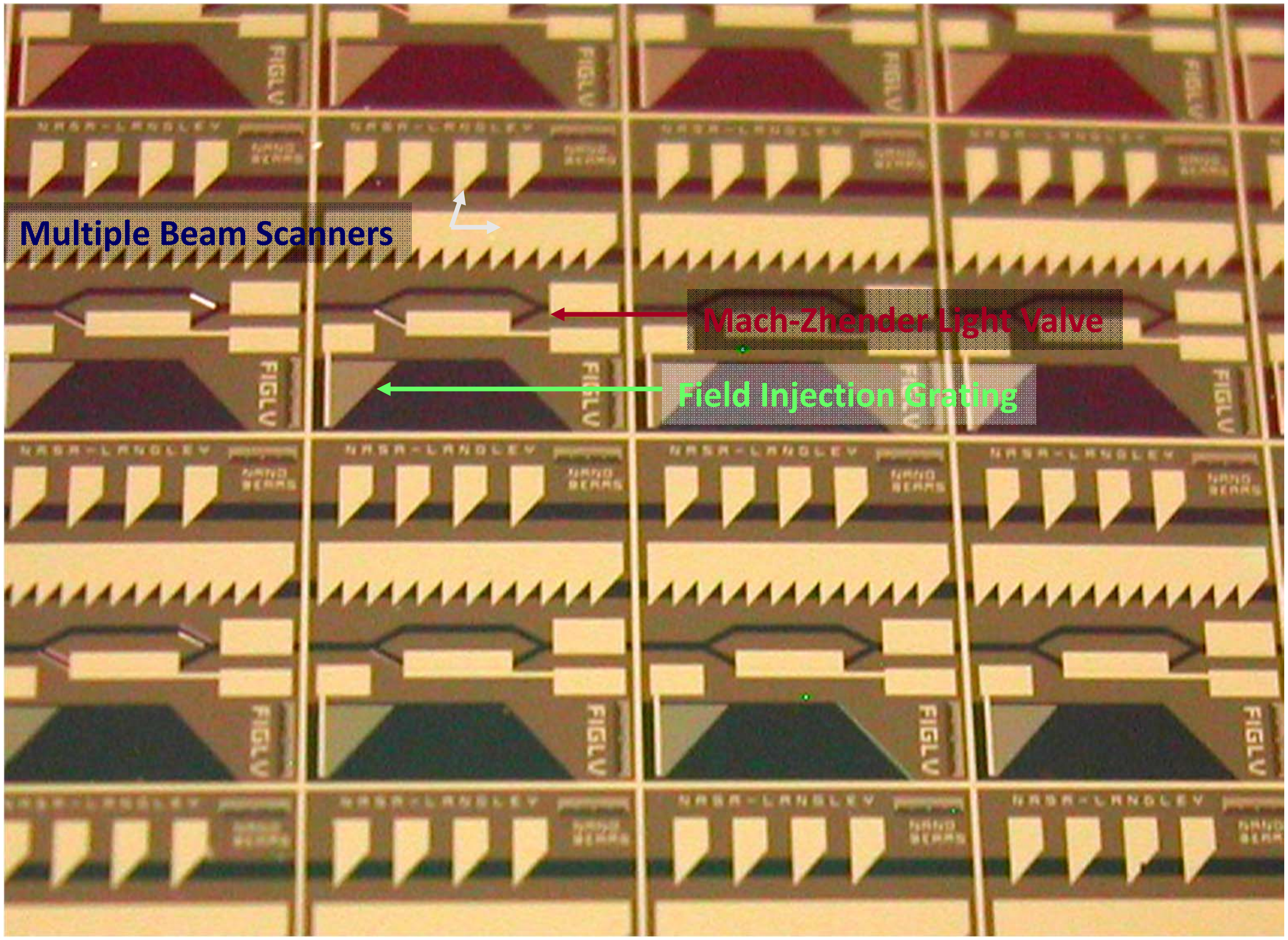


Beam Scanner Array

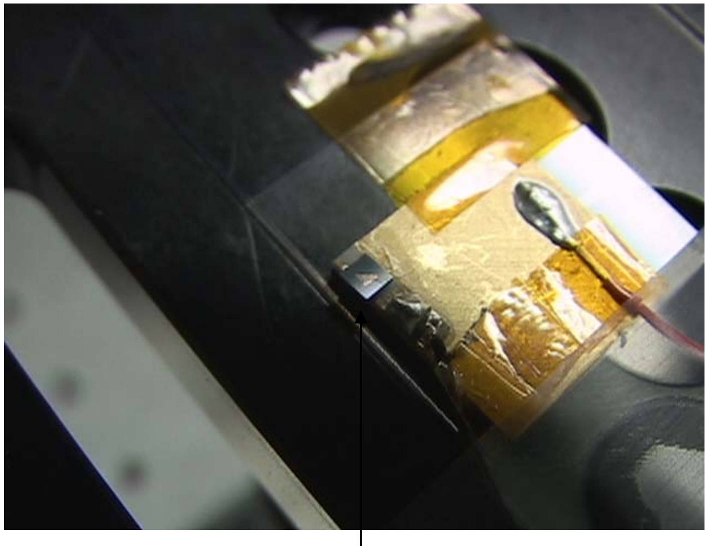


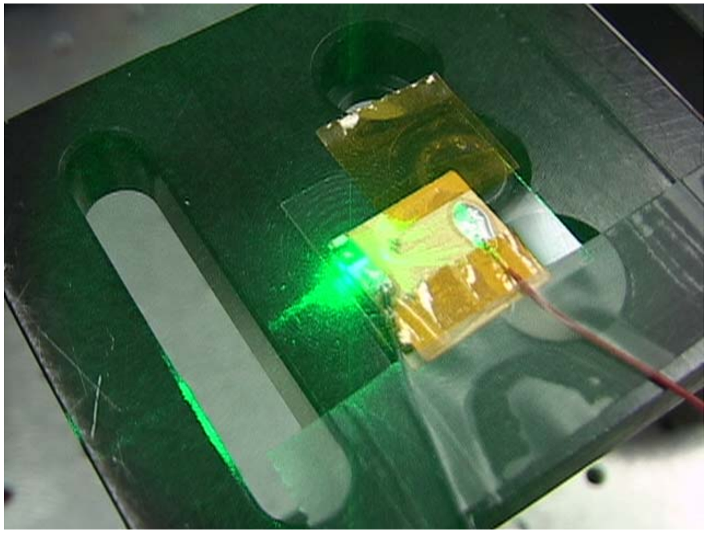
Beam Displacer

Field Injection Grating Light Valve



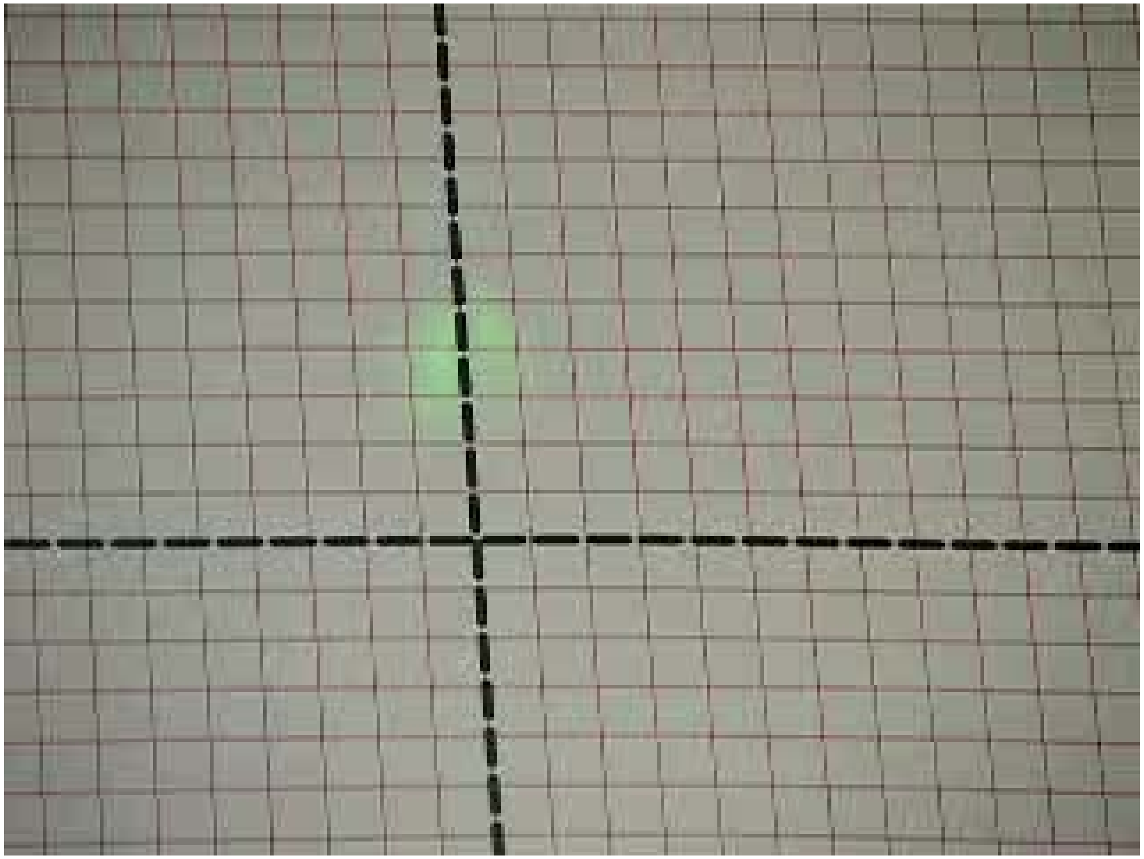
Device Under Test





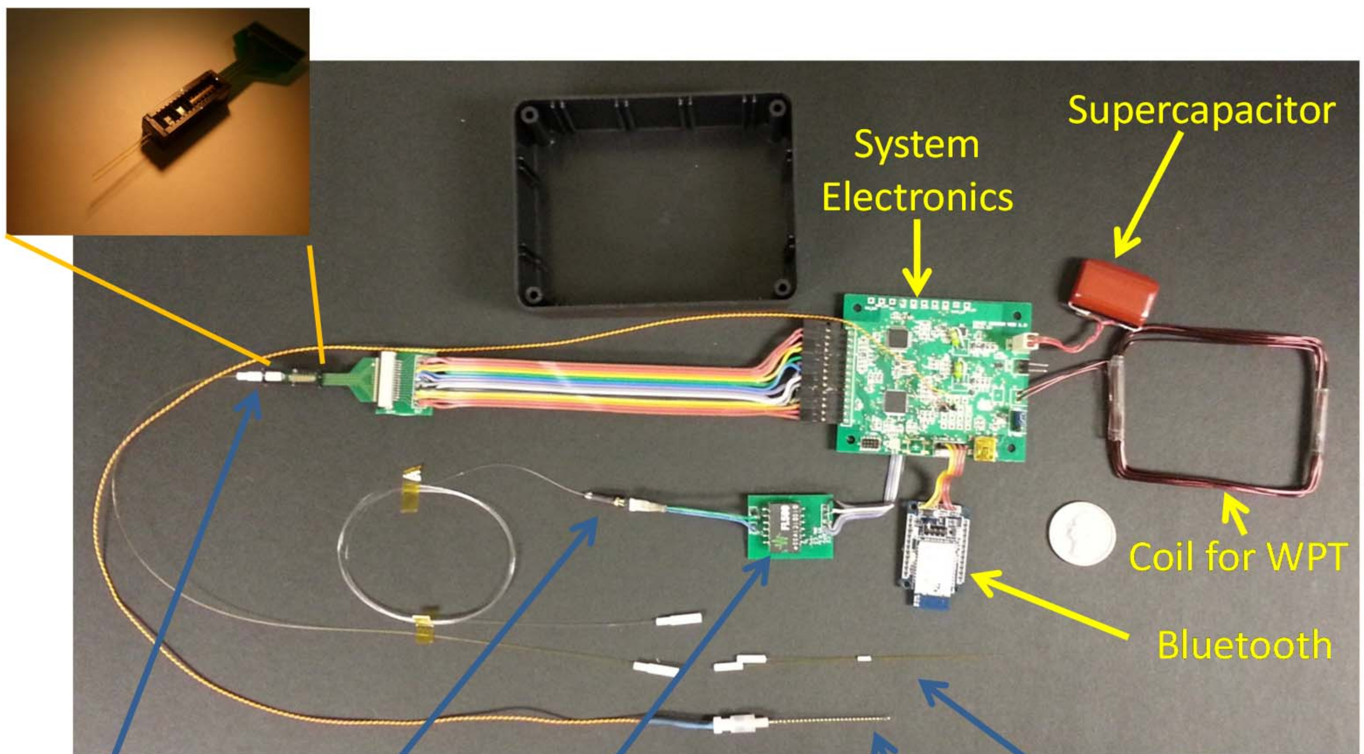
Light Scanning Control Device

Bending the light with E-field

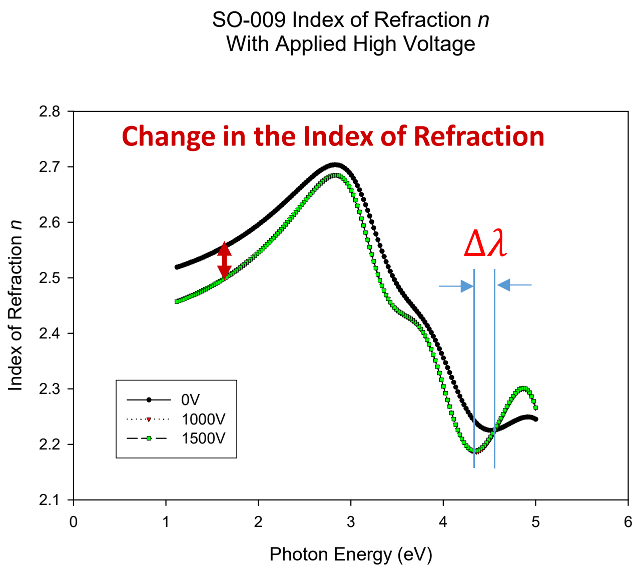


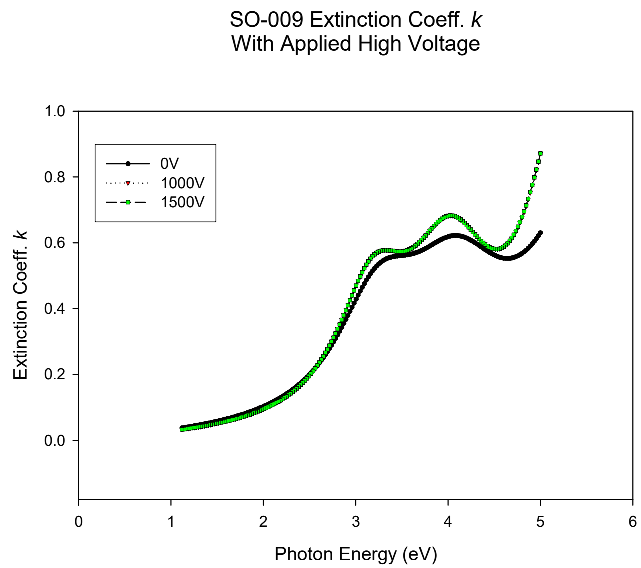
There is **No Mechanical Motion** in device!
Theoretically, it can approach 1GHz operating speed.

MICRO-SPECTROMETER



Change of the Index of Refraction in ScN

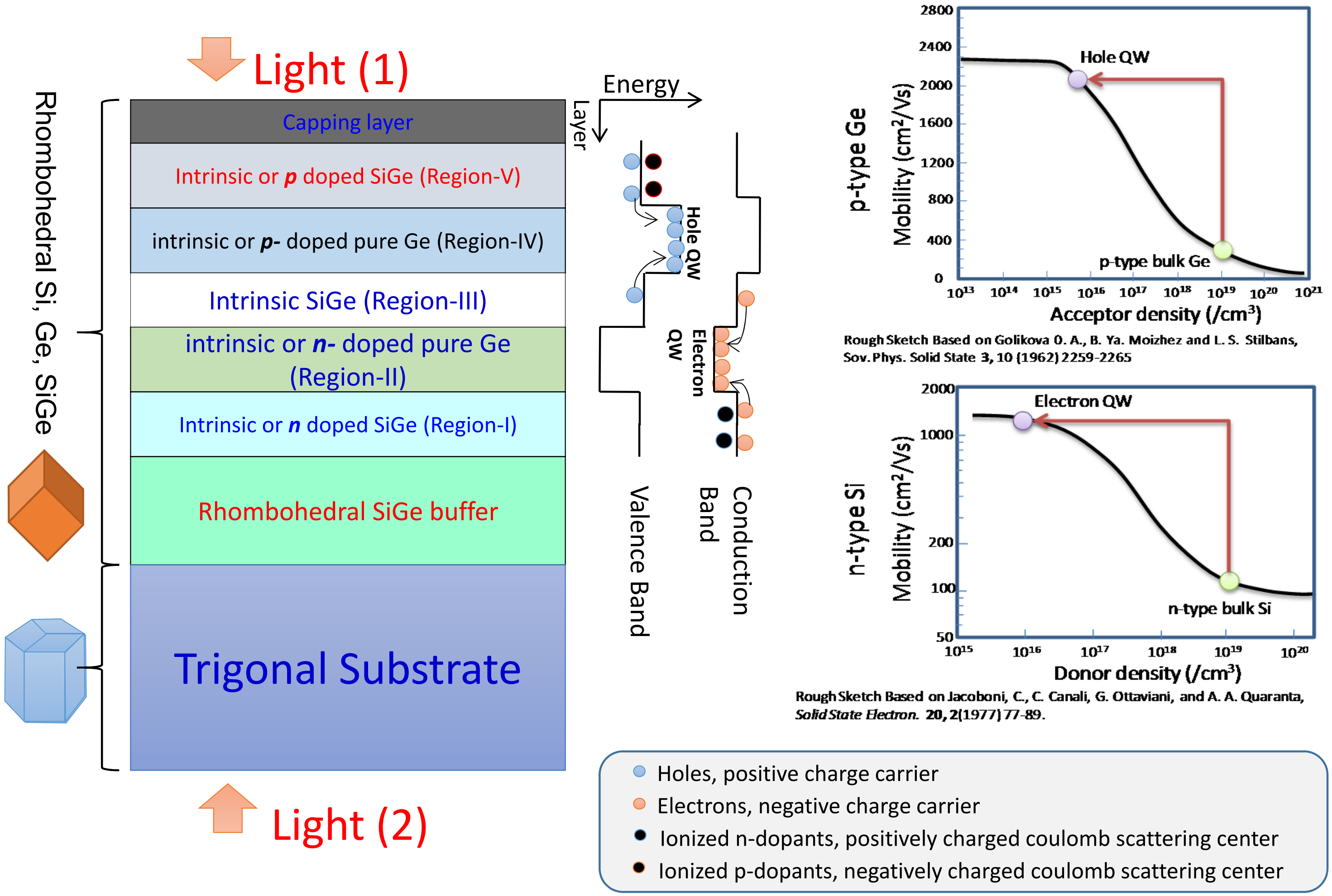




ScN film shows the change in the index of refraction with the applied electric field. The electric field was applied with a few mm gap. The required voltage can be reduced in the optimized structure.

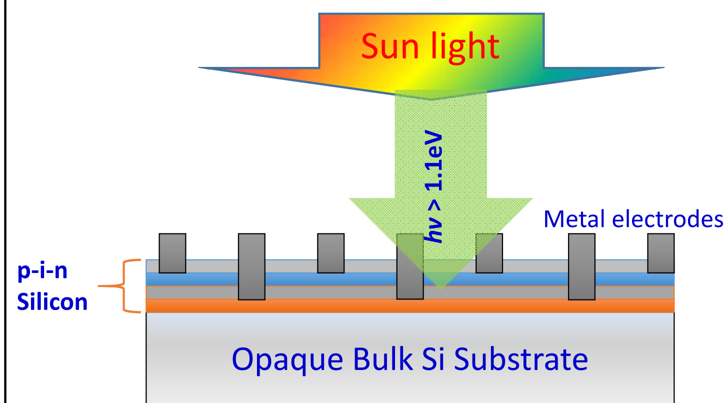
Rhombohedral Si/SiGe/Ge

Dual high mobility layer structure for Solar Cells



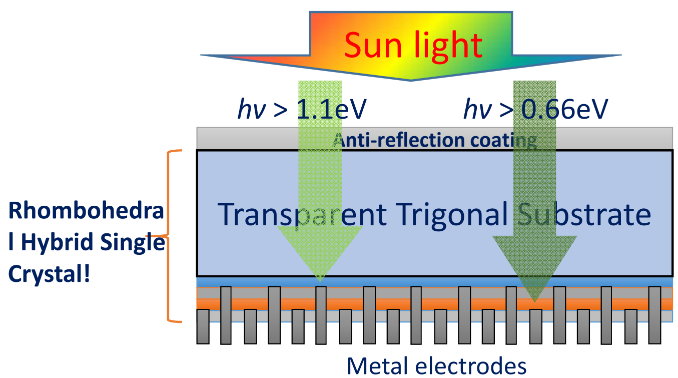
Rhombohedral Hybrid SiGe Photo-Voltaic Cell

(1) Conventional Silicon Photo-Voltaic Cell

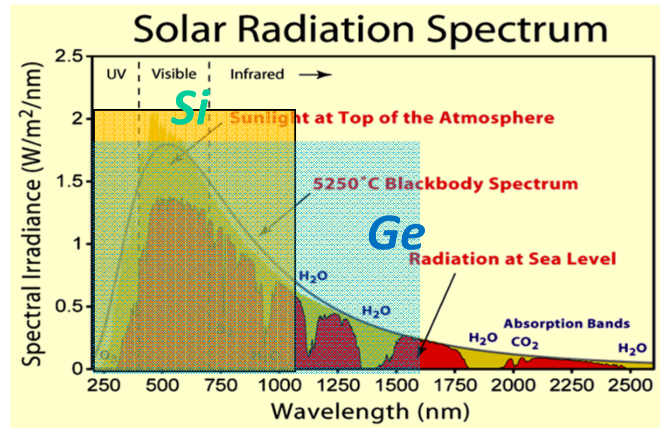


Metal electrodes block sun-light. Long carrier travel distance to electrodes: Less currents

(2) Hybrid Silicon-Germanium Photo-Voltaic Cell



Many metal electrodes do not block sun-light. Short carrier travel distance: More currents



Hybrid SiGe solar cell covers more solar spectrum with maximum power output!

$\eta \geq 30\sim40\%$

Unique Benefits:

1. Quantum well structures enhance carrier transport **10 times** compared with bulk Si materials.
2. Transparent trigonal substrate enables backside illumination, allowing many electrodes **without shadow, making short carrier travel distance for more current output without carrier loss**.
3. Engineered **wider mid bandgap levels** can be fabricated in SiGe layer to enhance photo-generation of electron-hole pairs in indirect bandgap SiGe.
4. Anti-reflection coating layer and ambient light absorbing layer can be built on transparent trigonal substrate such as sapphire.
5. SiGe and Ge absorb more sun-light than bulk Si.

Concluding Remarks

- QT is a new wave of emerging technology
- EU takes a new initiative for QT in 2016
- NASA has worked on device technology based on classical QM
- Current QT interest at NASA LaRC
    - Quantum state modification (1 invention disclosed)
    - Quantum energetics (8 inventions disclosed)
    - Nuclear fusion propulsion concept (1 invention disclosed)