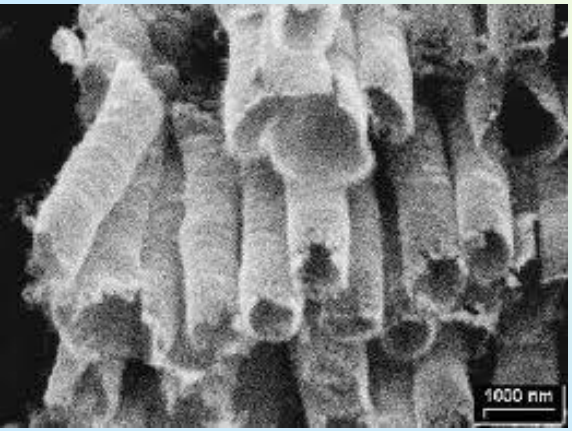
Biological and Bioinspired Nanostructured Materials: Basic Physics and Applications

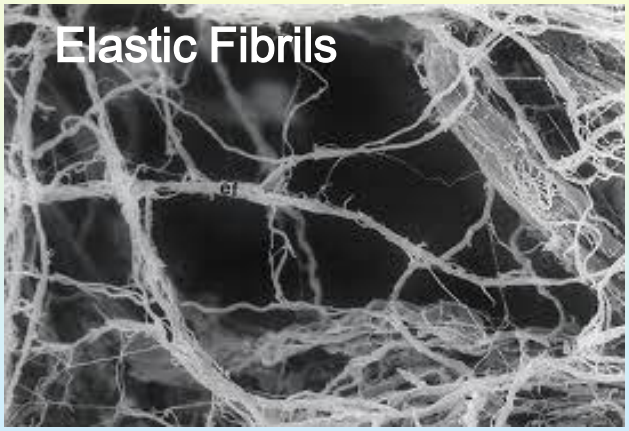
Gil Rosenman
School of Electrical Engineering-Physical Electronics,
Faculty of Engineering, Tel Aviv University

Nanostructured Materials

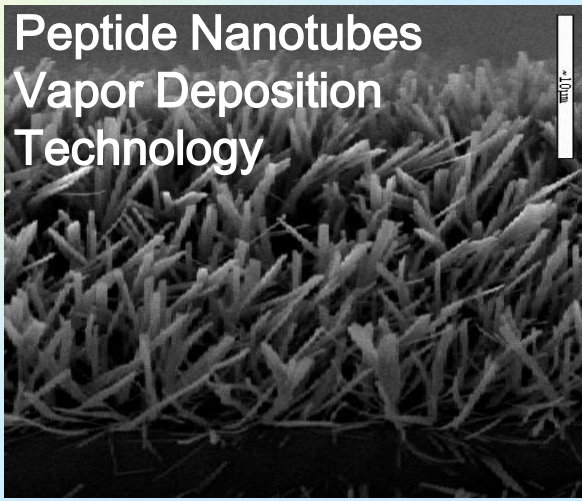
Inorganic World



Biological World



Bioinspired Materials

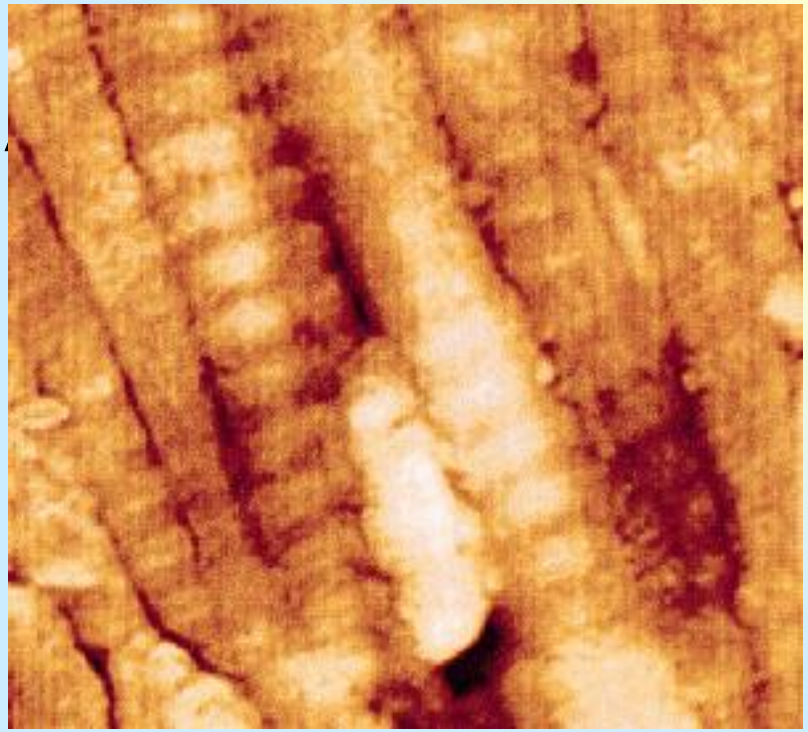


Biological and Bioinspired Materials at Nanoscale

Living Nature: Protein Fibers

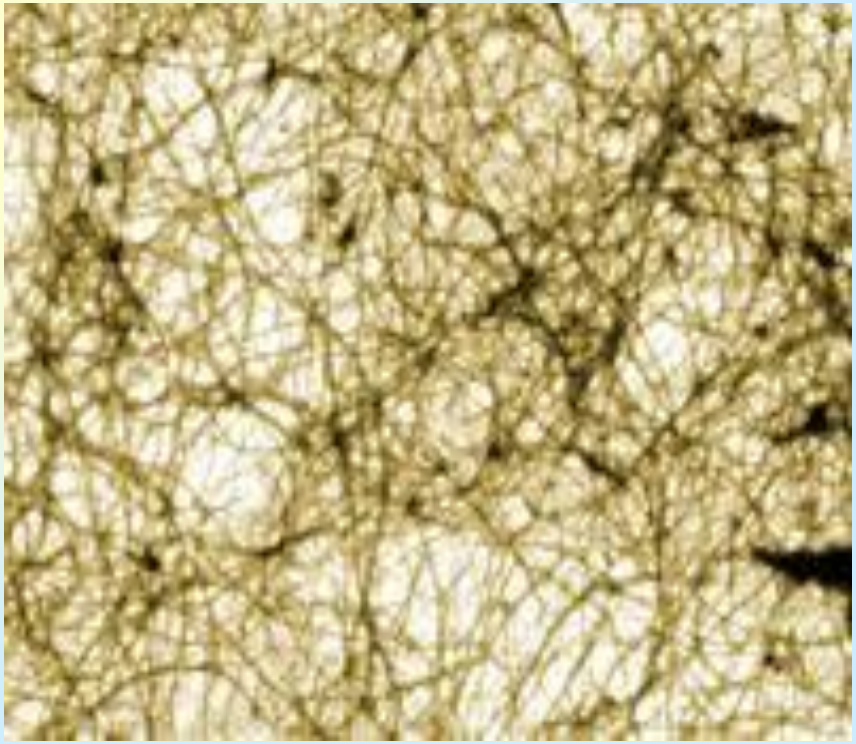
Natural Nanofibrils

Human Bone Collagen



Amyloid fibrils

Alzheimer amyloid nanofibrils

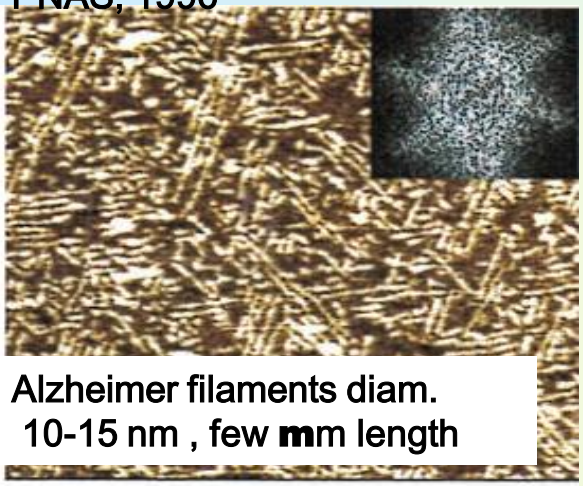


Nature: Amyloid Fibrils

There are ~ 20 distinct human diseases that are associated with amyloid fibrils formation: regular fibrillar structures micrometers in length, a few nanometers in diameter

Amyloid Fibrils-NATURAL BIOLOGICAL NANOFIBRILS

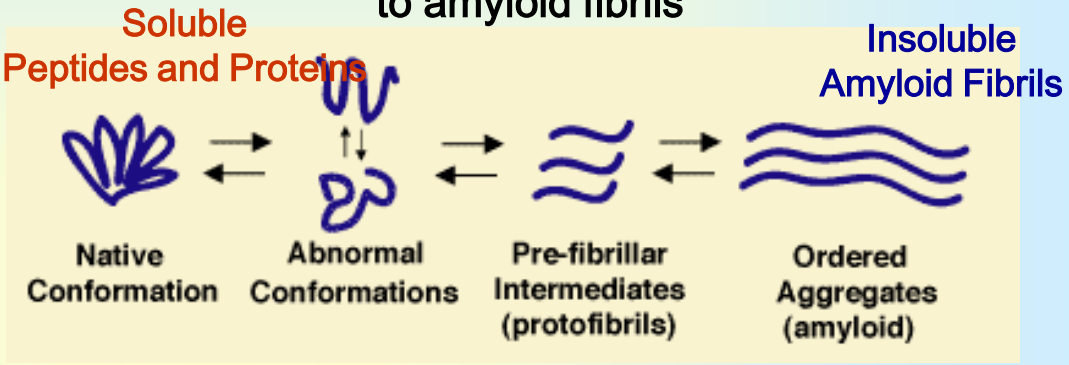
T. Kowalewski, D. Holtzman, PNAS, 1996



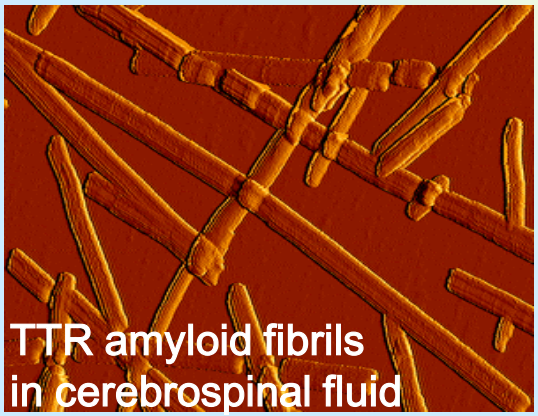
Alzheimer filaments diam. 10-15 nm , few **m**m length

Alzheimer's β–amyloid peptide

The transition from the native state conformation to amyloid fibrils

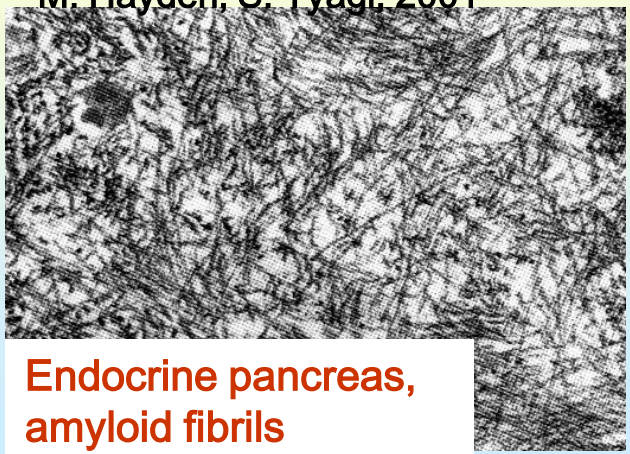


K. Dill, H. Chan, Nature Struct. Biology, 1997



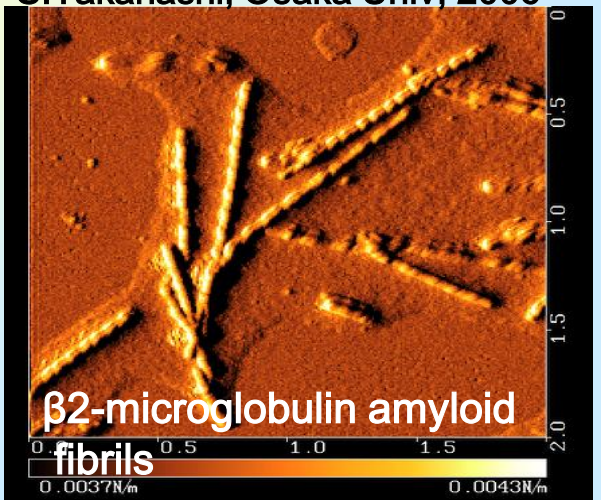
TTR amyloid fibrils in cerebrospinal fluid

M. Hayden, S. Tyagi, 2001



Endocrine pancreas, amyloid fibrils

S.Takahashi, Osaka Univ, 2006



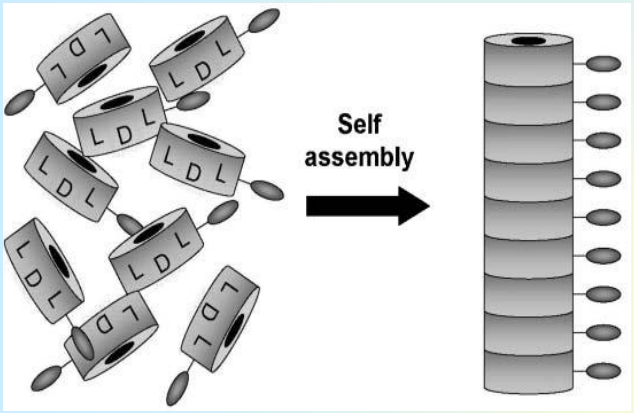
β2-microglobulin amyloid fibrils

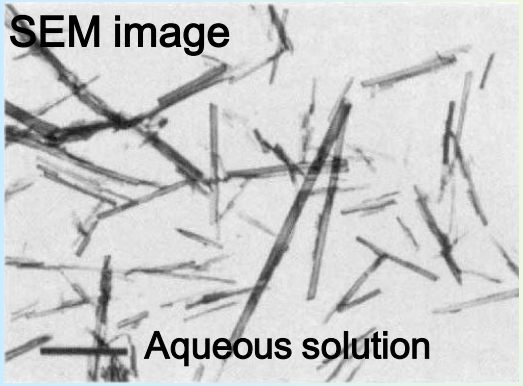
Bioinspired Peptide Nanotubes

Peptide Engineering:

M. R. Ghadiri, Nature, 1993

D- and L-amino-acid cyclic peptide





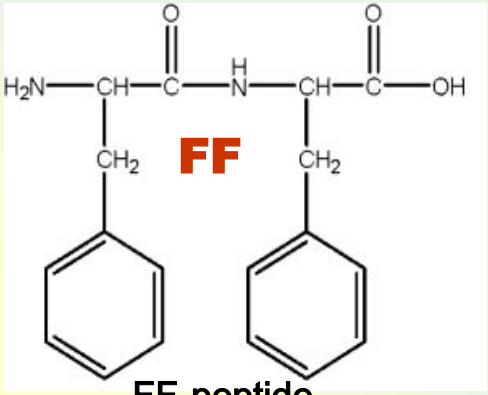
Zhang, (2002): "Peptide Lego“

– Peptide Engineering

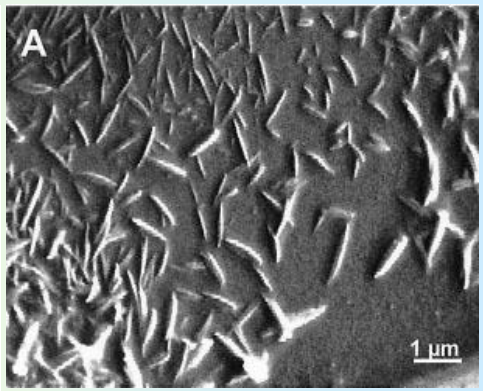
NH_2-DAEFRHDSGYEVHHQKLVFFAEDVGSNKGAIIGLMVGGVVIA-COOH

Bioinspired Chemically Synthesized Molecules- Core Motif of Alzheimer disease

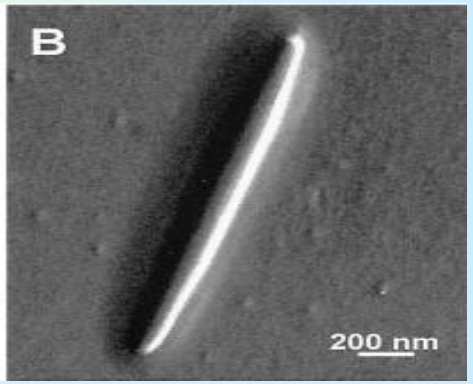
E. Gazit, et al, Science, 2003



FF-peptide



E. Gazit, et al, Nature Nanotechnology, 2006



New Generation of Bioinspired Materials

Bioinspired Peptide Nanotubes

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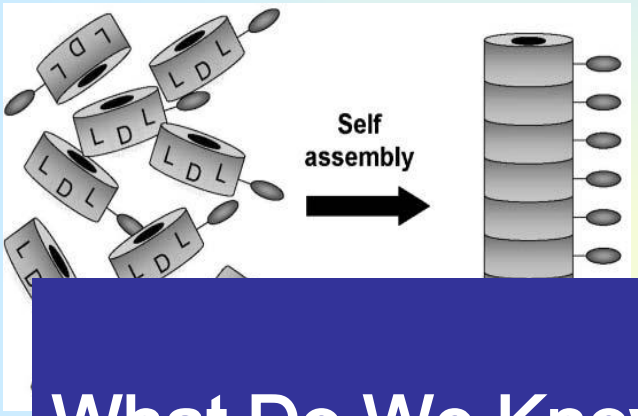

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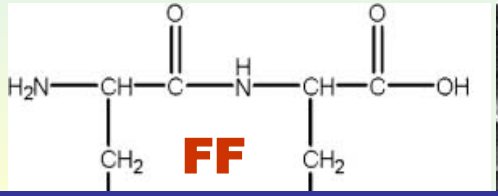
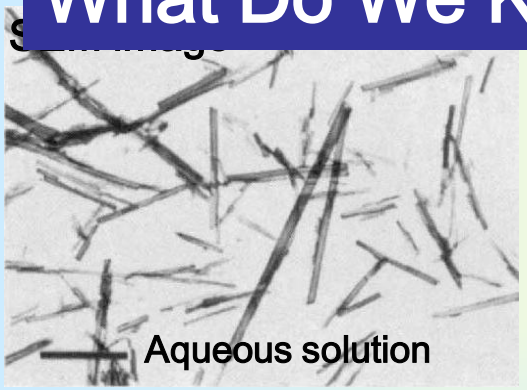


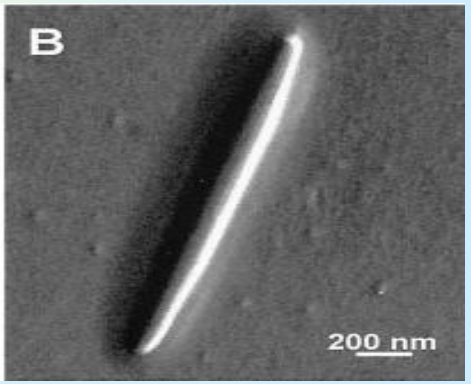
The Question is:
What Do We Know About These New Nanostructures?



Zhang, (2002): "Peptide Lego"
– Peptide Engineering

FF-peptide

E. Gazit, et al, Nature Nanotechnology, 2006

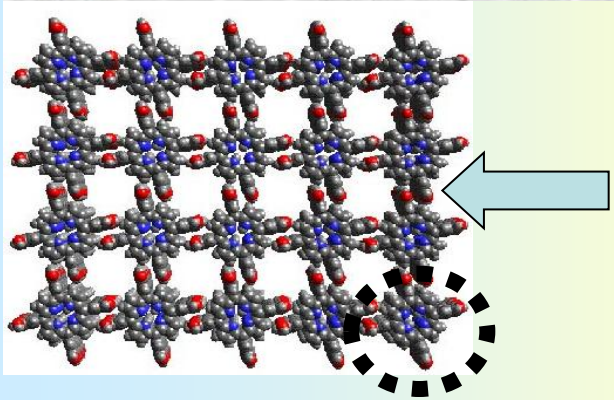


New Generation of Bioinspired Materials

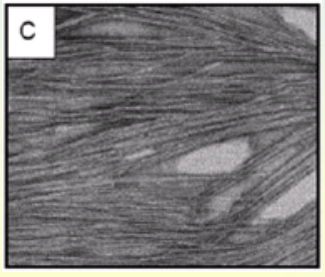
Biological and Bioinspired Supramolecular Structures

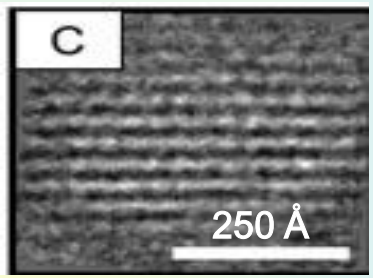
Nanocrystalline Building Blocks Linked by Noncovalent, Weak Interactions

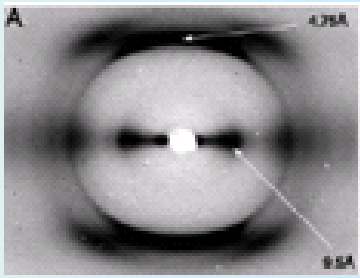
Self assembly mechanism
R. Ghadiri, Angew. Chem. 2001



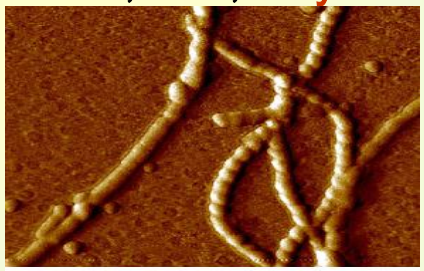
M. Perutz, Adenovirus-based on peptide fibrils,
J Biol. Chem, 2005

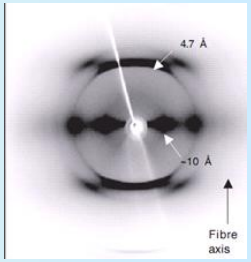


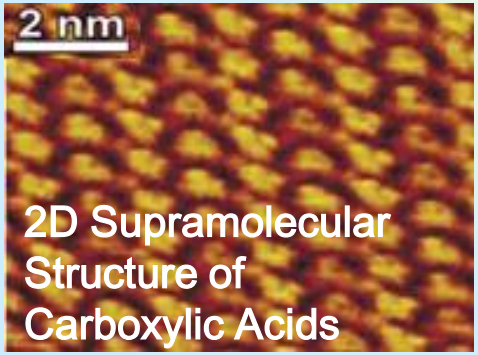




Makin, O. S., Amyloid Fibrils (Alzheimer) *Febs J. 2005*

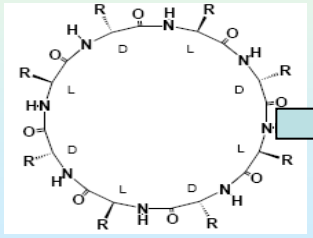


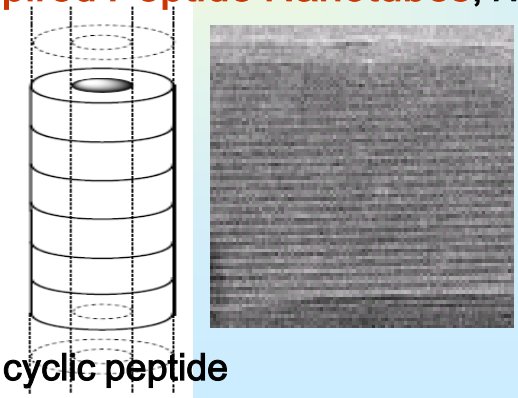


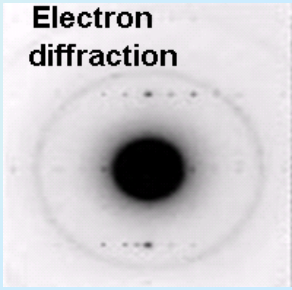


P. Samori, Adv Mater, 2010

R. Ghadiri , Bioinspired Peptide Nanotubes, *Nature, (1993)*



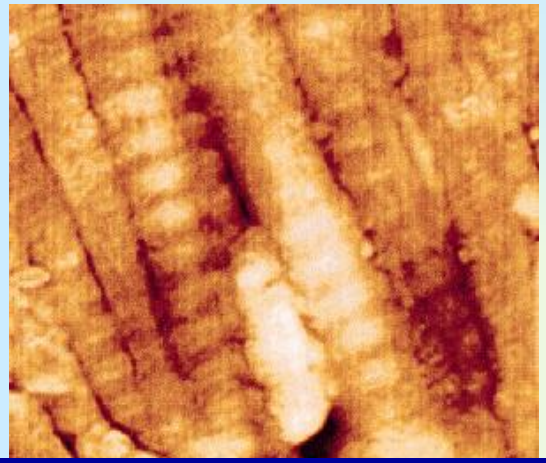




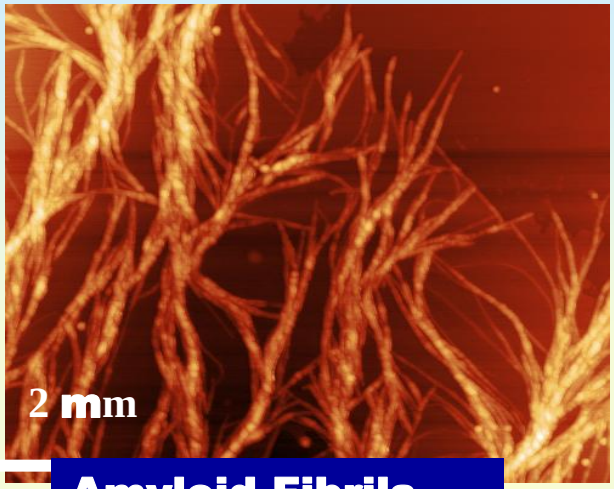
D- and L-amino-acid cyclic peptide

Biological Natural Nanofibrils

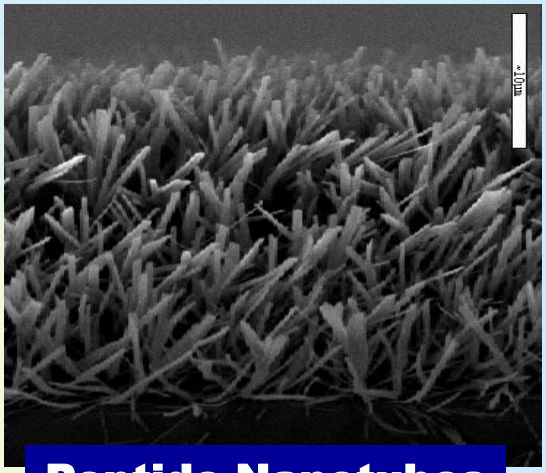
Bioinspired Nanostructures



Nanofibrillar Structure
Human Bone Collagen



Amyloid Fibrils
Human Insulin



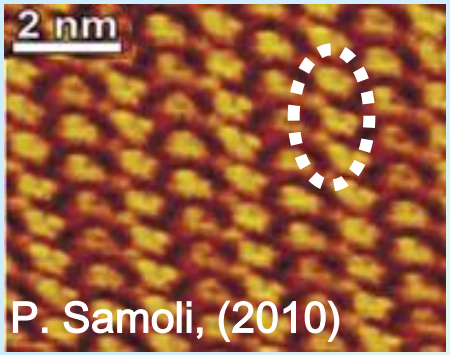
Peptide Nanotubes

Common Basic Features:

1. Identical core biomolecule composition
2. Similar molecular recognition and self assembly mechanisms
3. Supramolecular nanofibrillar structures containing nanoscale crystalline elementary building blocks assembled due to noncovalent weak, reversible, dynamic interactions

Common Intrinsic Physical Properties?

Biological and Bioinspired Structures: Motivation and Goals



-Structural Nanoordering (scale of ~10-30 Å)

Exceptional Physical Situation

-Low Dimensional Structures: Quantum confinement, Exciton PL, LED and Lasers; QD-biomarkers Virtual Optical Microscopy

-Symmetry of Nanocrystalline Blocks: Piezoelectric, Linear Electrooptic and Nonlinear Optical Effects

Motivation and Goals

1. Basic Intrinsic Properties at the Interchange Physics-Biology

2. Self Assembly Mechanism

3. New Generation of Nanostructural Bioinspired Materials

-Nanophotonics (Bio-LEDs, Bio-Lasers, Non-Linear Optical Converters, etc)

-Nanopiezotronics, Nano-Bio-Piezotronics and Bio-Piezoceramics

-Energy Storage Devices (Batteries and Supercapacitors)

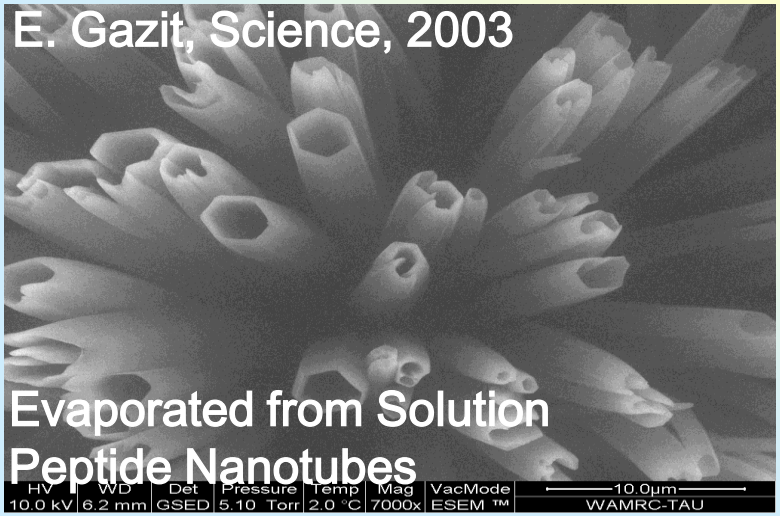
Could Self Assembly Bioinspired Peptide Nanostructures be a Model of Biological Materials?

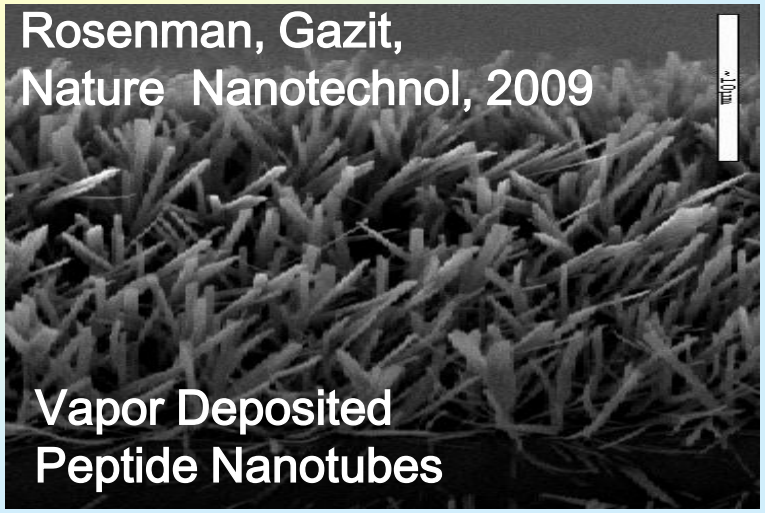
Part I

Bottom-up Nanotechnology of

Bioinspired Peptide Nanostructures

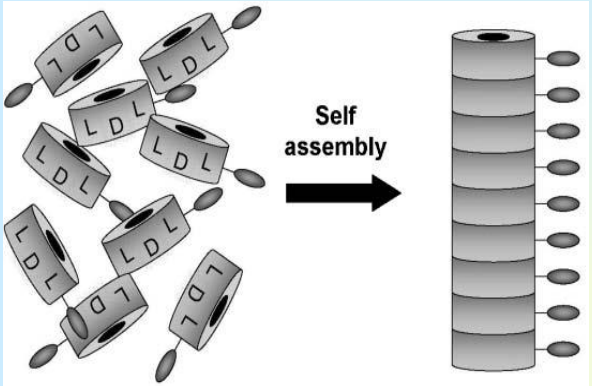
Self Assembly-
Technology Developed by Nature

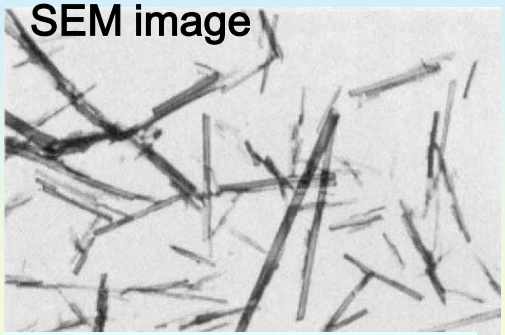




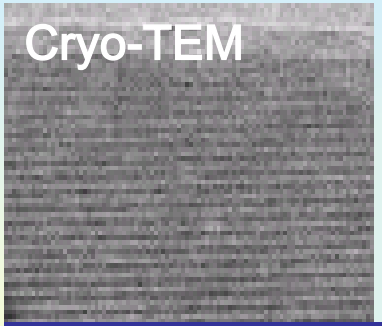
Peptide Engineering and Self Assembly Mechanism

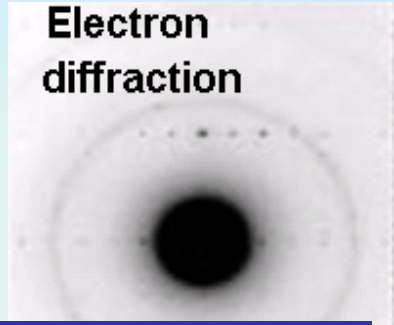
M. R. Ghadiri, Nature, 1993,





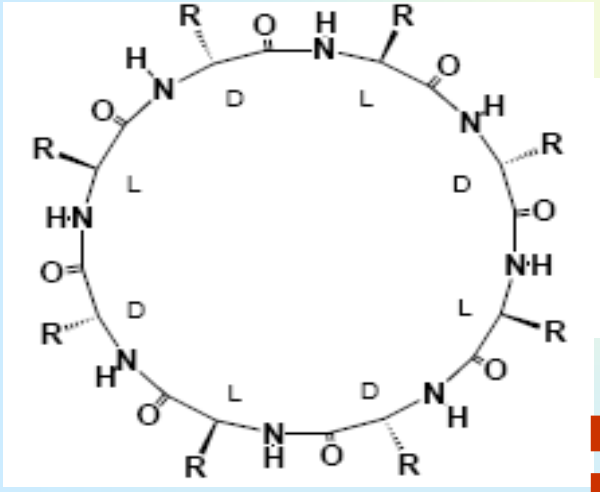
Aqueous solution

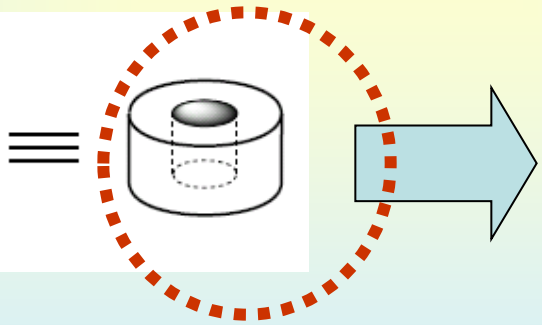




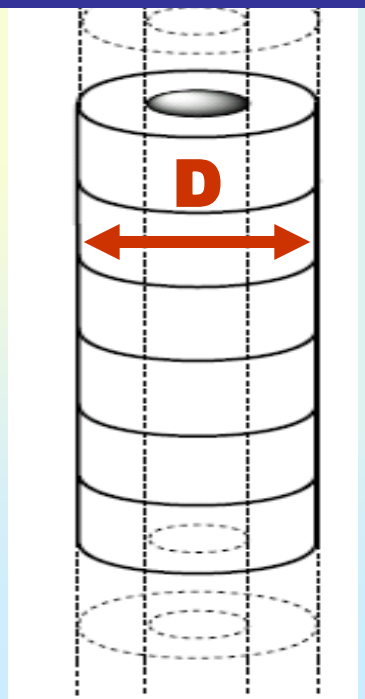
Striations in the TEM image are ~ 18 A diameter of peptide ring Subunit distances of 4.8 A

D- and L-amino-acids (8 units forming Cyclic Peptide)





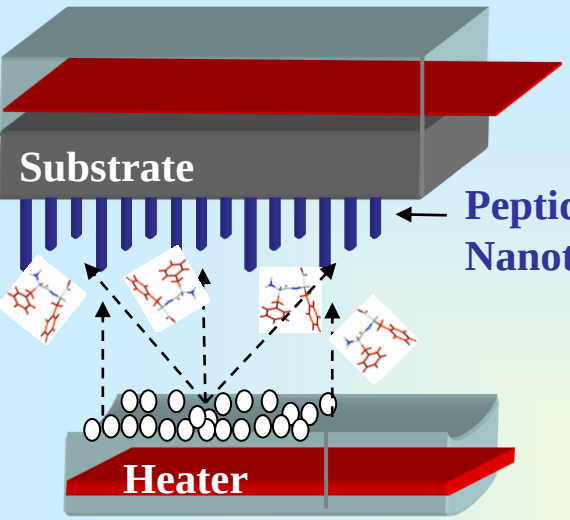
Elementary Building Block 2 Peptide Molecules

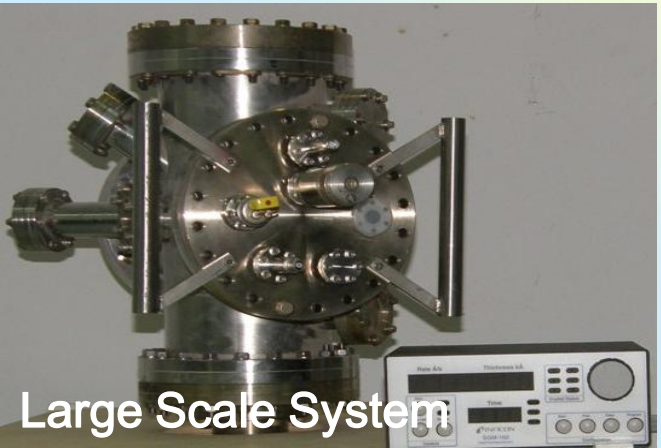


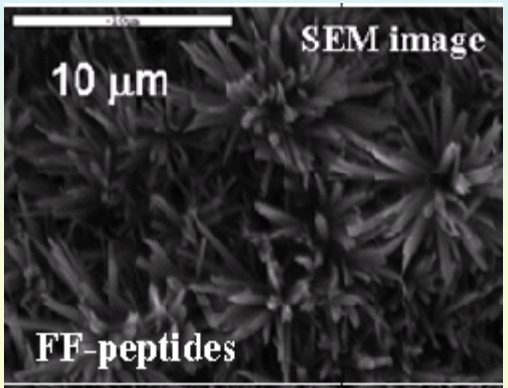
Peptide Nanotubes Vapor Deposition

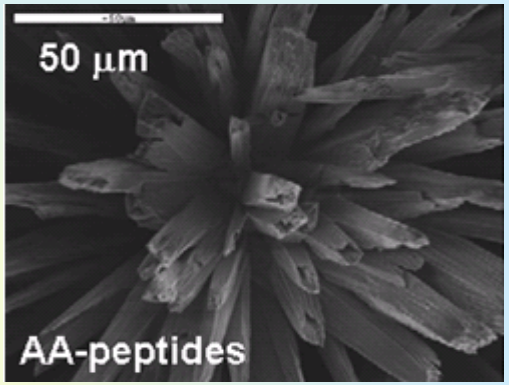
PCT Patent Application No. PCT/IL2008/001118, 2008

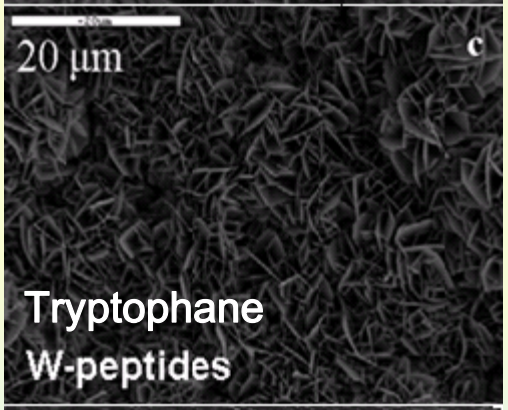
Nature Nanotechnology, 2009

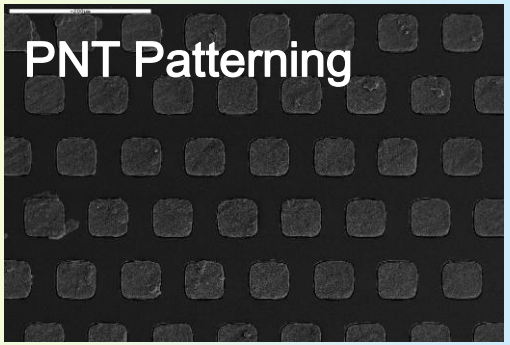


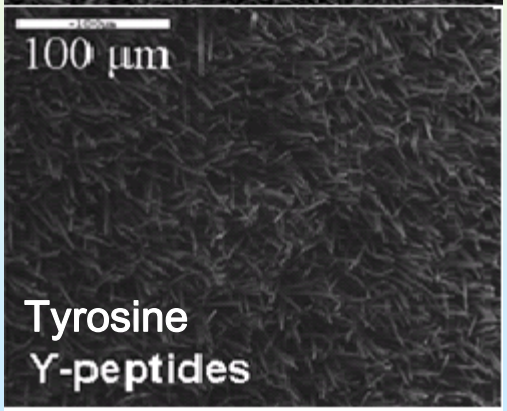


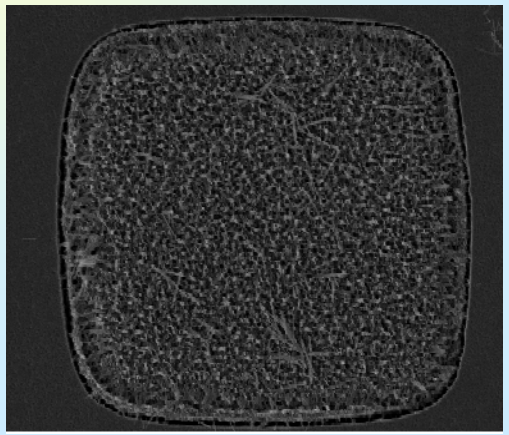












Peptide Nanotubes Vapor Deposition

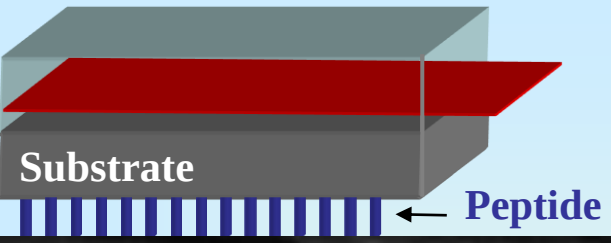
PCT Patent Application No. PCT/IL2008/001118, 2008

Nature Nanotechnology, 2009

~10μm

J. Pept. Sci, 2011

Regular Cross Section: Tetragonal Symmetry $\bar{I}4$



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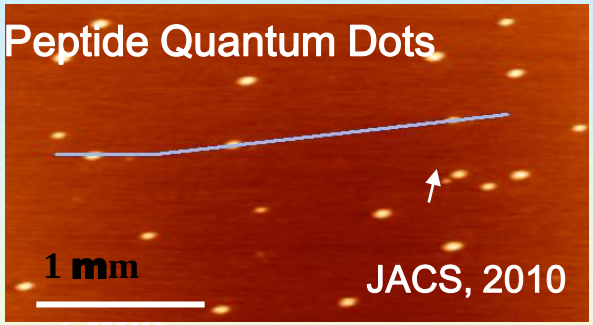
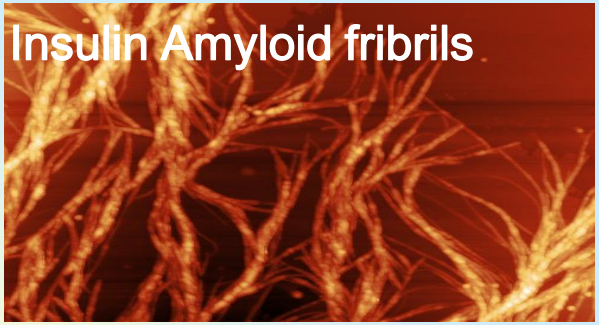
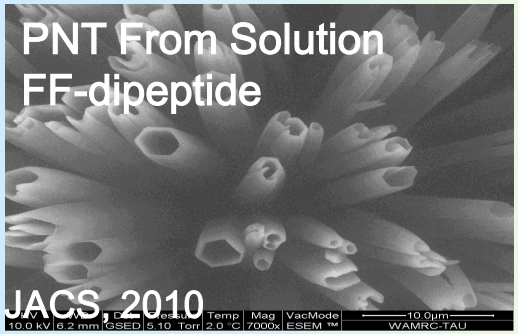
Self Assembly Mechanism?

Elementary Building Blocks?

Peptide Nanostructures

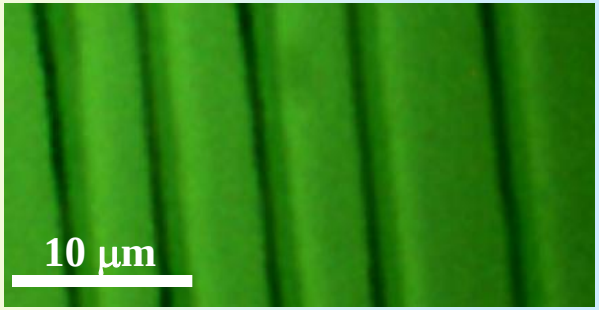




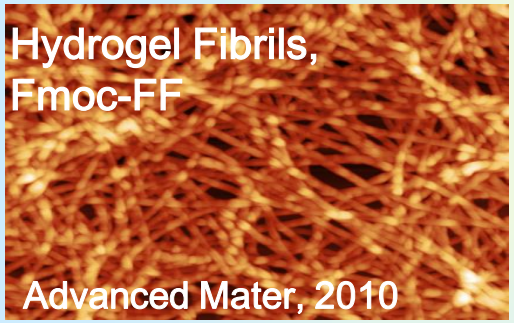


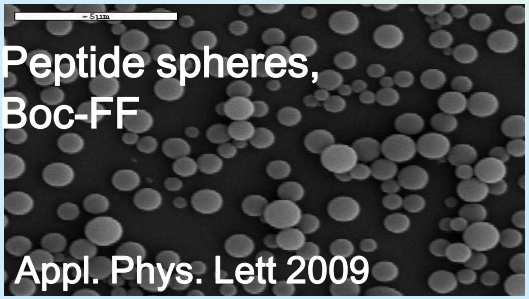
Recent Publications

-Nature Nanotechnology, (2009)
-Nano Lett, (2009)
-Appl Phys. Lett, (2009)
-ACS Nano (2010)
-Advanced Materials (2010)
-J. of Materials Research (2010)
-J. of Materials Science (2010)
-Material Science and Engineering, B (2010)
-Ferroelectrics (2010)
-JACS(2010), ➡ Nature, News & Views (2010)
-J. Pept Sci (2011)
-J. Biomacromol (2011)



Bio-Piezoceramics





Part II

Optical Properties of Bioinspired Materials:

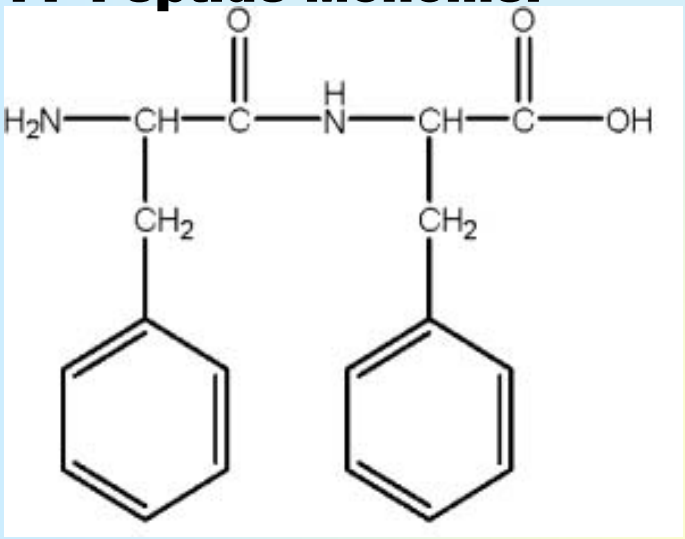
Nanostructure and Quantum Confinement

Y. L. Dory, Angew. Chem. Int. Ed. 2001

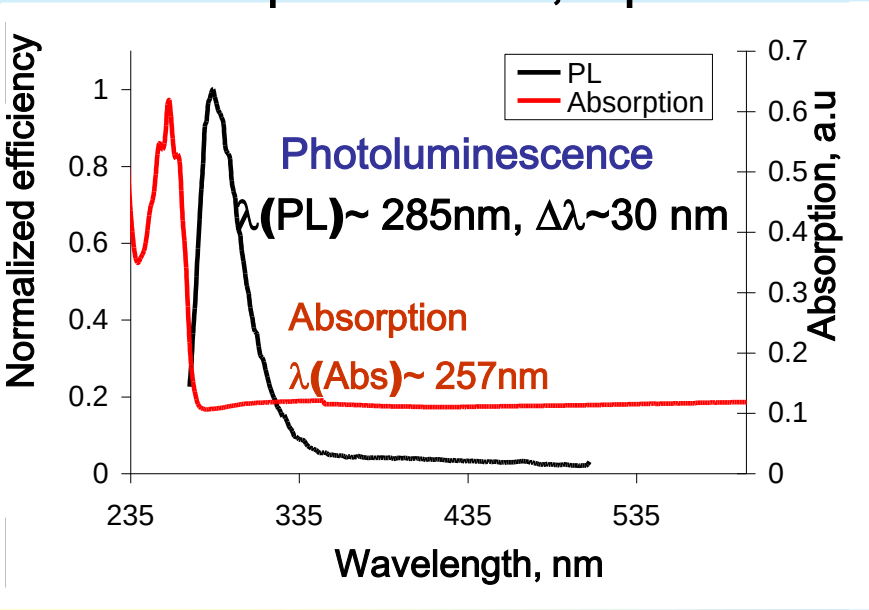
Could This Nanotube Be A Quantum Well Structure?

Self Assembled Bio-Inspired Peptide Nanotubes

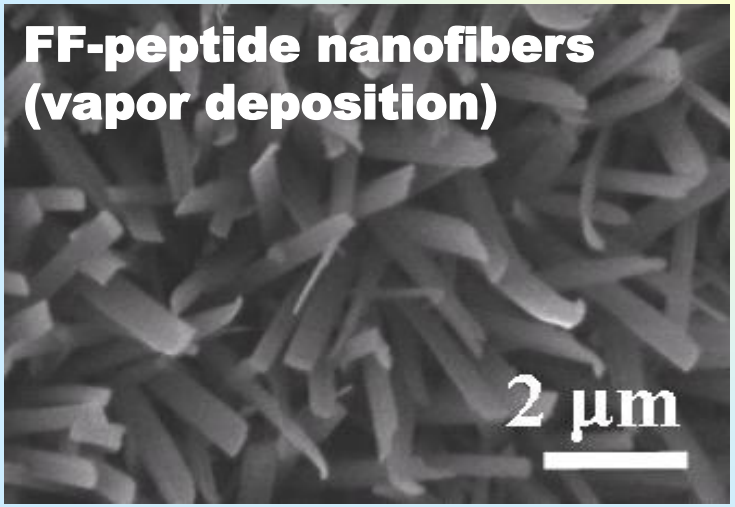
FF-Peptide Monomer



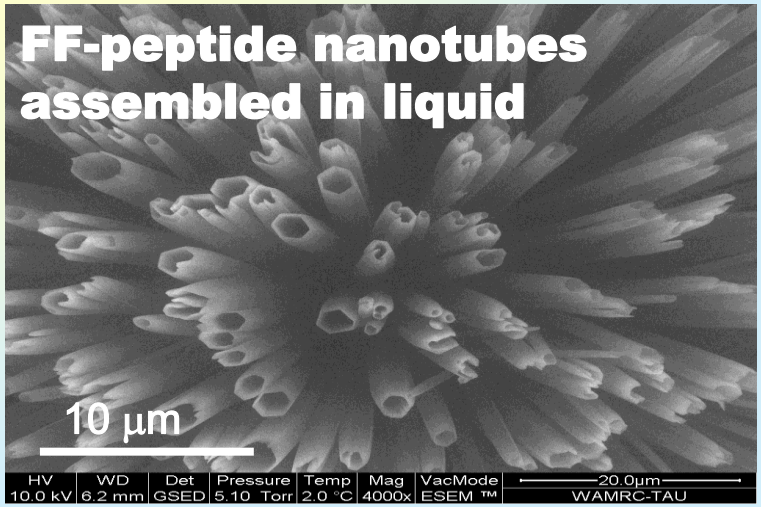
Monomer Diphenilalanine, Aqueous Solution



The Same Monomer Diphenilalanine FF-Peptide

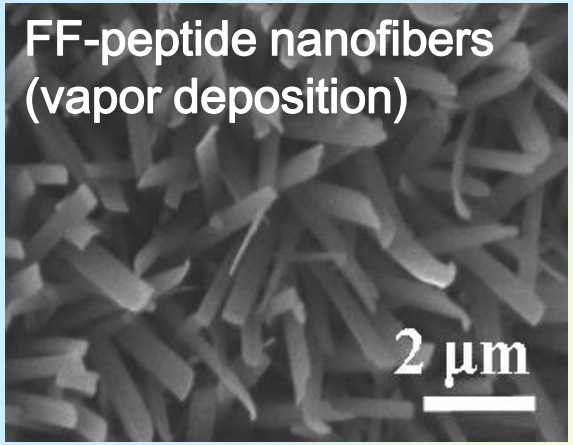


Nature Nanotechnol, 2009
Nano Letters, 2009

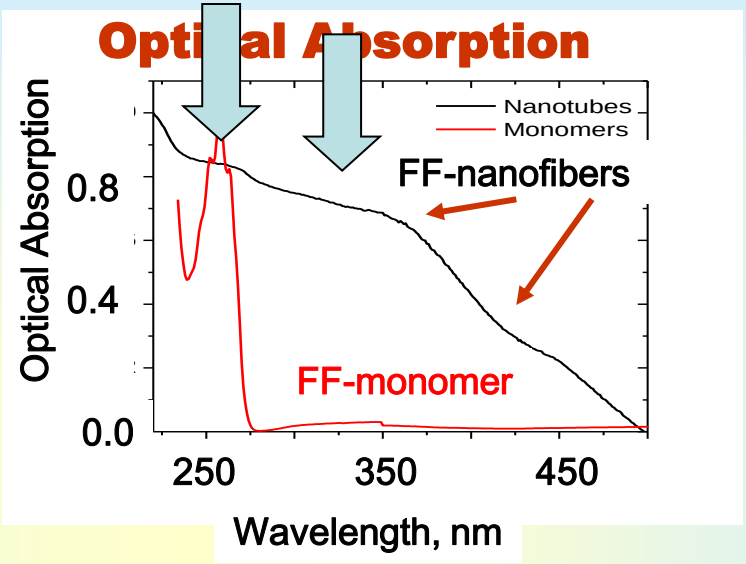


JACS, 2010

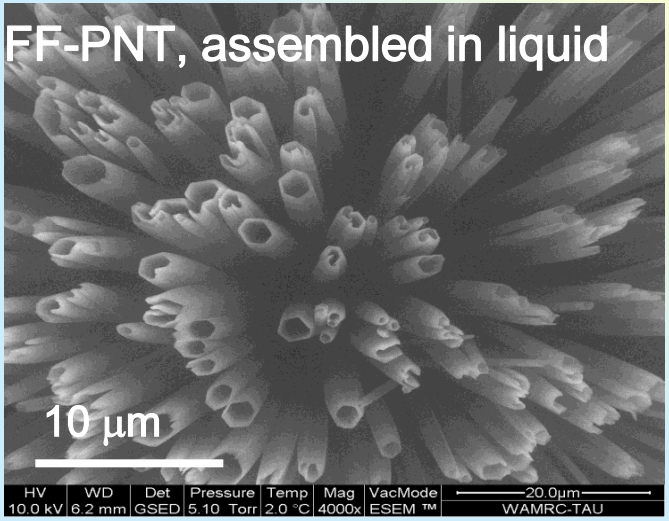
Optical Absorption of Self Assembled Bio-Inspired Peptide Nanotubes



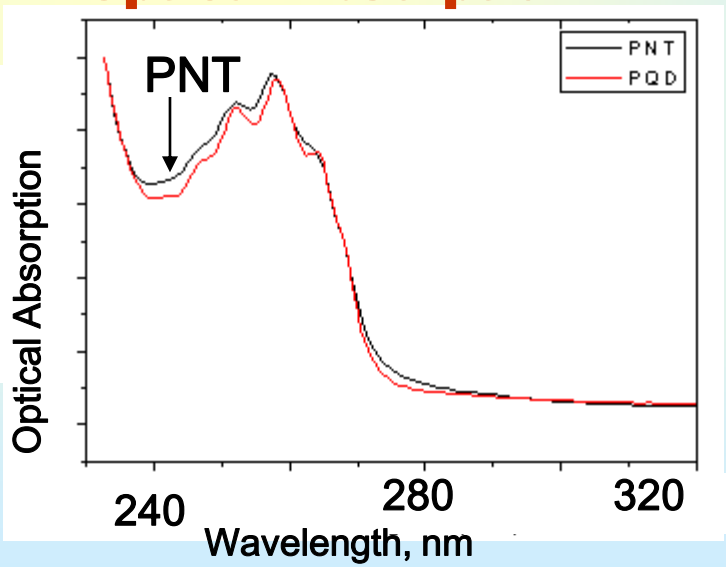
Nature Nanotechnol, 2009
Nano Letters, 2009



Step-like absorption



JACS, 2010

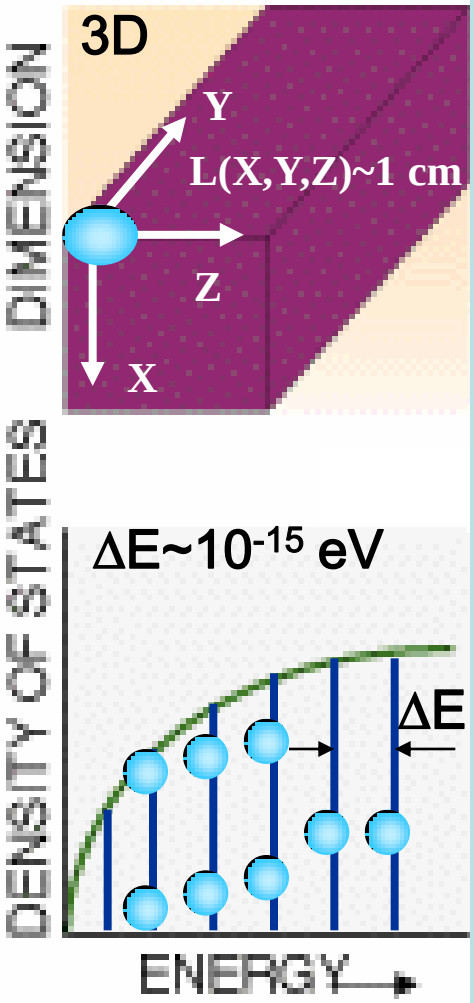


Peak-like Optical Absorption

Quantum Confinement Phenomena

L~λ(de Broglie wavelength of an electron, λ~10-40 Angstrom)

Bulk crystal

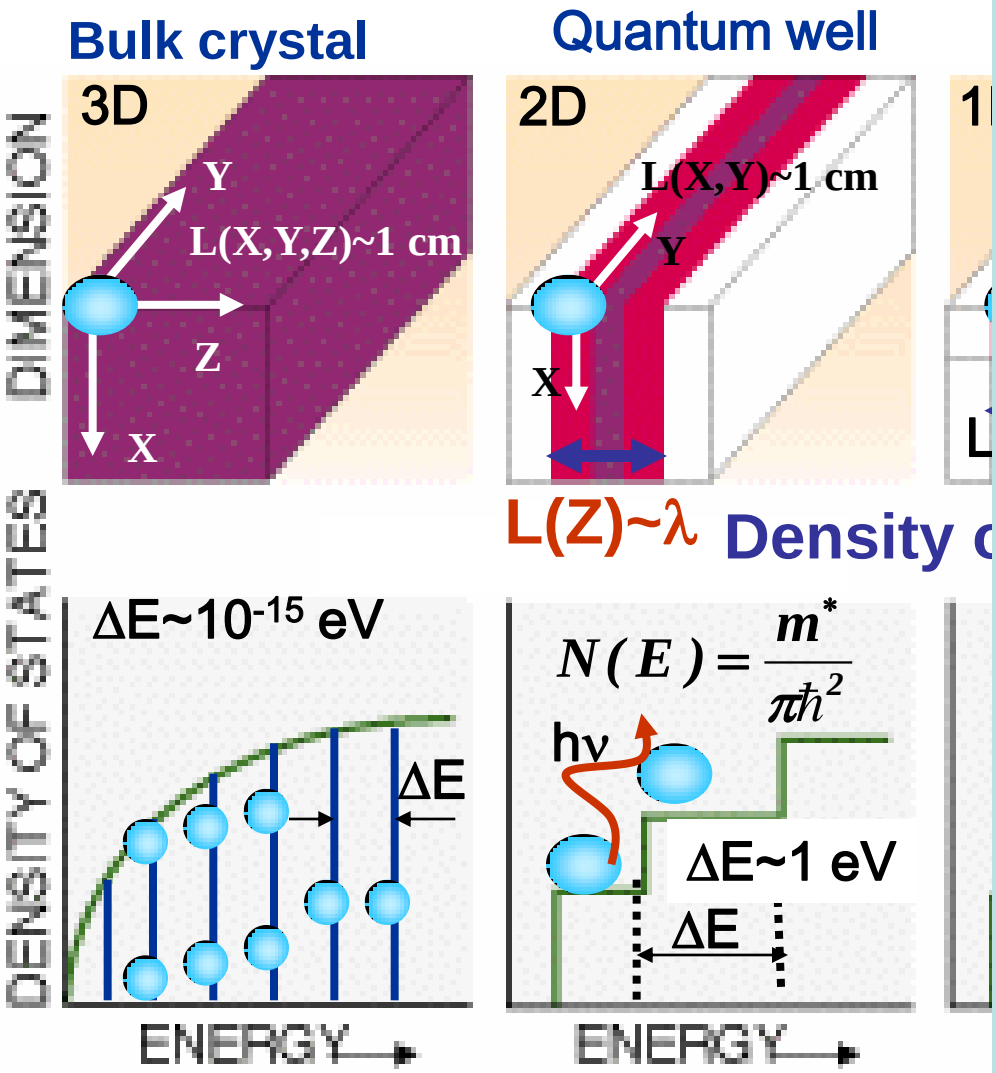


Optical Absorption is Defined by Electron Density of States

$$E_n = \frac{}{2m\left(\frac{}{L}\right)}$$

Quantum Confinement Phenomena

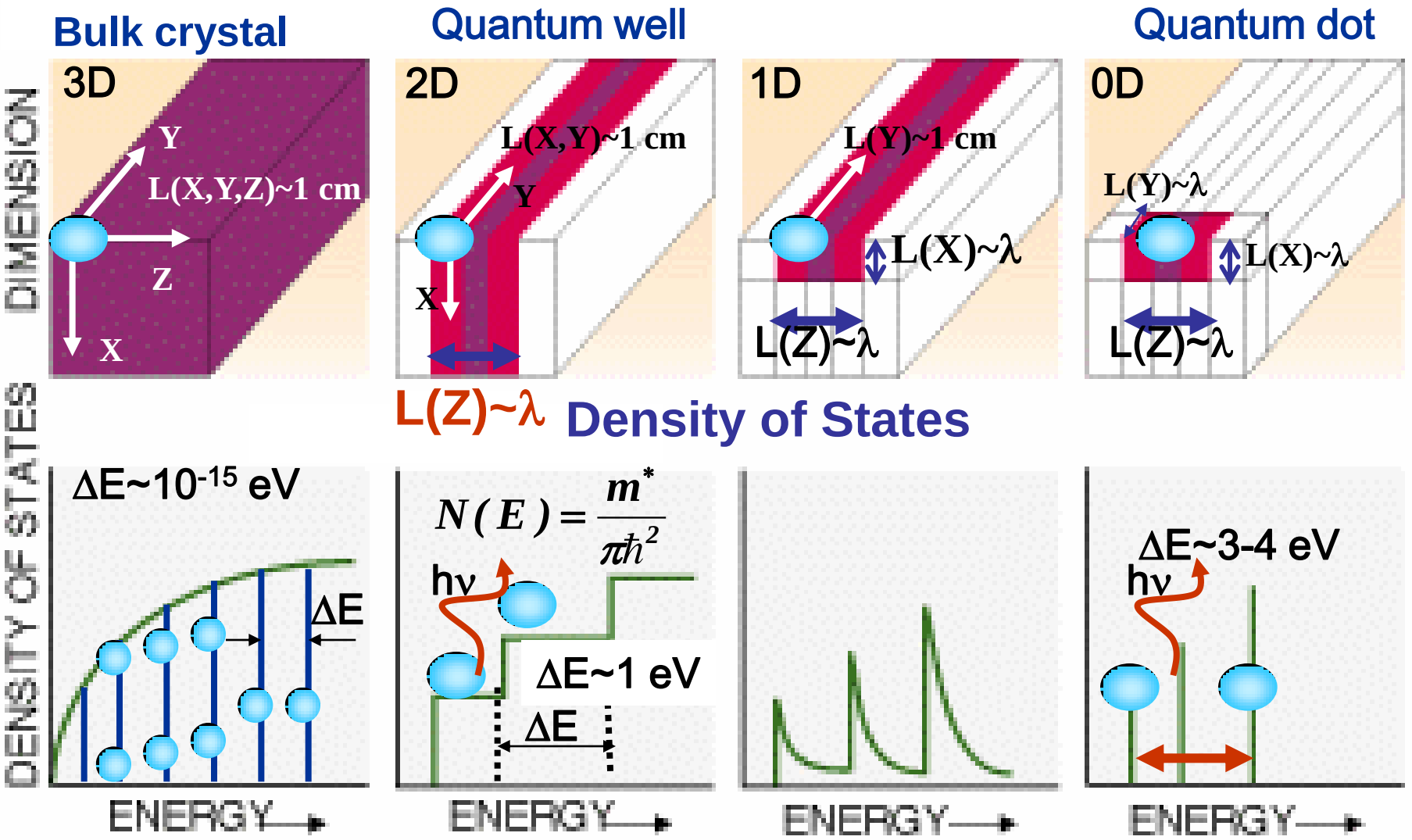
L~λ(de Broglie wavelength of an electron, λ~10-40 Angstrom)



$$E_n = \frac{}{2m}\left(\frac{}{L}\right)$$

Quantum Confinement Phenomena

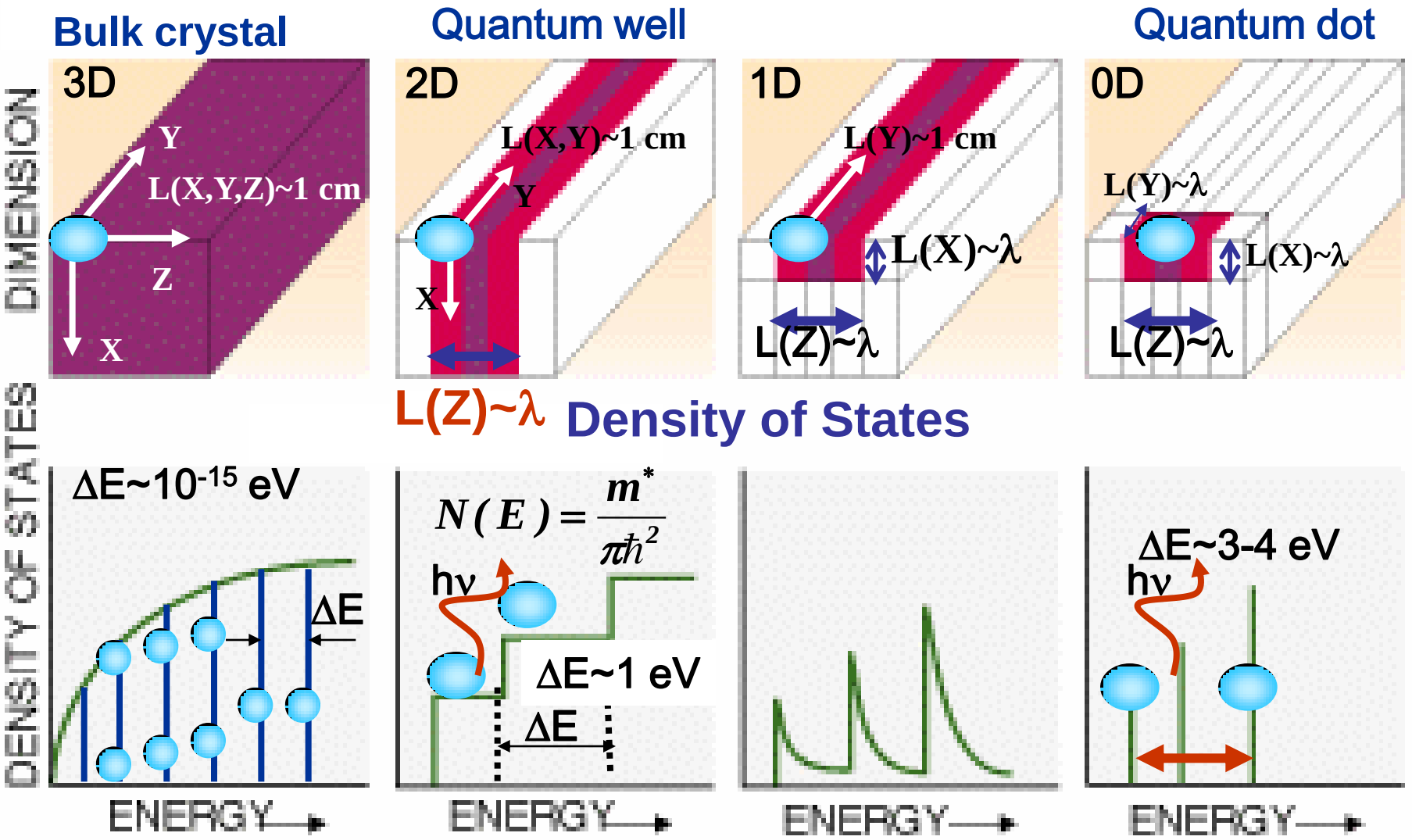
L~λ(de Broglie wavelength of an electron, λ~10-40 Angstrom)



$$E_n = \frac{\hbar^2}{2m}\left(\frac{n\pi}{L}\right)^2$$

Quantum Confinement Phenomena

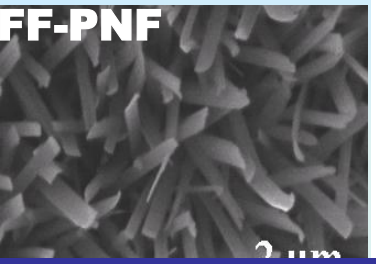
L~λ(de Broglie wavelength of an electron, λ~10-40 Angstrom)



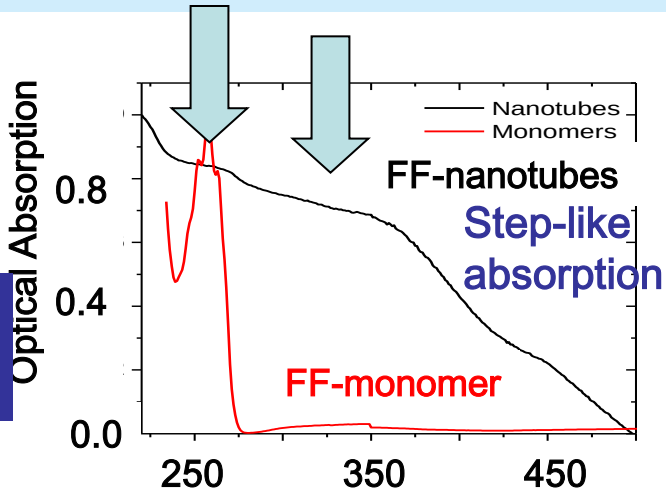
$$E_n = \frac{\hbar^2}{2m}\left(\frac{n\pi}{L}\right)^2$$

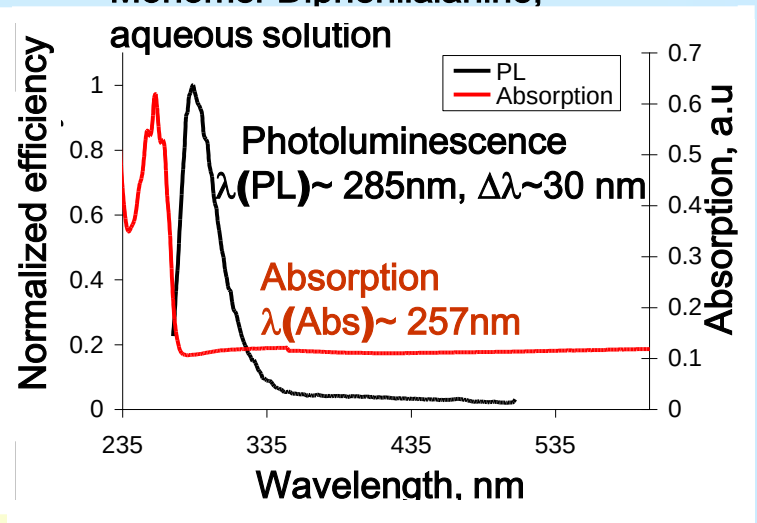
Optical Data-Virtual Probe Microscopy

Quantum Confinement in Self Assembled Bio-Inspired Peptide Nanotubes

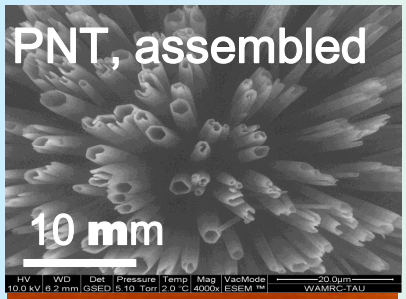


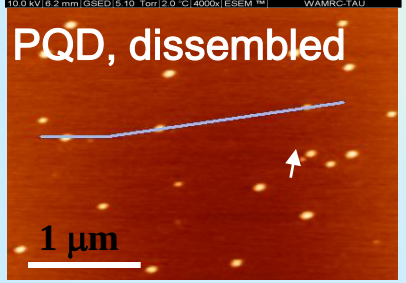
Quantum Well Structure

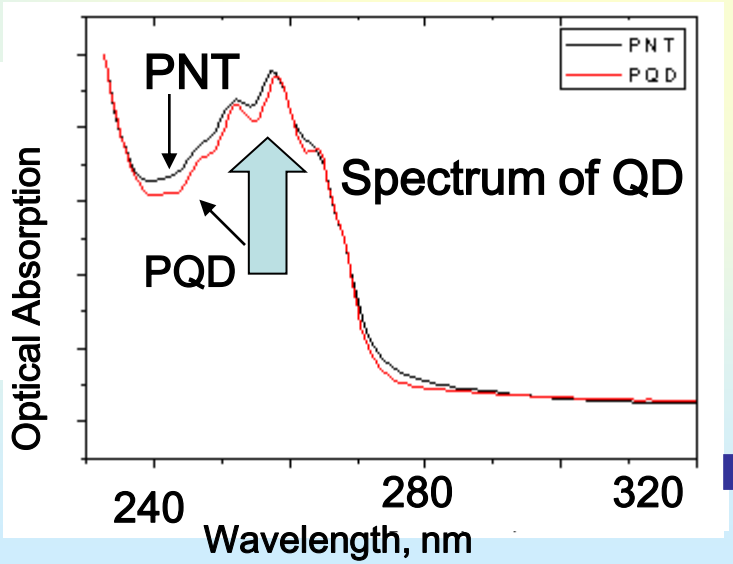




FF-peptide nanotubes (evaporation from solutions)







FF- Vapor Deposited Peptide Nanofibers

Step-like optical absorption

2D-Quantum Confinement

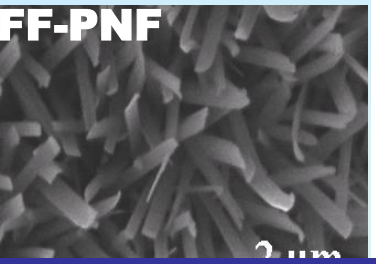
PNT-Assembled from Solution

Peak-like optical absorption

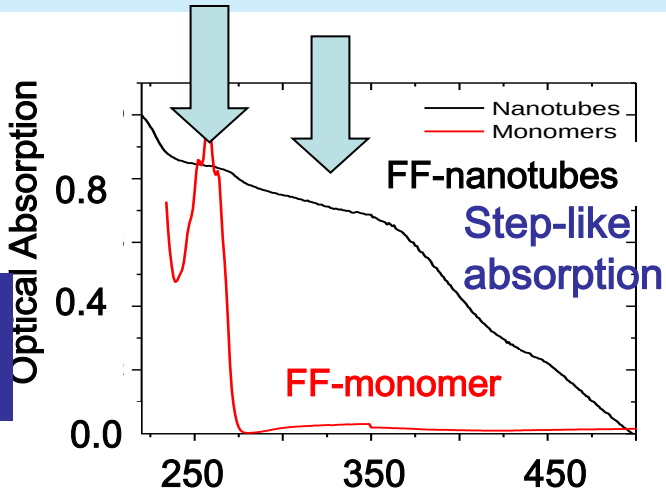
OD-confinement

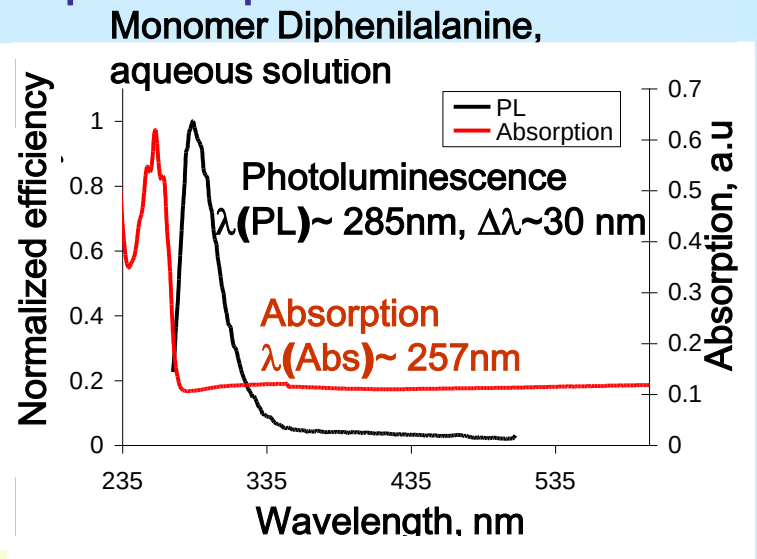
JACS, 2010

Quantum Confinement in Self Assembled Bio-Inspired Peptide Nanotubes

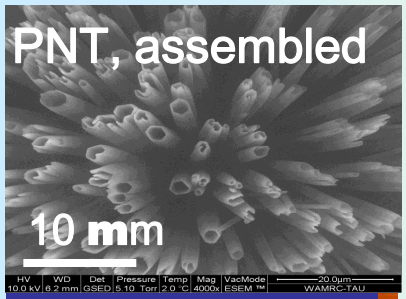


Quantum Well Structure

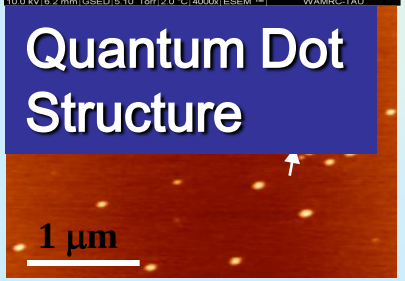


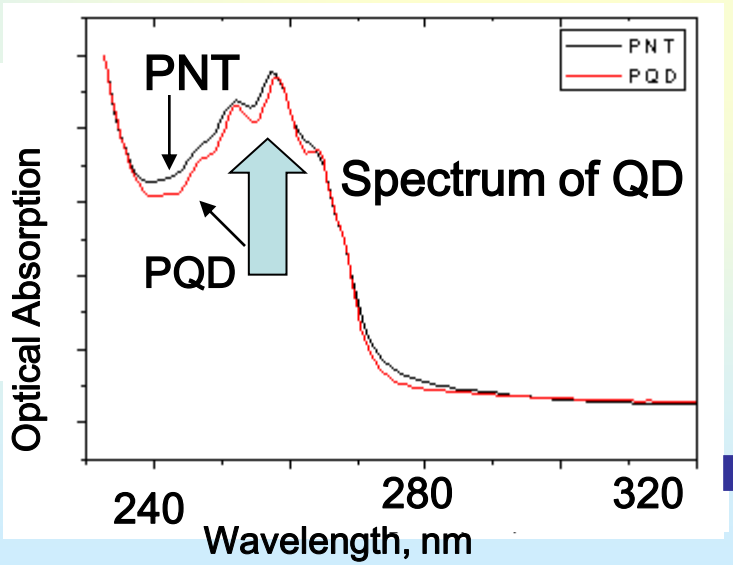


FF-peptide nanotubes (evaporation from solutions)



Quantum Dot Structure





FF- Vapor Deposited Peptide Nanofibers

Step-like optical absorption

2D-Quantum Confinement

PNT-Assembled from Solution

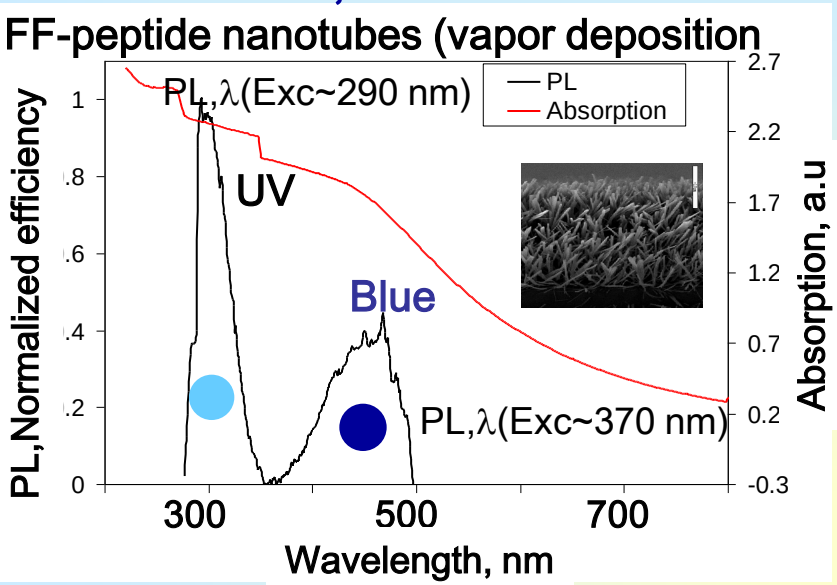
Peak-like optical absorption

OD-confinement

JACS, 2010

Photoluminescence in Quantum Confined Bio-Inspired Nanostructures

Nano Letters, 2009

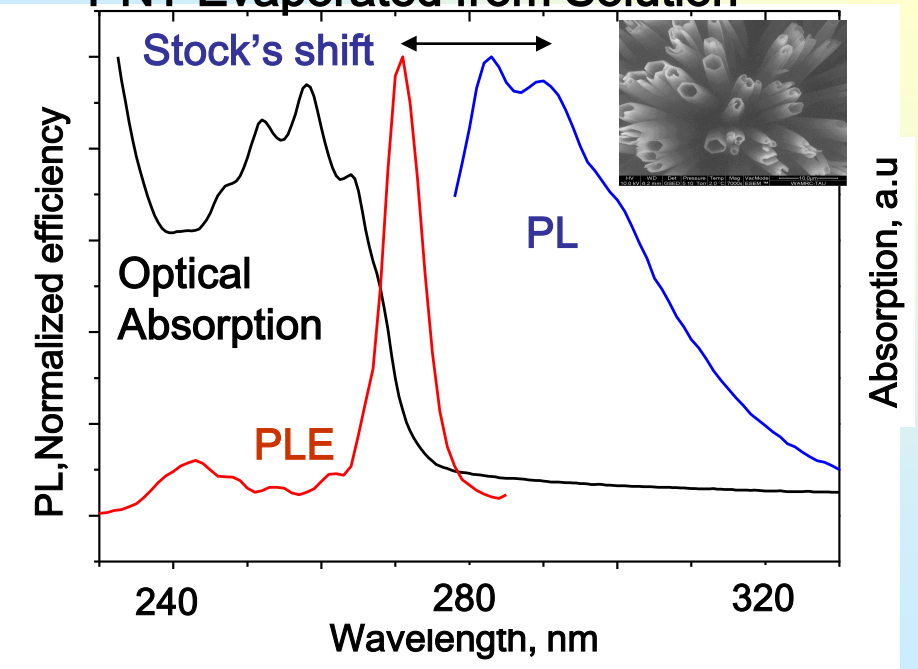


1. Step-like optical absorption spectra

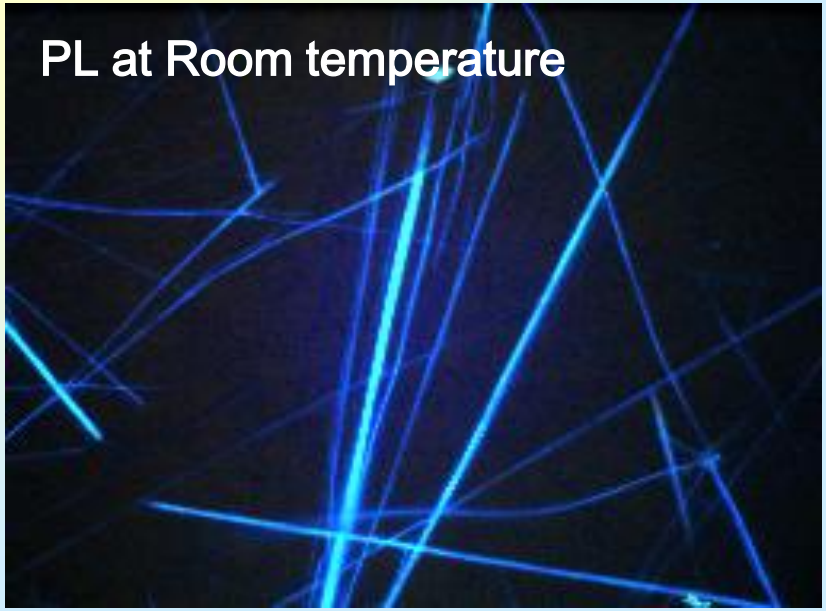
2D-quantum confinement
in self assembled FF-nanofibers
Highly Ordered Nanocrystallized QW Structure

2. Photoluminescence in UV and visible region of Exciton origin at Room Temperature

ΔE=0.98 eV, L~10-13 Å

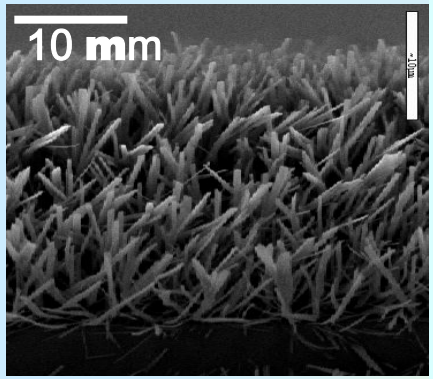


Vapor Deposited PNT



Cyclic Peptide Nanotubes-QW Engineering

FF-peptide nanotubes (vapor deposition)



Nano Lett., 2009

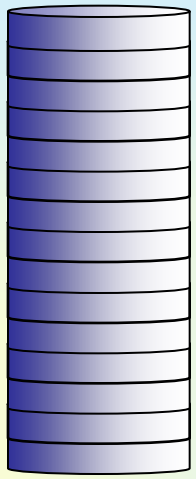
Self Assembly Process:
PNT of 10 μm length:
10,000 QW in dozen of seconds

QW structure in PNT is intrinsic structure for Laser-

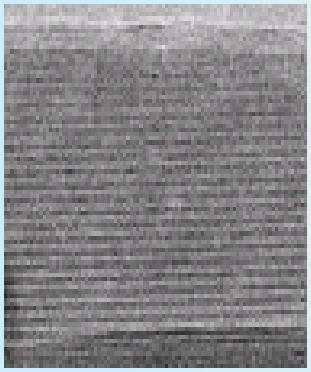
QW-Bio-Laser?

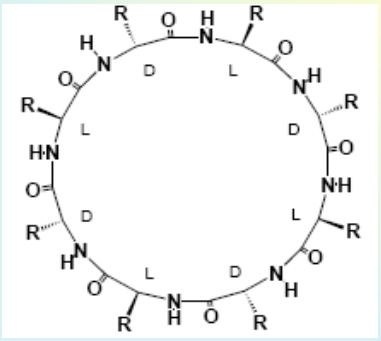
Quantum Well Structure

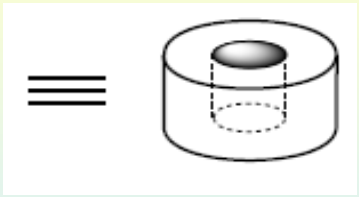
Δ~13 Å

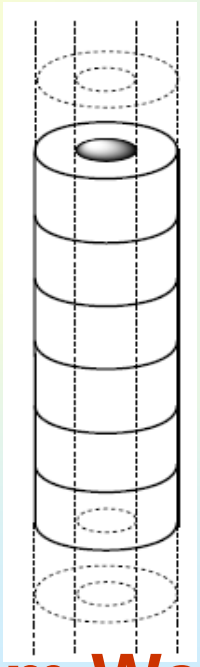


R. Ghadiri , *Nature., (1993); J. Am. Chem. Soc., (1996)*





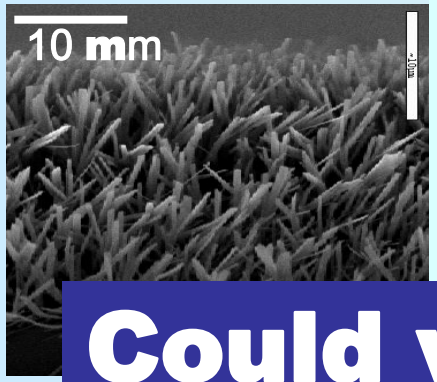




Cyclic Peptides → **Quantum Wells**

Cyclic Peptide Nanotubes-QW Engineering

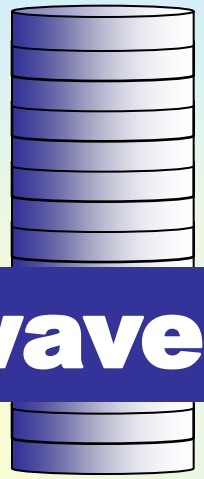
FF-peptide nanotubes (vapor deposition)



Self Assembly Process:
PNT of 10 μm length:
10,000 QW in dozen of seconds

Quantum Well Structure

Δ~13 Å

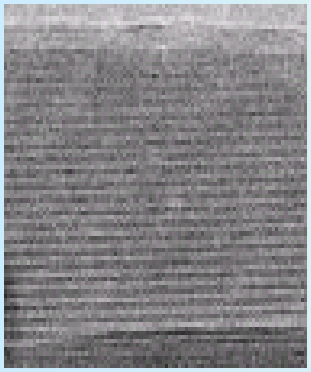


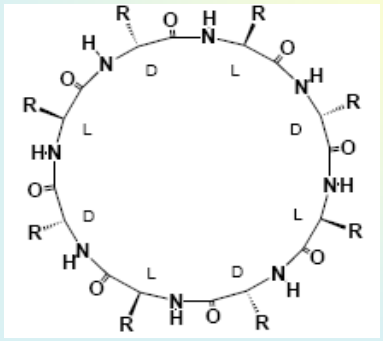
Could we TUNE the wavelength?

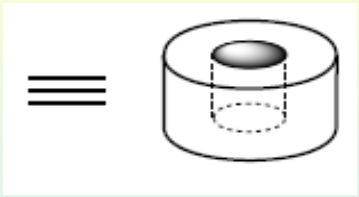
Nano Lett., 2009

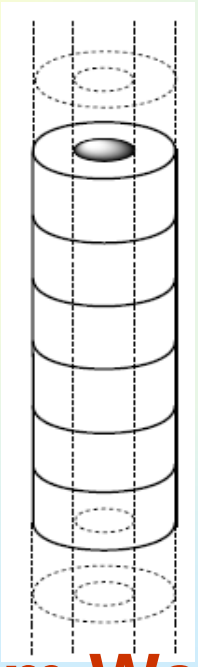
QW-Bio-Laser?

R. Ghadiri , *Nature., (1993); J. Am. Chem. Soc., (1996)*



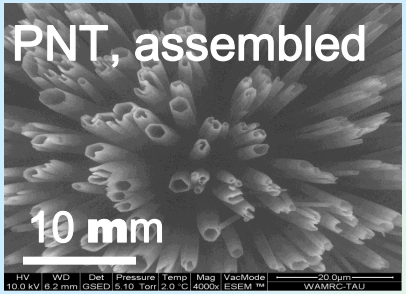


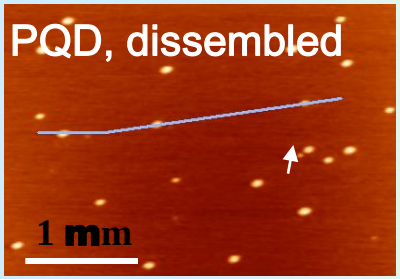


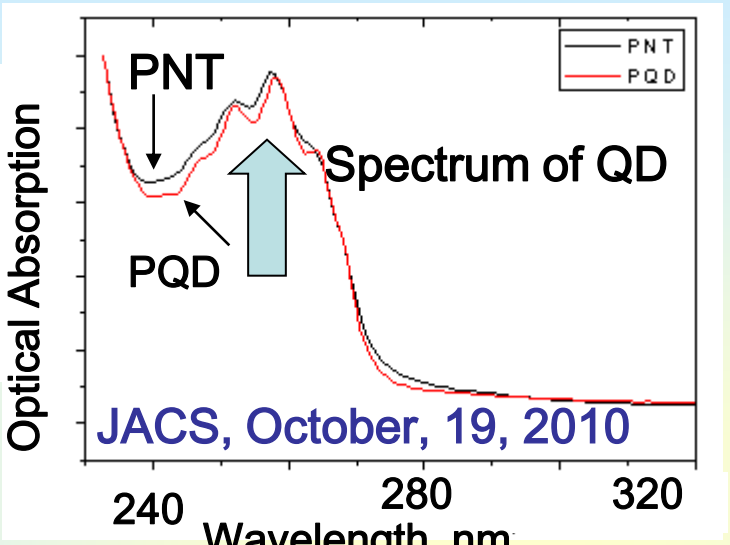


Cyclic Peptides → **Quantum Wells**

FF-peptide nanotubes (evaporation from solutions)

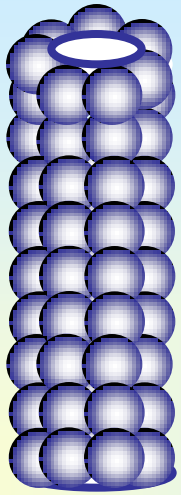


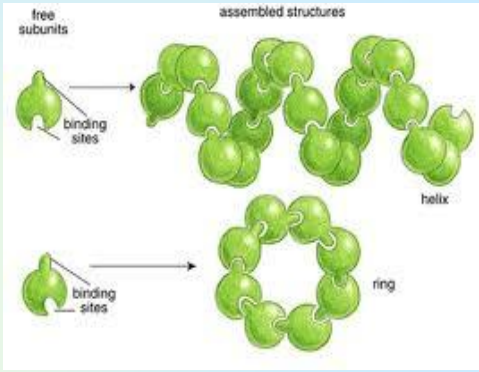


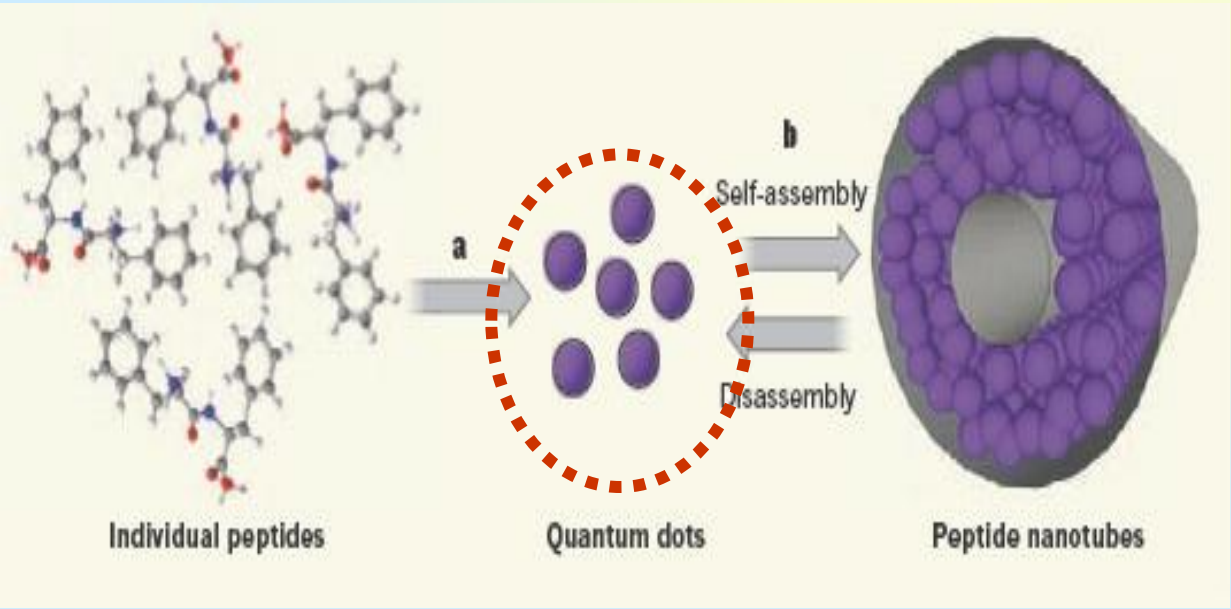


Quantum Dot Structure

Δ~15 Å





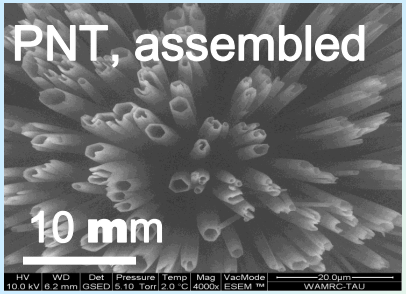


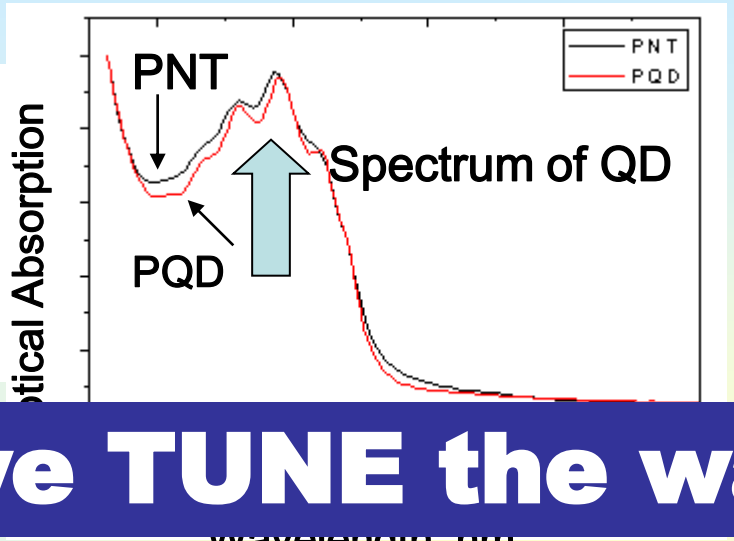
QD-Bio-Laser?

QD-Bio-Markers?

Nature, N&V, 468, Nov 25, 2010

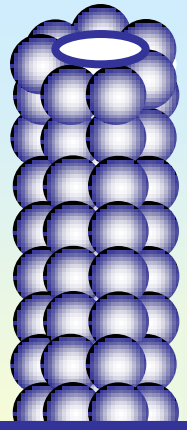
FF-peptide nanotubes (evaporation from solutions)

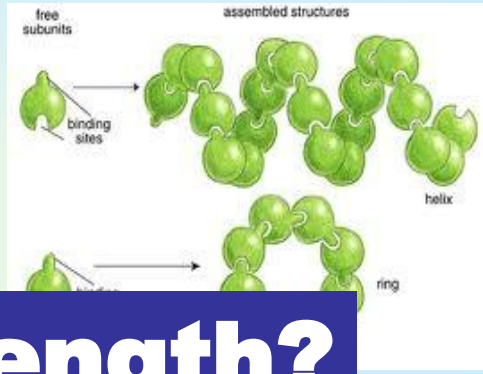




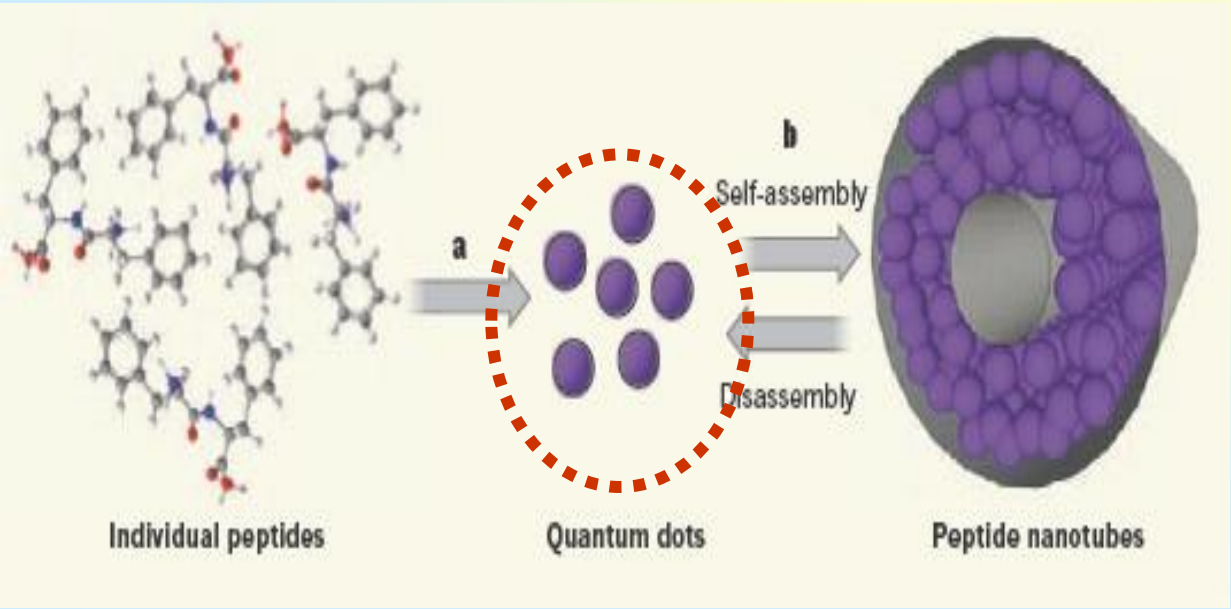
Quantum Dot Structure

Δ~15 Å





Could we TUNE the wavelength?



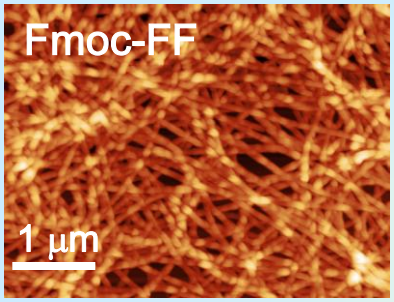
QD-Bio-Laser?

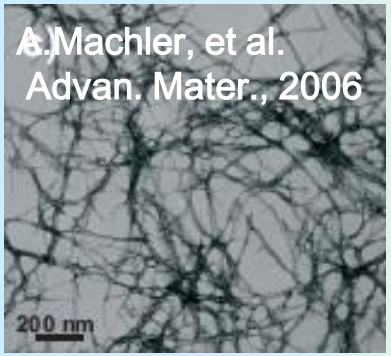
QD-Bio-Markers?

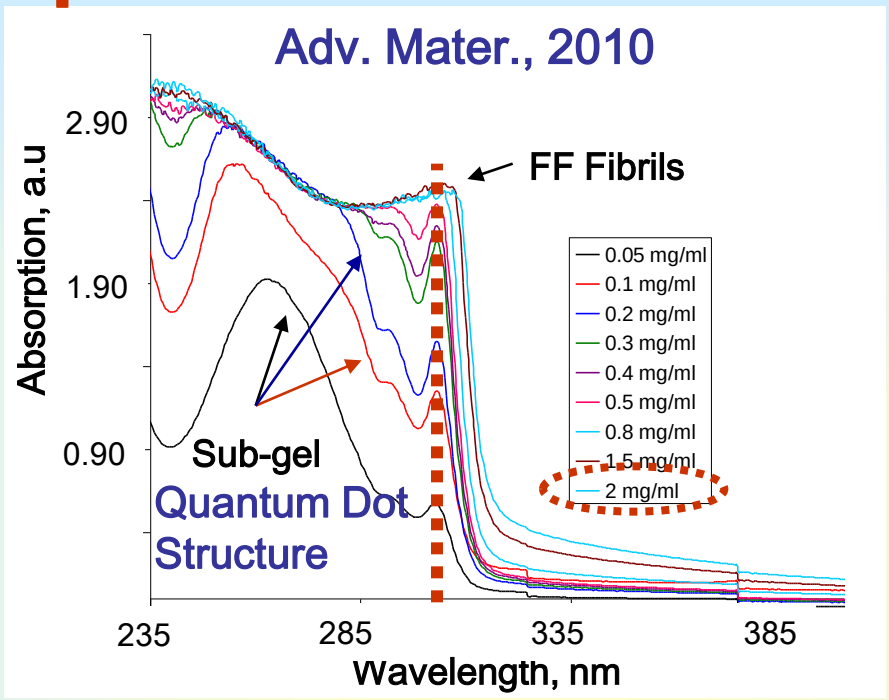
Nature, N&V, 468, Nov 25, 2010

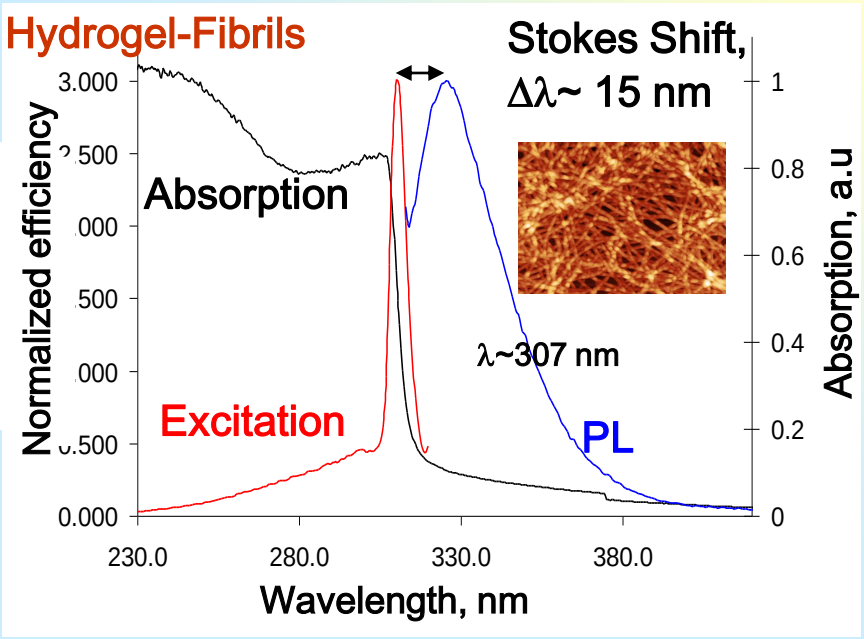
Peptide Nanotubes Self Assembly Mechanism

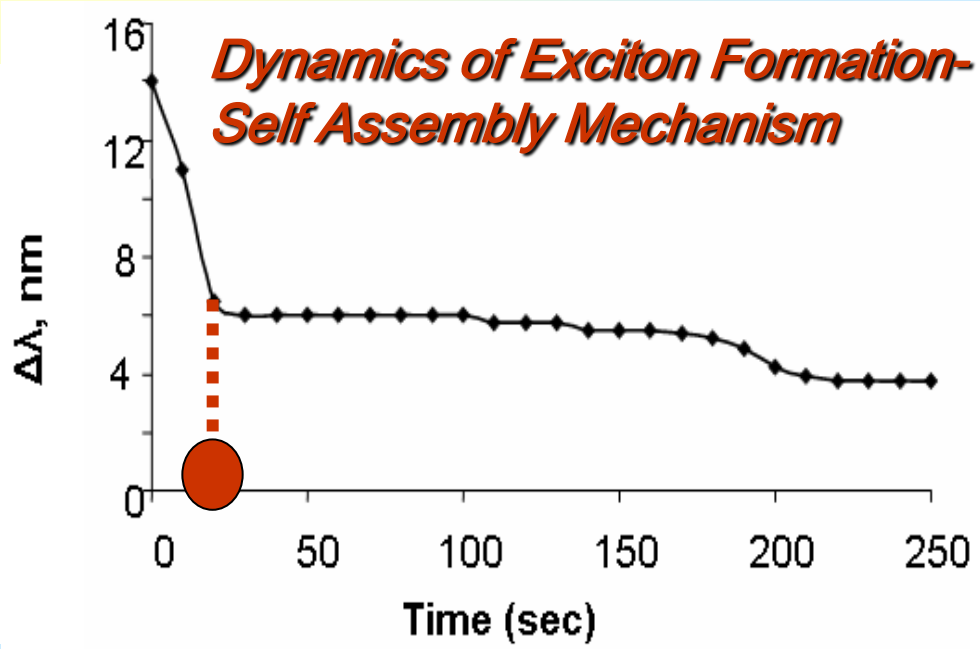
Hydrogel Fmoc-FF





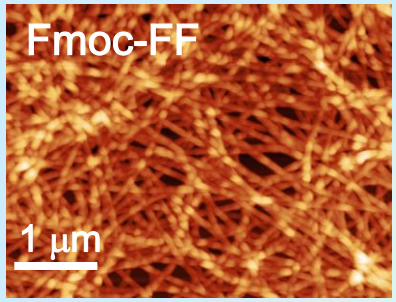




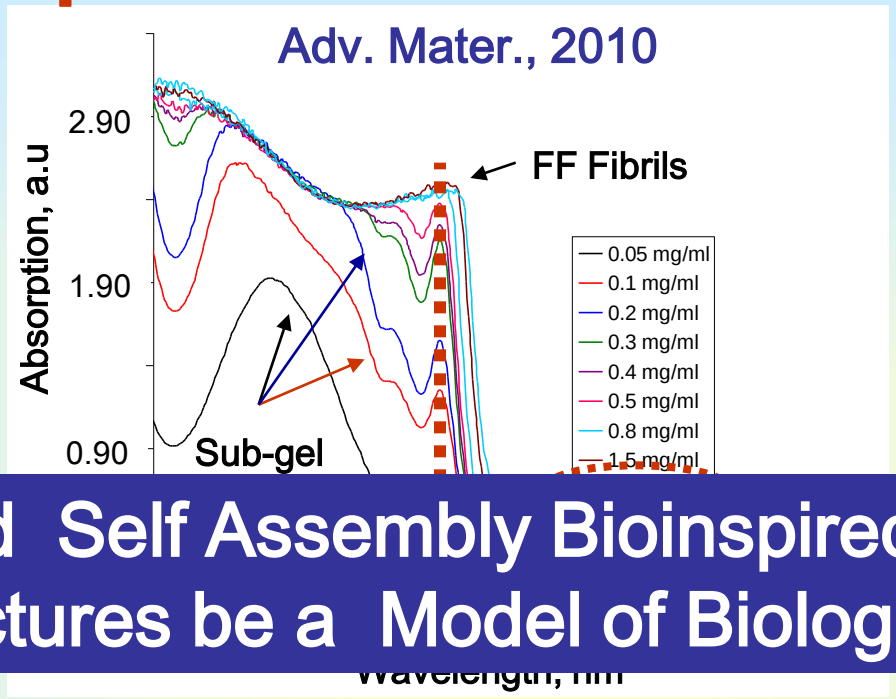


Peptide Nanotubes Self Assembly Mechanism

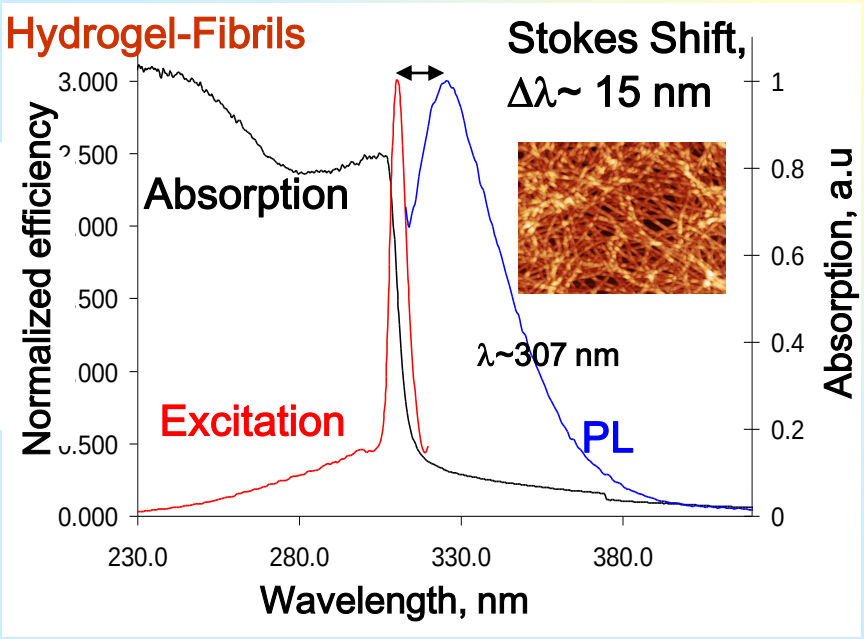
Hydrogel Fmoc-FF

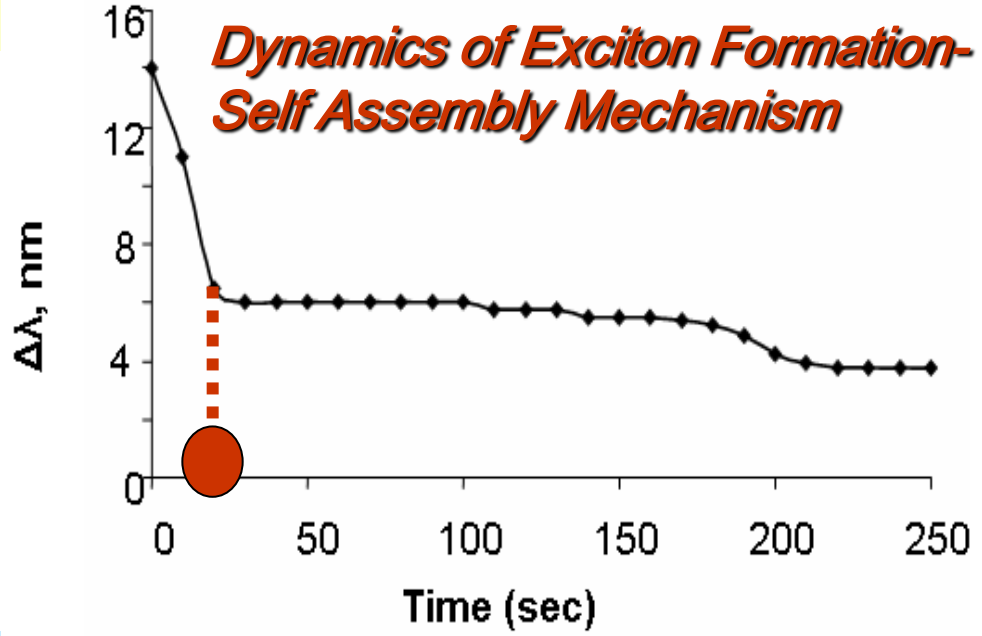


A.Machler, et al.
Advan. Mater., 2006

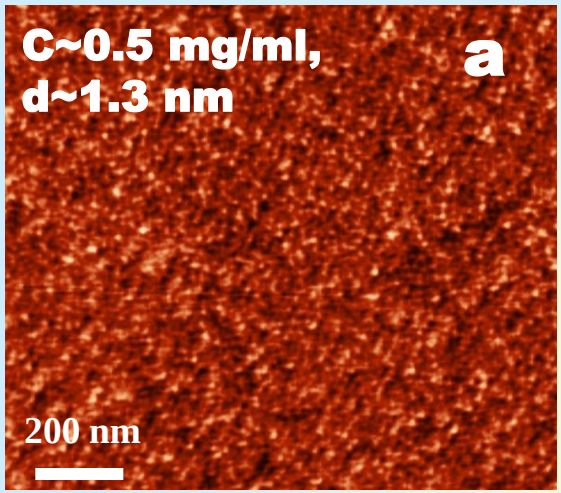


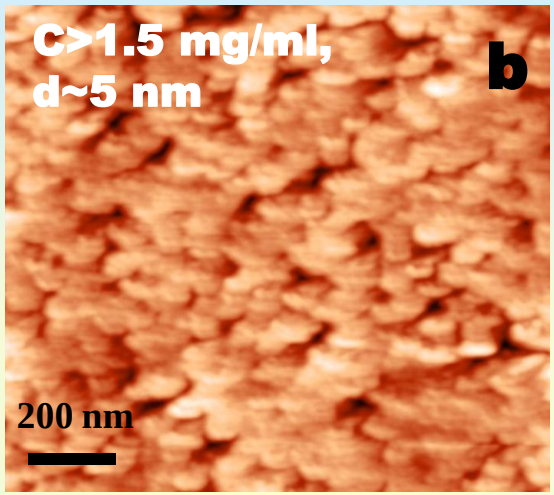
Could Self Assembly Bioinspired Peptide Nanostructures be a Model of Biological Materials?

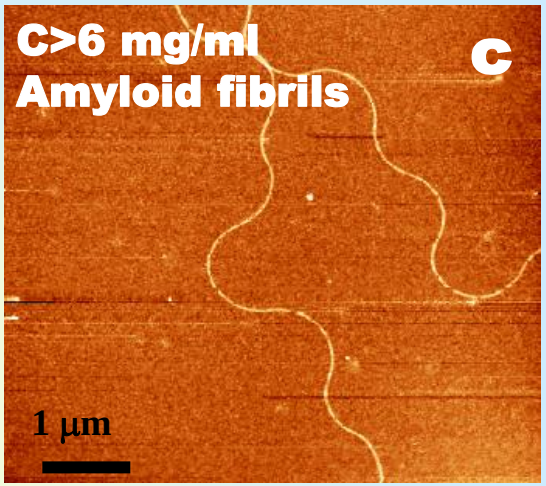


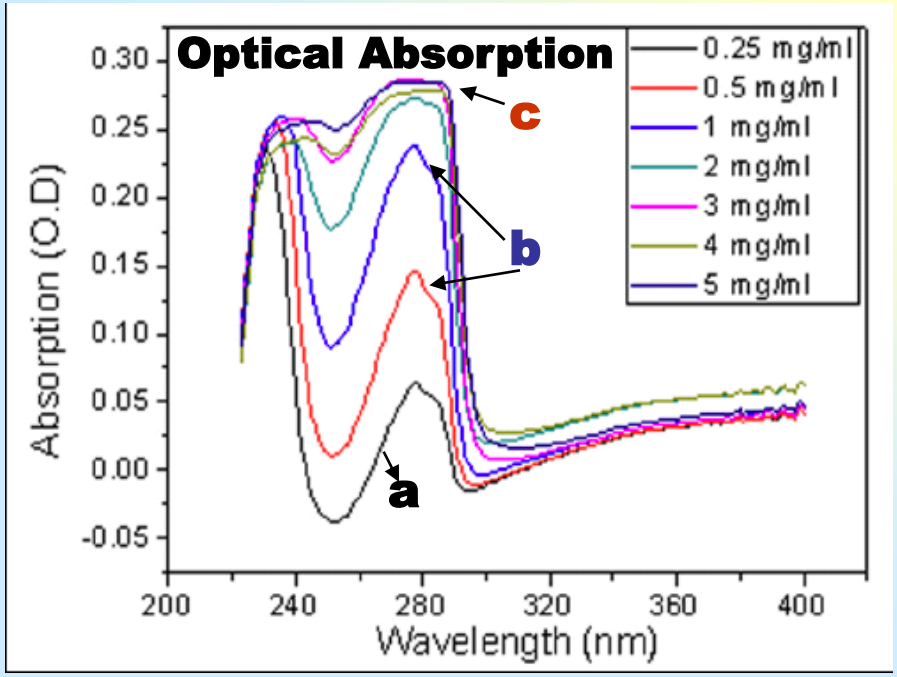


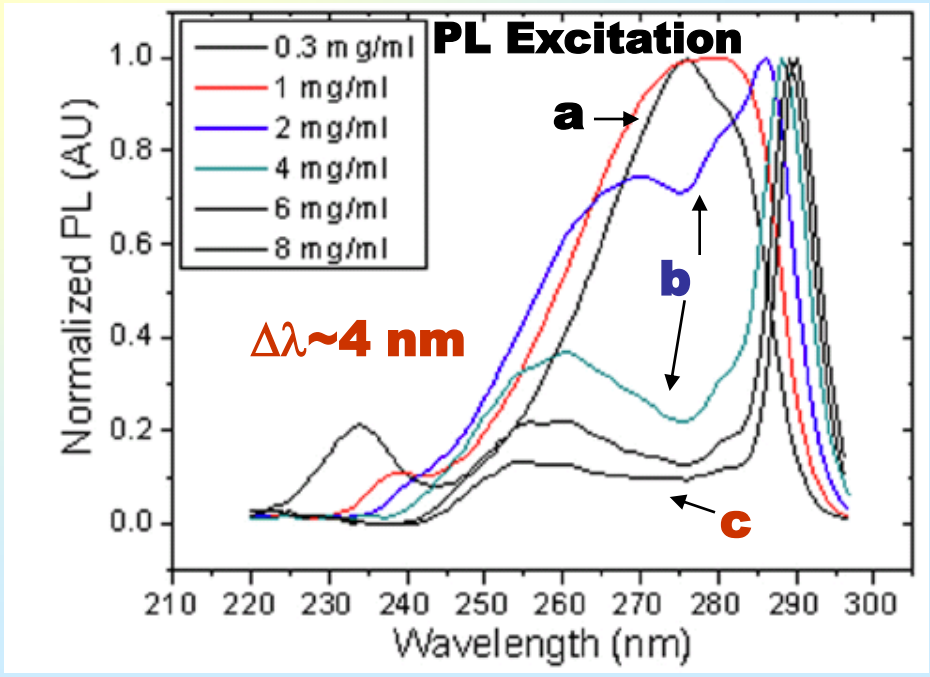
Self Assembly Insulin Amyloid Fibrils











Part III

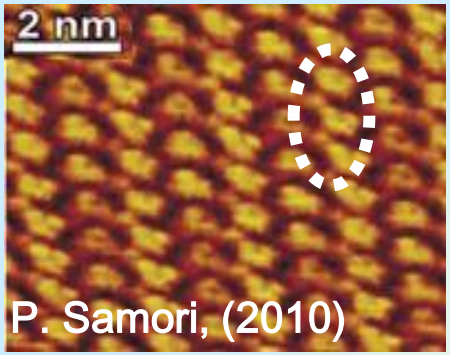
BIOLOGICAL AND BIOINSPIRED NANOSTRUCTURES:

FERROELECTRICITY AND RELATED PHENOMENA

Pasteur, 1860:

Biological systems have a common basic feature: pronounced chiral dissymmetric structures

Biological and Bioinspired Structures: Motivation and Goals



-Structural Nanoordering (scale of ~10-30 Å)

New Physical Situation

-Low Dimensional Structures: Quantum confinement, Exciton PL, LED and Lasers, Diagnostics of Amyloid Disease

-Symmetry of Nanocrystalline blocks: Ferroelectric and Related Phenomena Such as Piezoelectric, Linear Electrooptic and Nonlinear Optical Effects

Motivation and Goals

-Ferroelectric Properties in Bioinspired Nanostructures

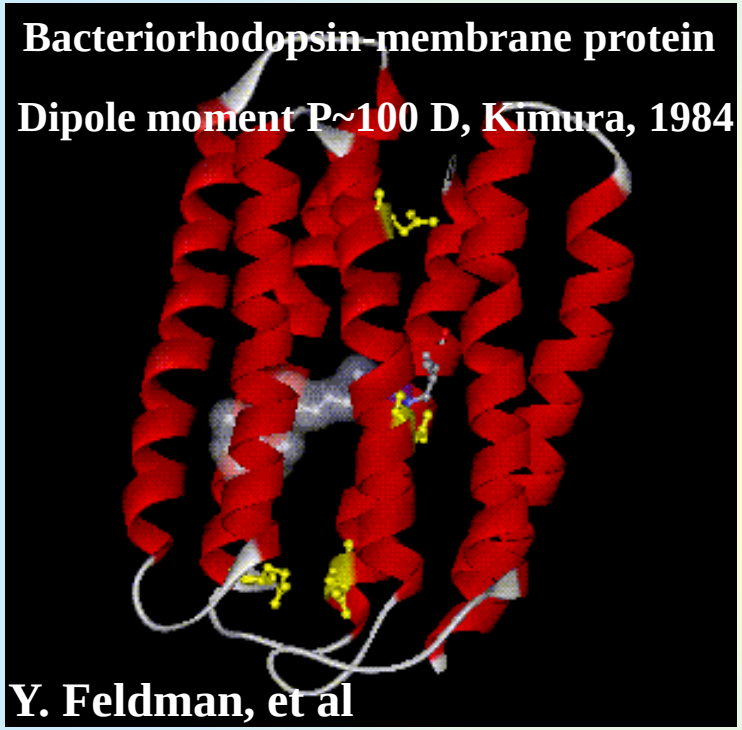
- Bottom-up Technology

-Ferroelectric (Piezoelectric) Bioinspired Biocompatible Materials

Ferroelectricity in Biology

Piezoelectricity, SHG are Fundamental and INTRINSIC Property of Biological Materials.

Plants, animal and human tissues are Piezoelectrics.



J. Phys. Chem. B, 105, No. 14, 2001

Ferroelectric and related phenomenon

Piezoelectric effect in bones
Fukada, J. Phys. Soc. Japan, 1957

Linear electroptic effect in nerve fibers
Tasaki, Jpn. J. Physiol, 1993

Second harmonic generation in pineal gland
Lang, IEEE Trans. on Dielectrics, 1996

Electrical Spontaneous Polarization

Pyroelectric properties in tendon and bones
Lang, Nature, 1966
Athenstaedt, Ann NY Acad. Sc., 1974
and in nerve tissue

Pyroelectric and piezoelectric properties in amino acids-based crystals
Lemanov, Ferroelectrics, 1998

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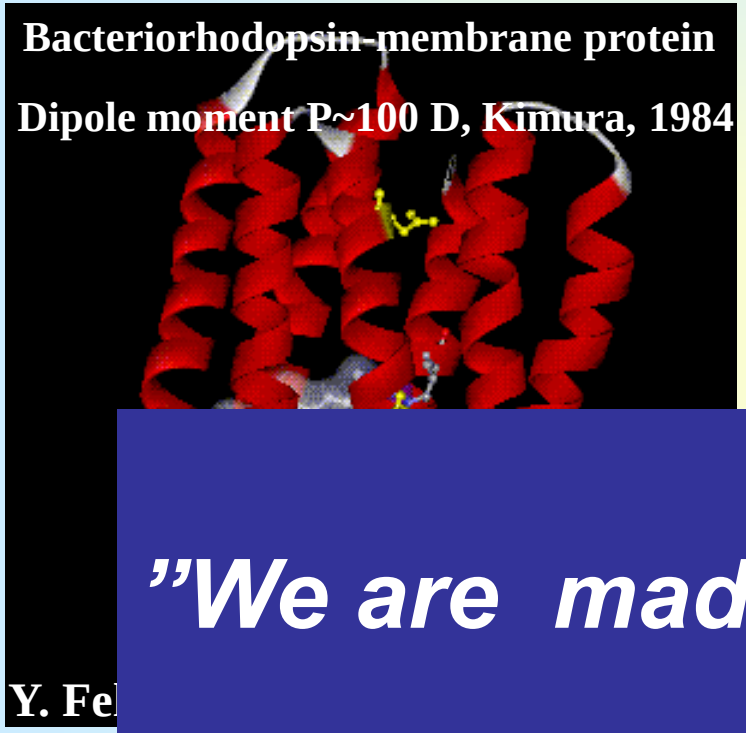

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Second harmonic generation in pineal gland and in nerve tissue

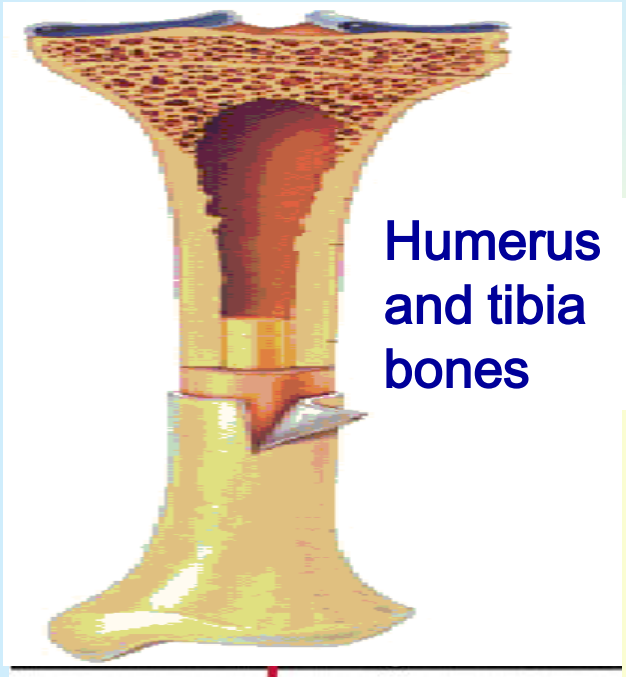
Pyroelectric and piezoelectric properties in amino acids-based crystals
Lemanov, Ferroelectrics, 1998

Y. Fe
J. Phy

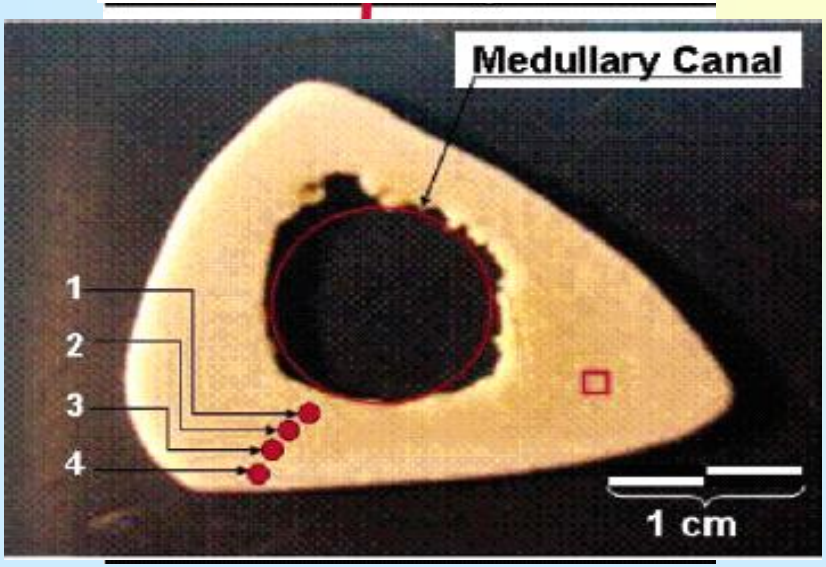
Matthias:
"We are made up of Ferroelectrics"

Piezoelectric Effect in Human Bones at Nanoscale

Rosenman, Nano Letters, (2004)



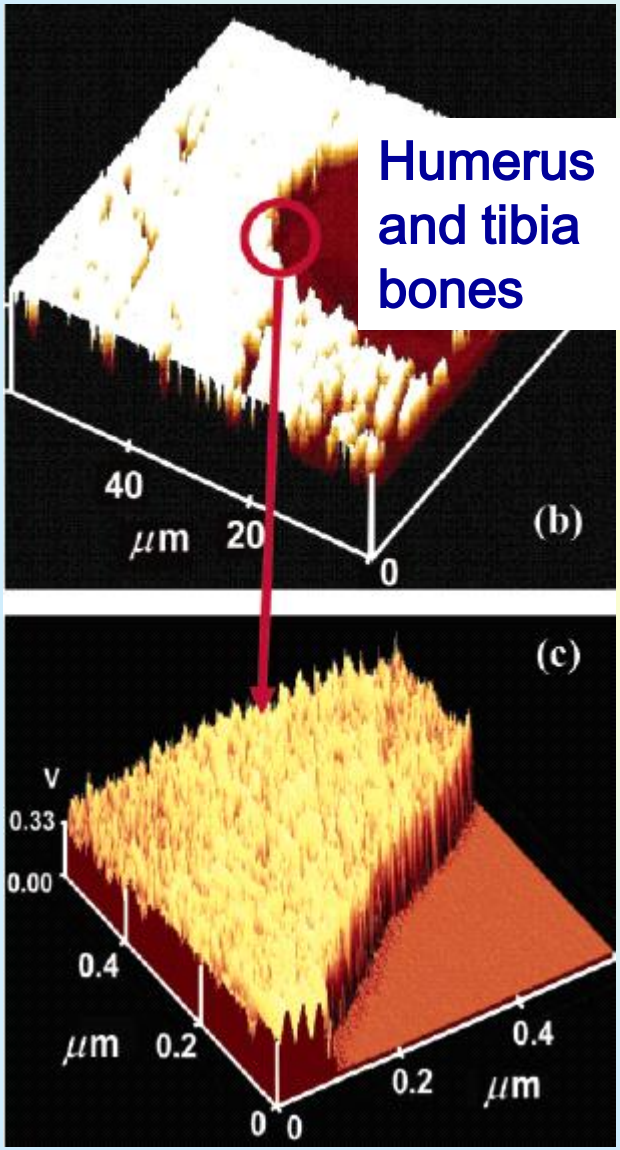
Humerus and tibia bones



Piezoelectric Effect in Human Bones at Nanoscale

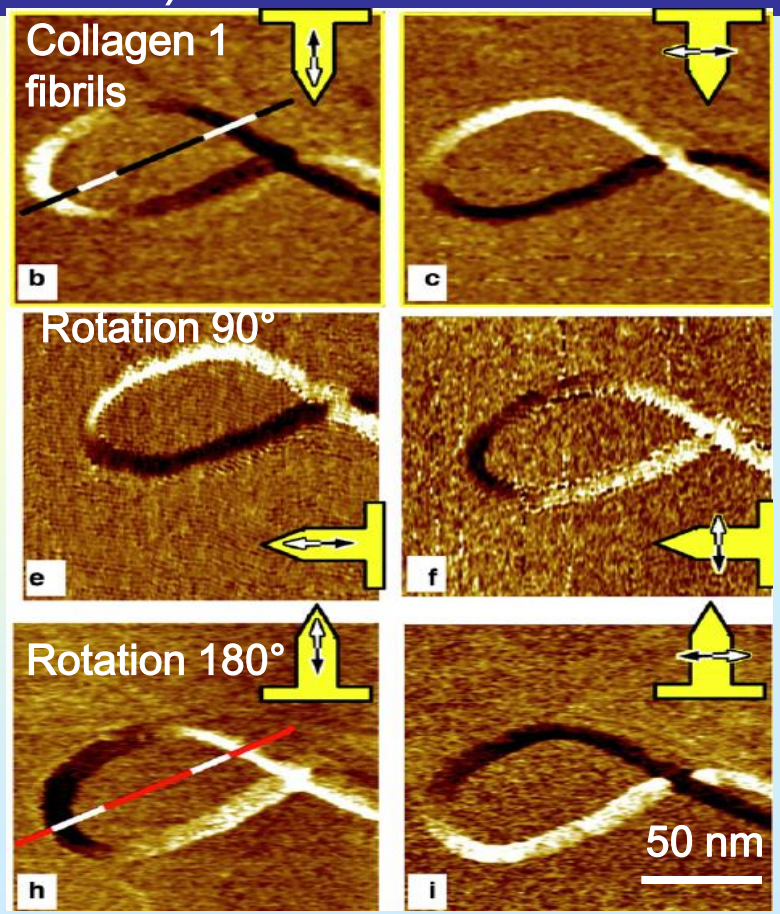
Rosenman, Nano Letters, (2004)

Piezoresponse image



A.Gruverman, Biophysical Journal, 2010
Collagen Type 1Fibrils, Piezoresponse,

Fibrils within parallel bundles in fascia tissues can have opposite polar axis orientation and are organized in small groups (domains) having the same polar orientation (180° domains).



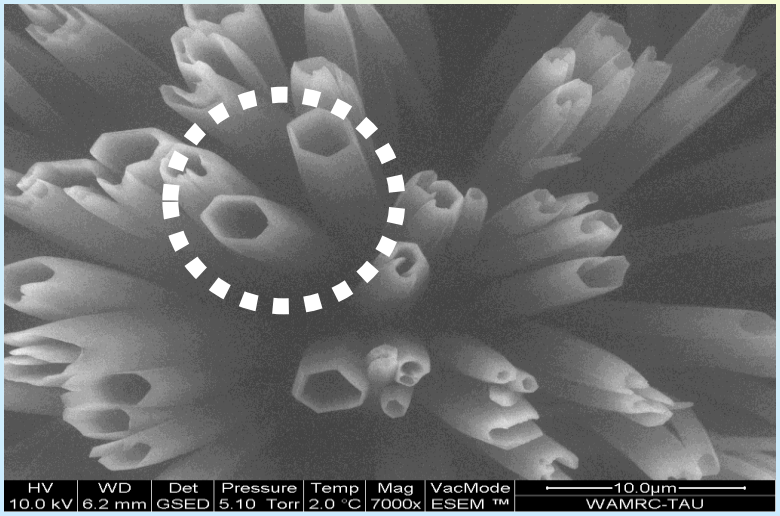
Ferroelectric and Related Properties in Bioinspired Peptide Nanotubes

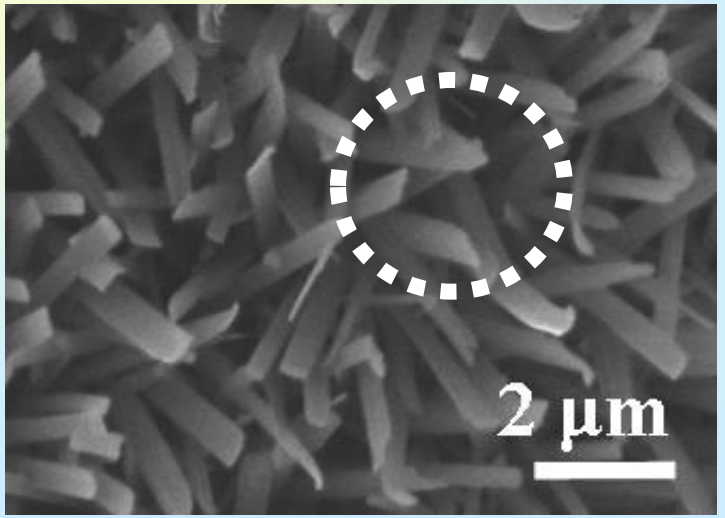
C. H. Görbitz, University of Oslo: Structure and Symmetry of 160 Dipeptide Nanotubes:

Chem. Eur. J. 2001
Chem. Commun. 2006;
Acta Cryst. 2010;
Curr. Opin. Sol. St. Mater. Sci. 2002

Dipeptides:	Space Group
LL-orthorhombic,	$P2_12_12_1$
LF-monoclinic	$P2_1$
FL-orthorhombic	$P2_12_12_1$
FF-hexagonal	$P6_1$

Diphenilalanine (FF) Peptide Nanostructures





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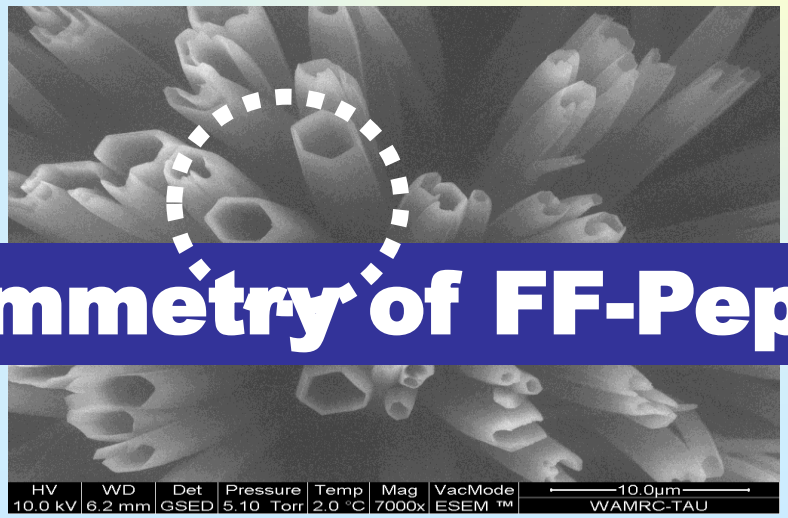
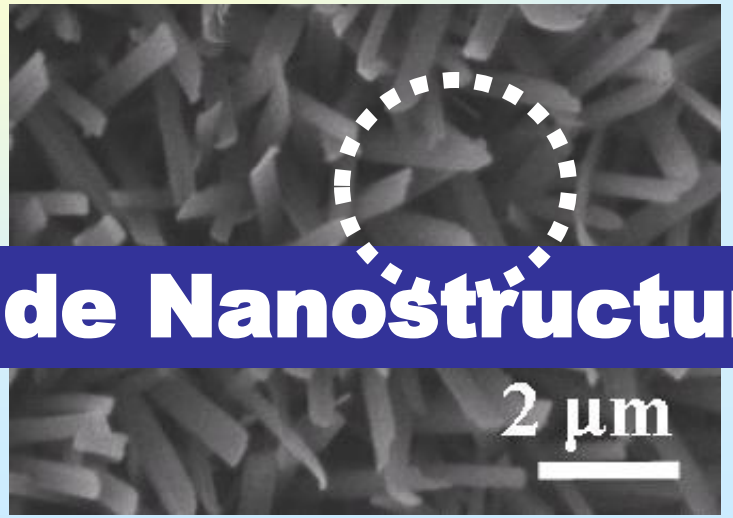
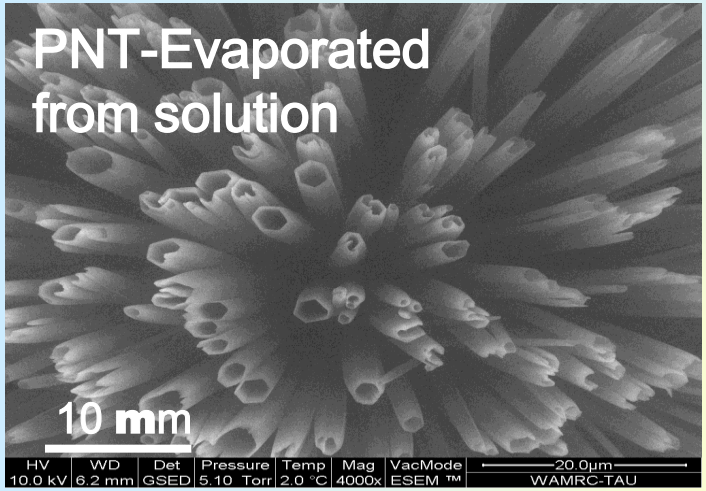


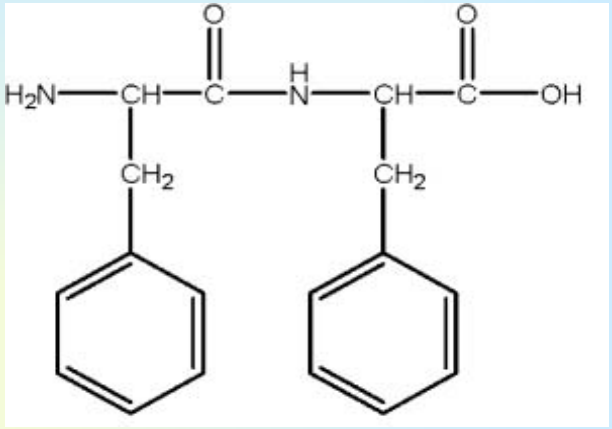


Symmetry of FF-Peptide Nanostructures?

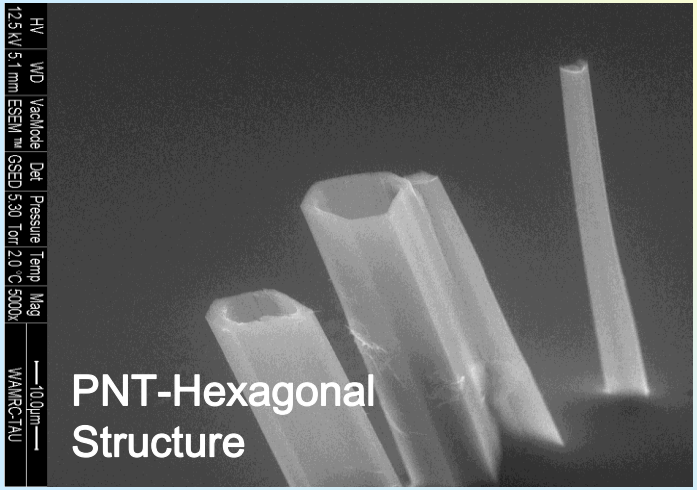
Ferroelectric Properties of FF-Peptide Nanotubes



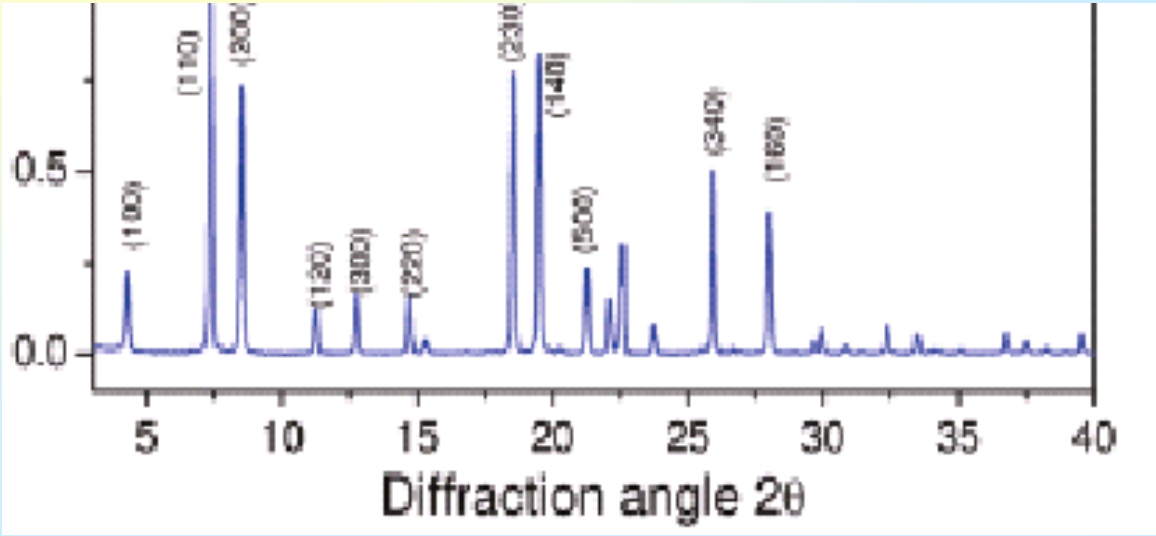
Self Assembly



Linear Diphenilalanine Peptide



Native PNT: Hexagonal Symmetry $P6_1$

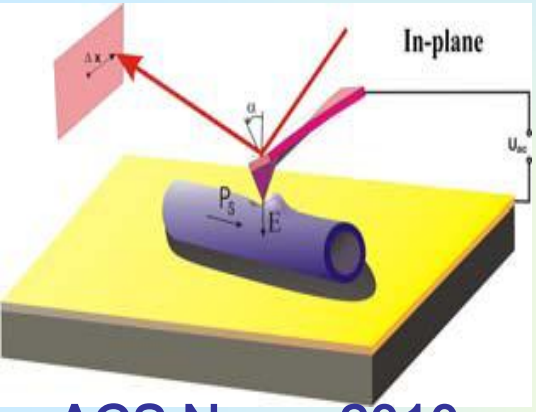


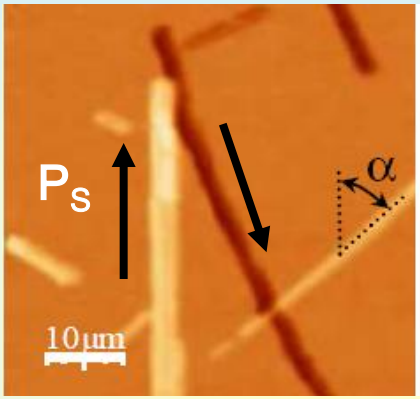
JACS, 2010
Biomacromolecules, 2011

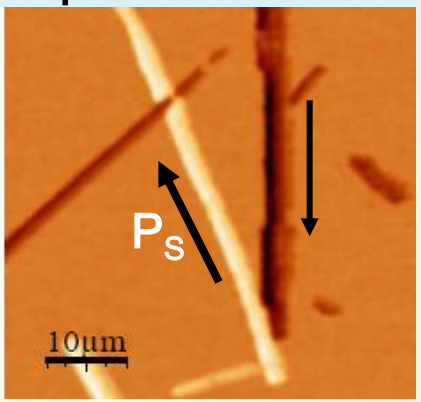
Peptide Nanotubes Piezoelectricity : Phase Transition

Piezo-Force Microscopy: cooperation with Dr. A. Kholkin (Portugal)

PFM-room temperature







1.Piezoelectric effect:

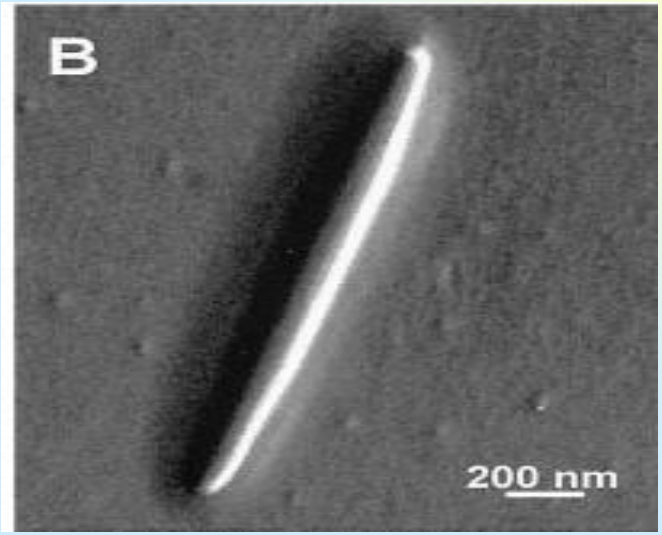
d_{15} ~ 100 pm/V

d_{33} ~ 7 pm/V

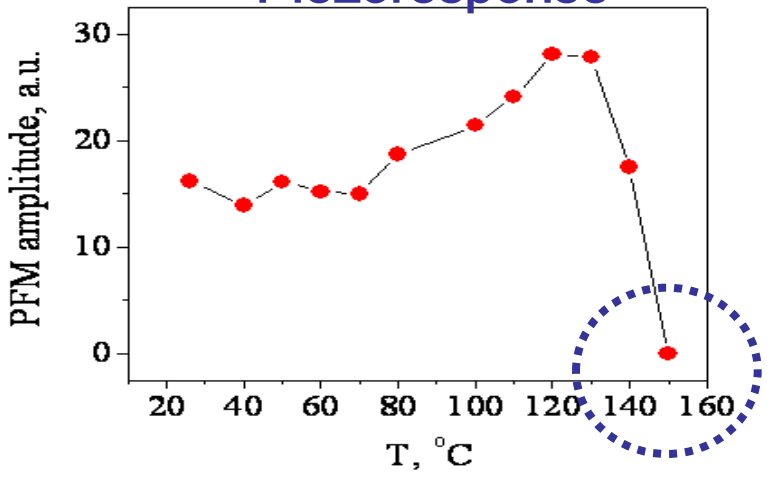
2. Spontaneous Polarization

ACS Nano, 2010

Piezo-Force Microscopy: cooperation with Prof. A. Gruverman (USA, Nebraska-Lincoln)



Piezoresponse



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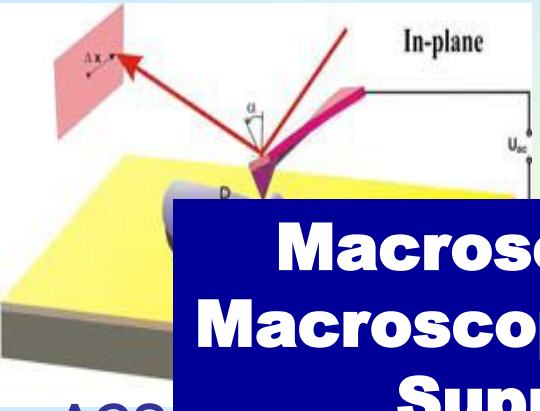

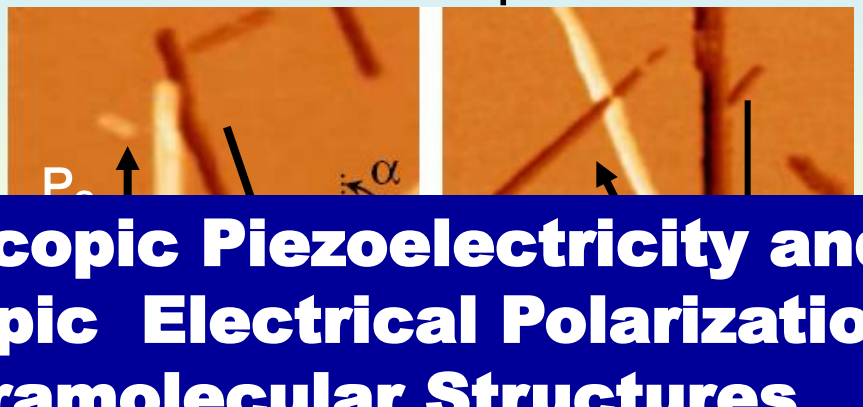

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ntaneous

zation

Macroscopic Piezoelectricity and Macroscopic Electrical Polarization in Supramolecular Structures

ACS

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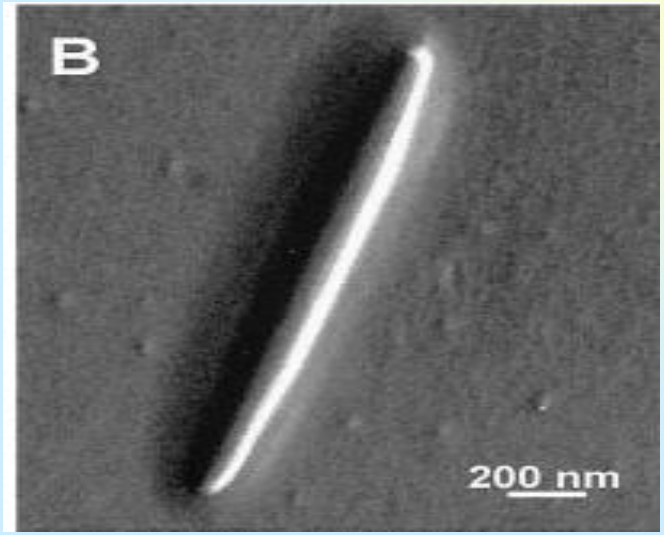
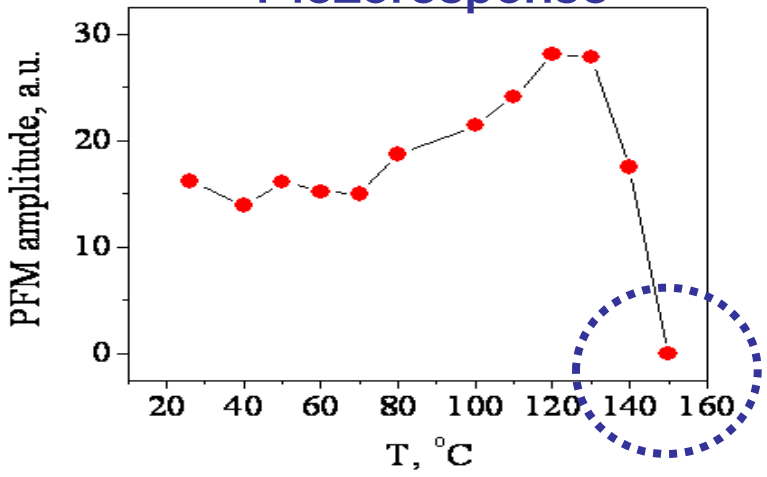


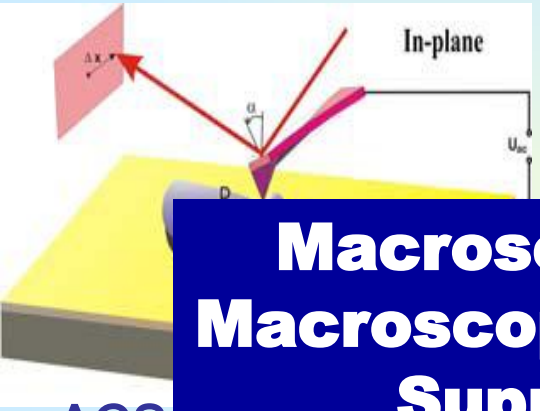
Piezoresponse

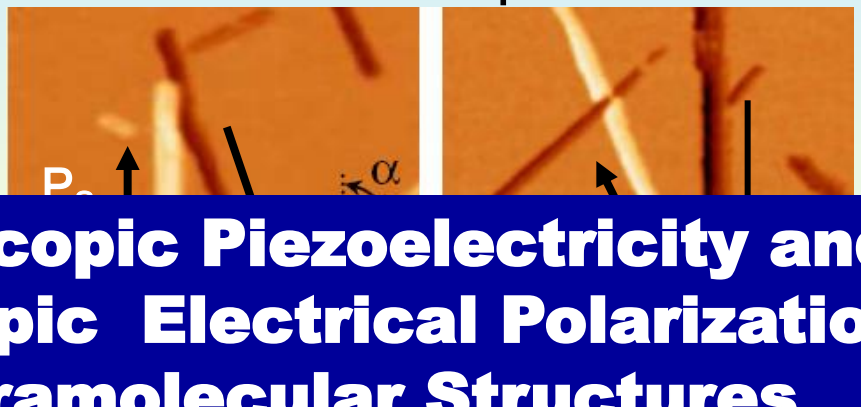


Peptide Nanotubes Piezoelectricity : Phase Transition

Piezo-Force Microscopy: cooperation with Dr. A. Kholkin (Portugal)

PFM-room temperature





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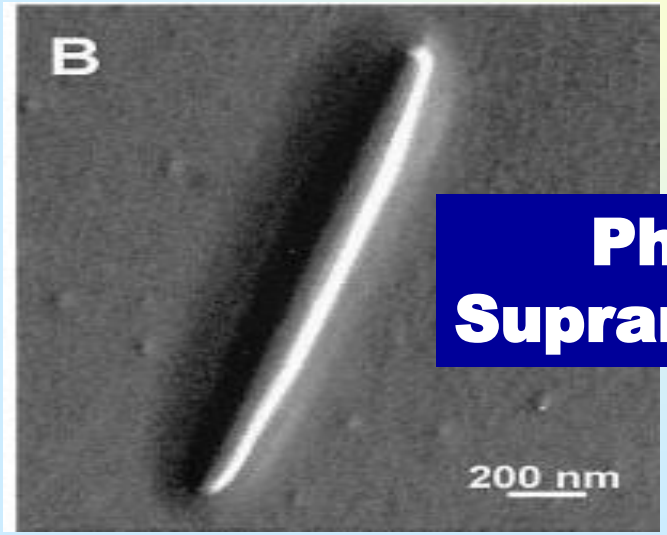
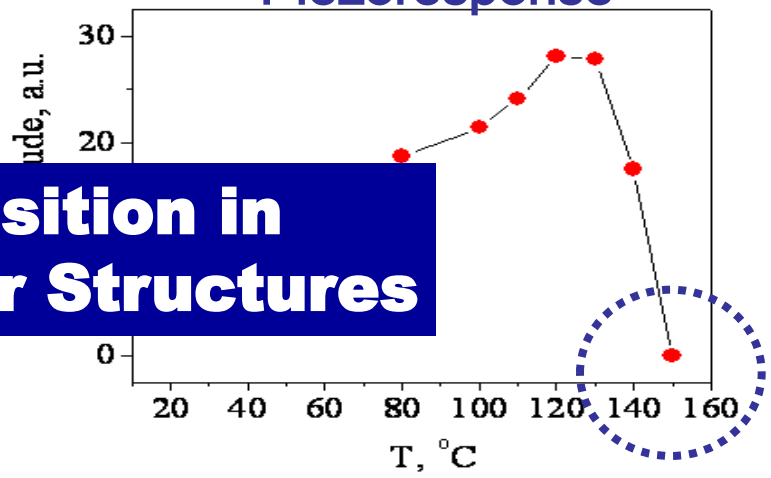


Phase Transition in Supramolecular Structures

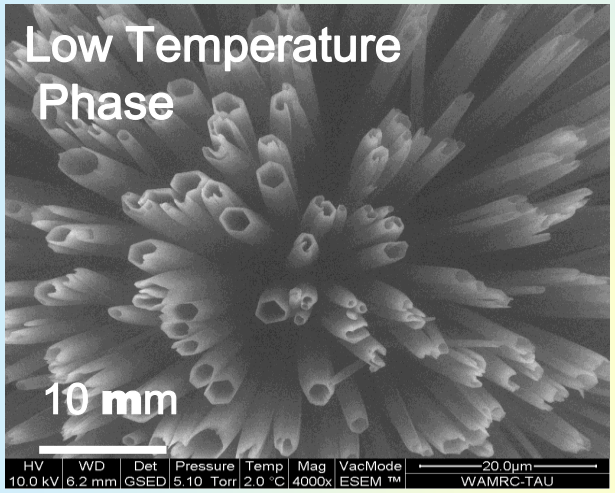
Piezoresponse



Phase Transition in FF-Peptide Nanotubes

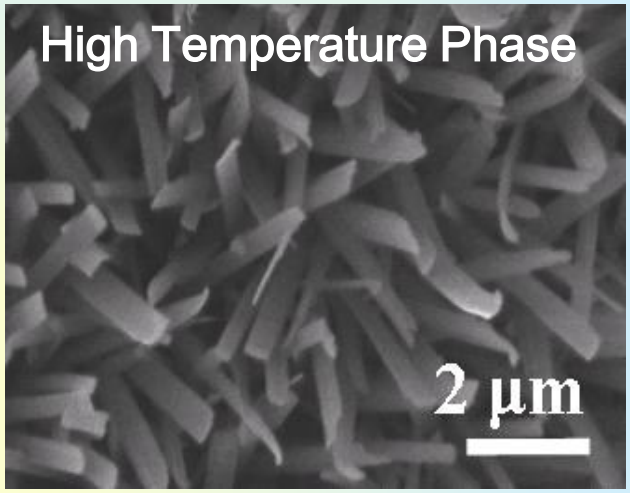
Diphenilalanine (FF) Peptide Nanostructures

Hollow Nanotubes



T~150C

Nanofibers



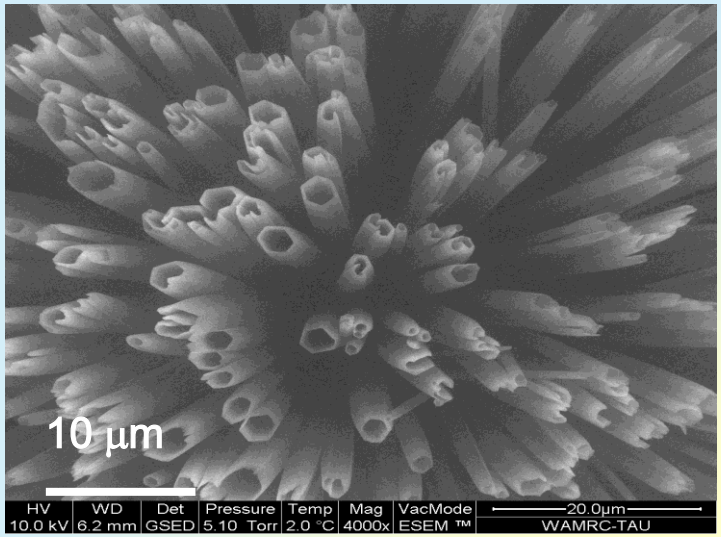
The Same Diphenilalanine Monomer BUT Absolutely Different Properties At All Levels:

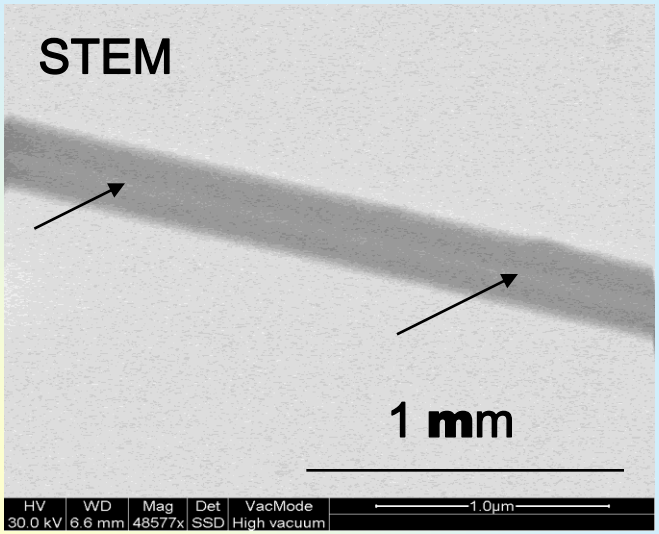
Morphology, Symmetry, Molecular, Piezoelecric, SHG, Electronic, Optical, Wettability..and More

J.Pept. Sci, 2011
Biomacromolecules, 2011

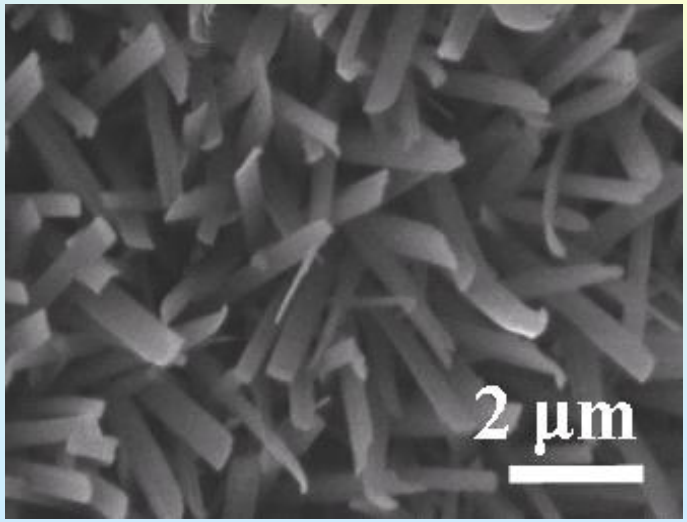
Peptide Nanotubes Morphological Transition

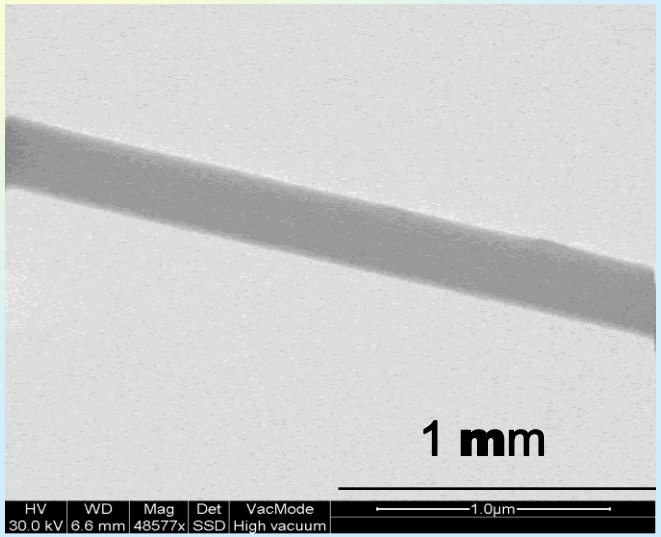
Biomacromolecules, 2011





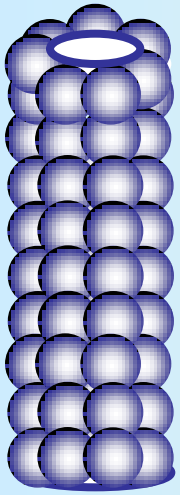
T~150 C

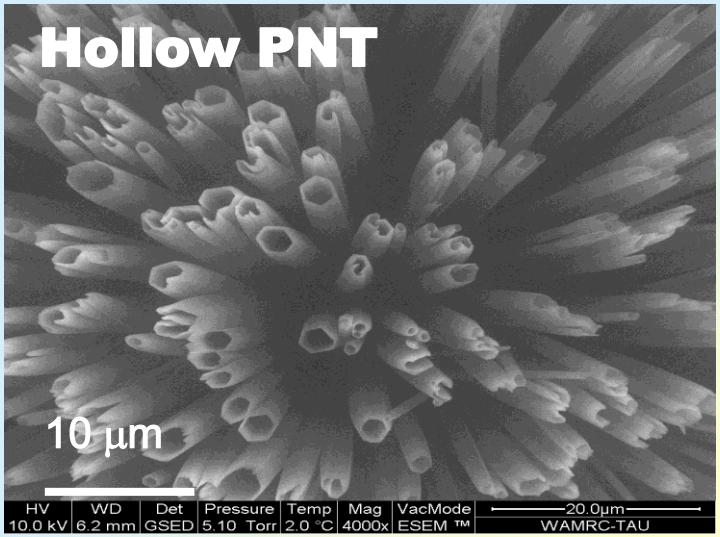


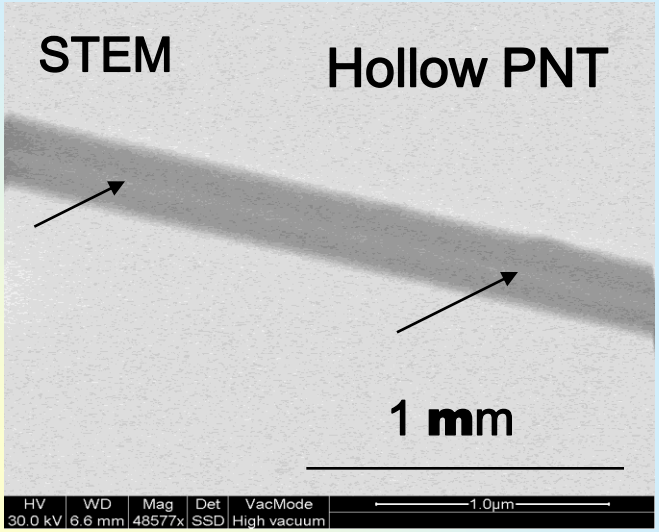


Peptide Nanotubes Morphological Transition

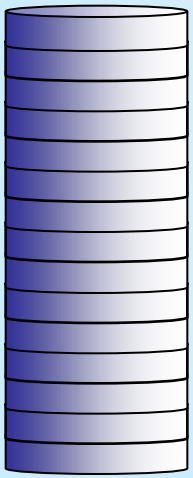
Biomacromolecules, 2011

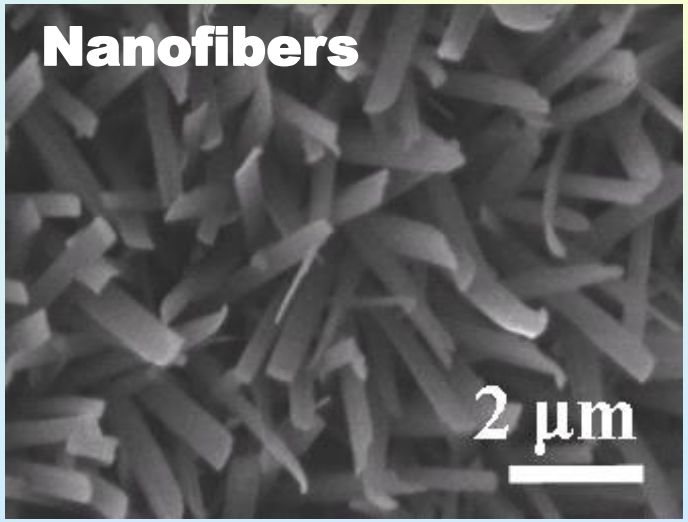


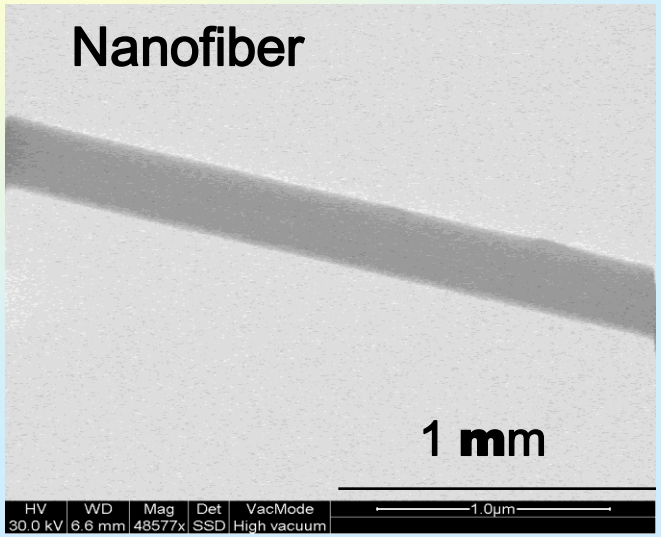




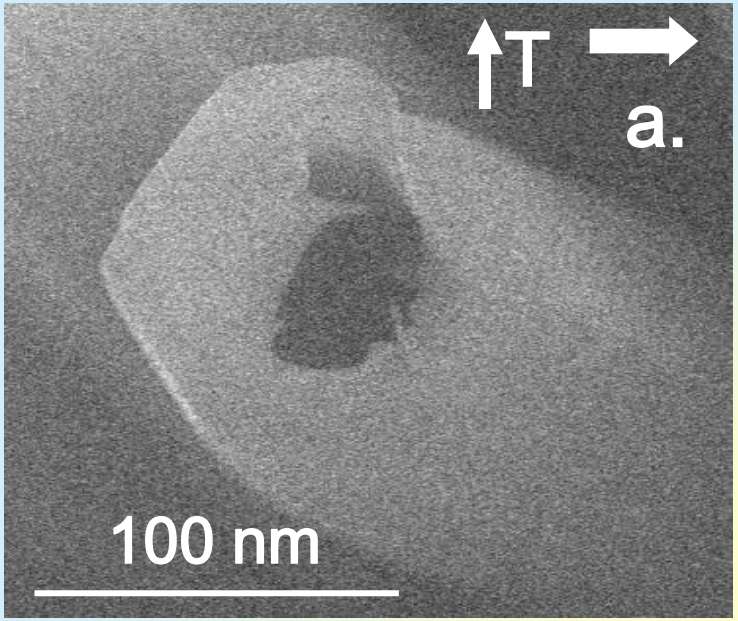
T~150 C

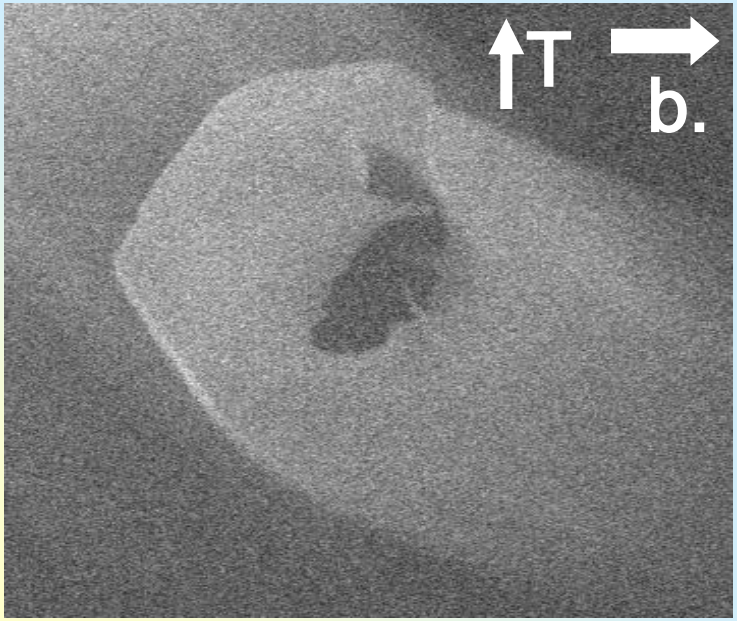


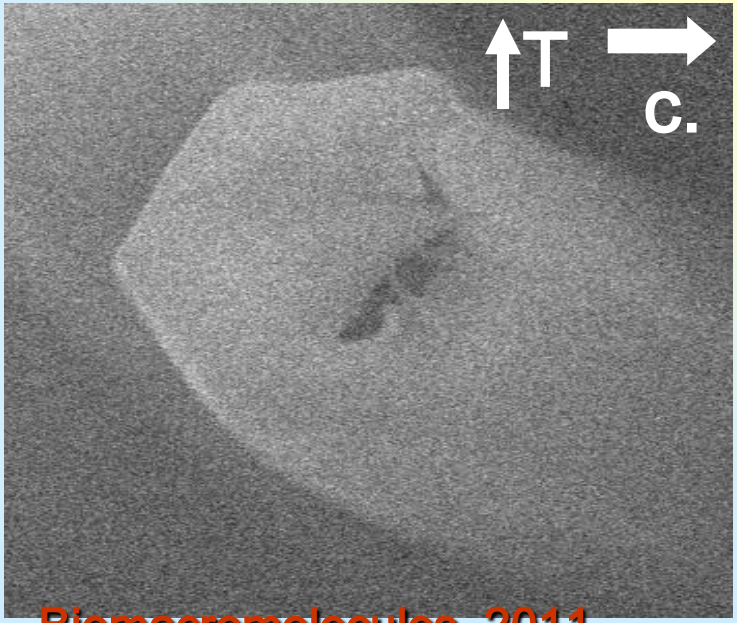


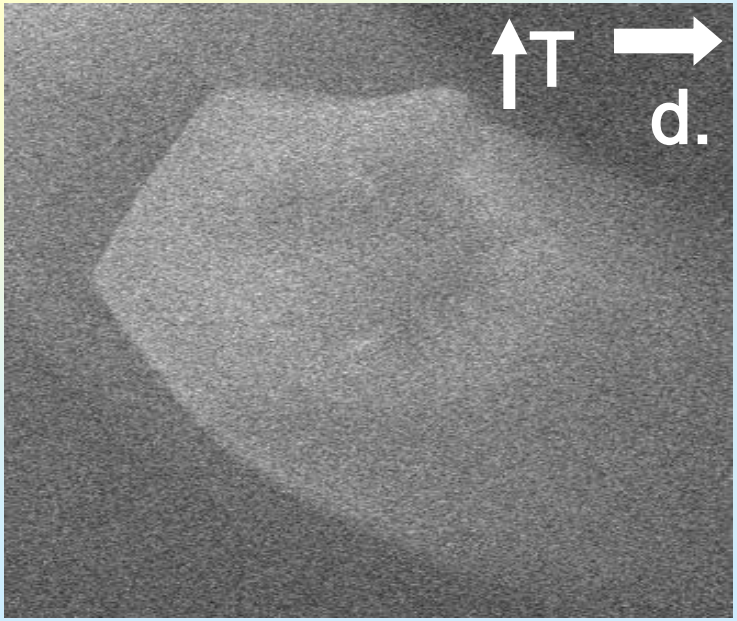


Peptide Nanotubes Morphological Transition



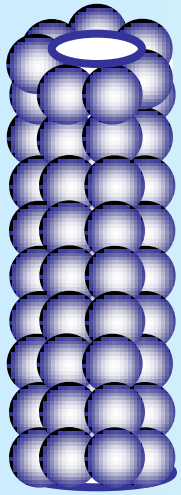


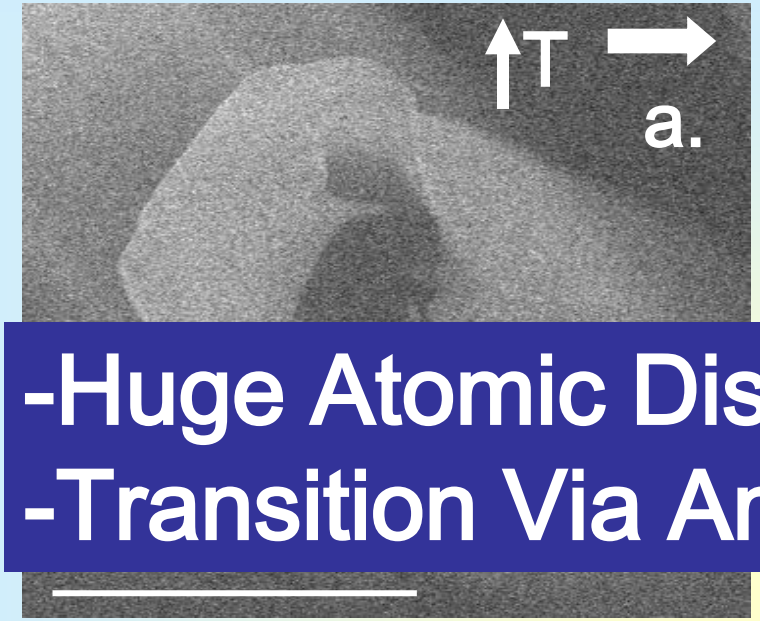


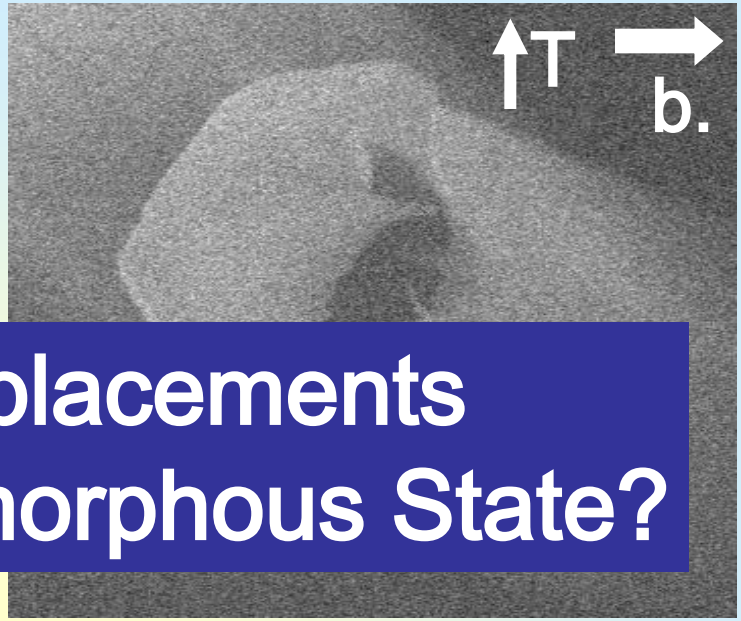


Biomacromolecules, 2011

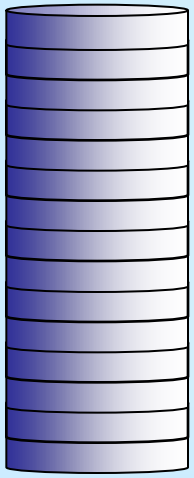
Peptide Nanotubes Morphological Transition

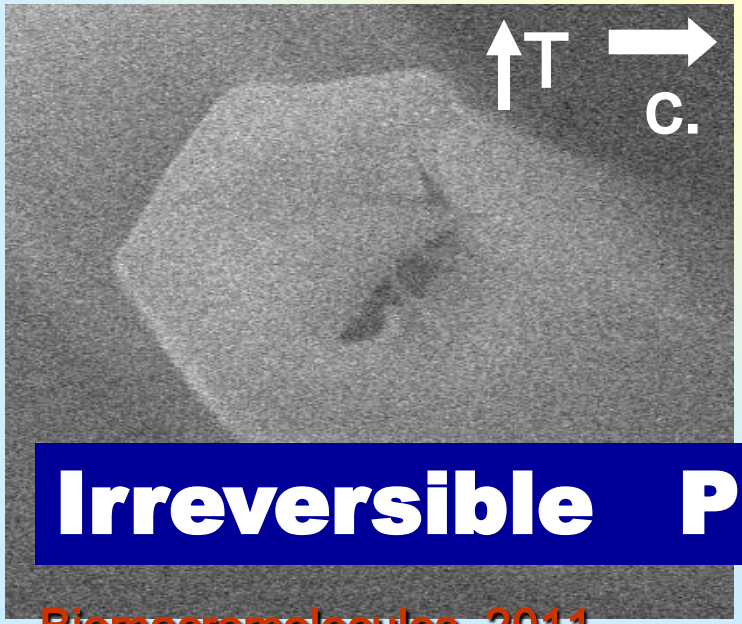


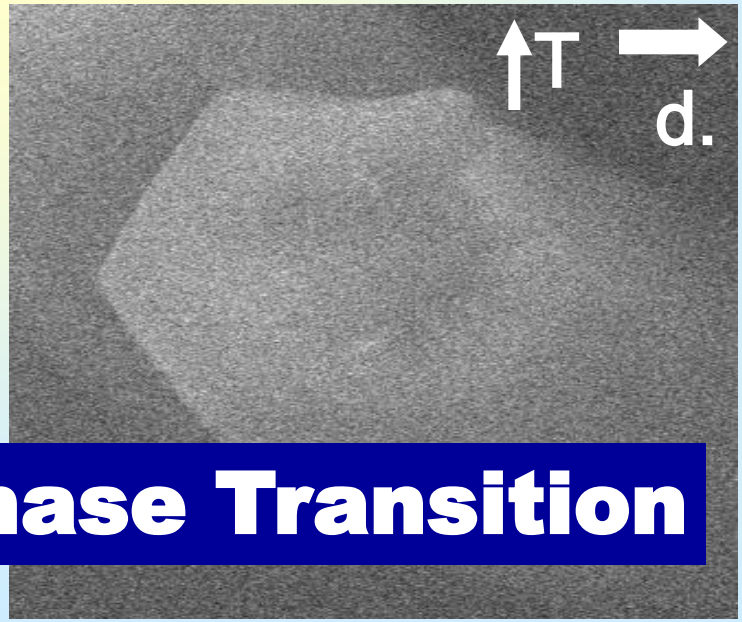




-Huge Atomic Displacements
-Transition Via Amorphous State?



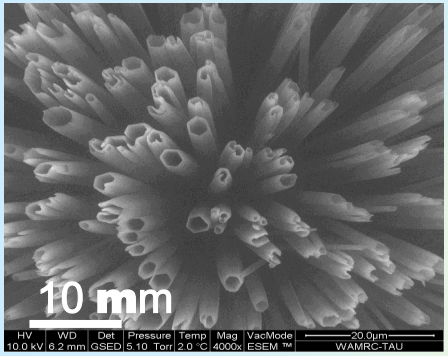




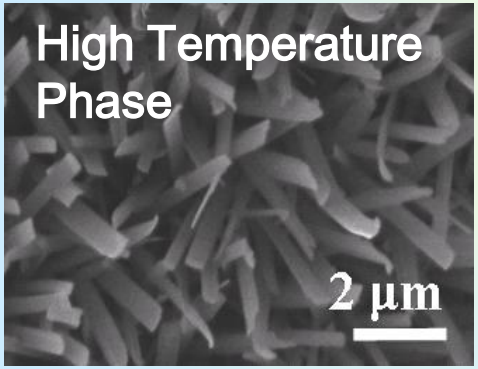
Irreversible Phase Transition

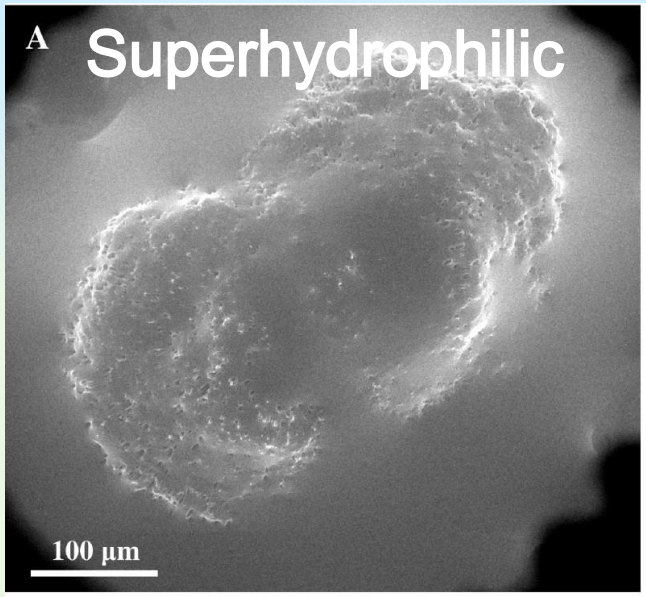
Biomacromolecules, 2011

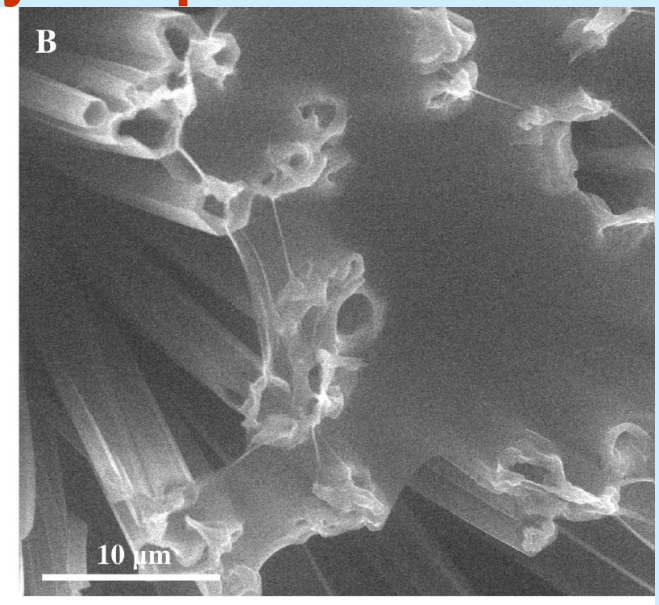
Phase Transition: Wettability Properties

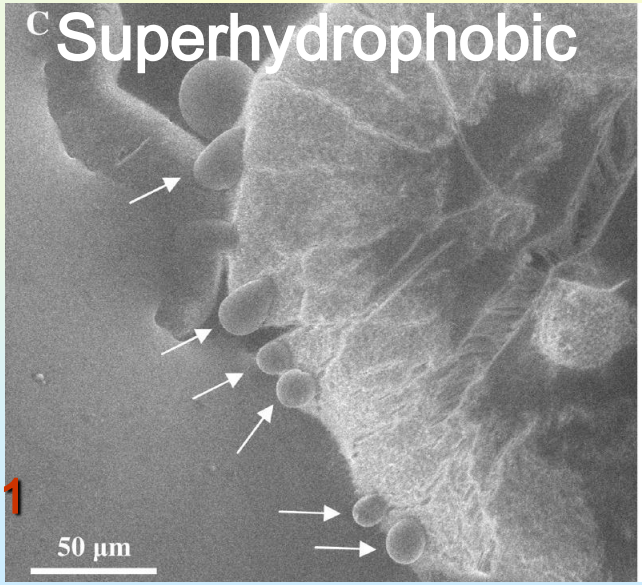


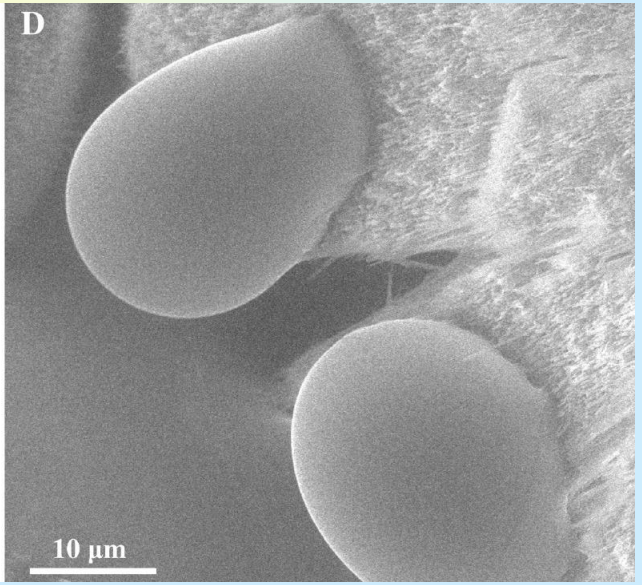
T~150 C





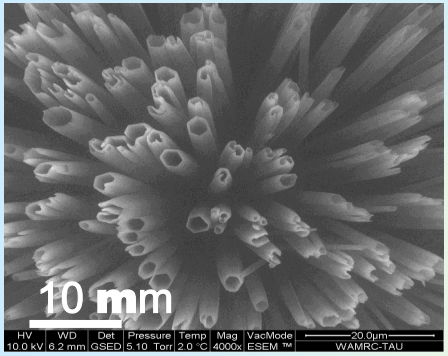


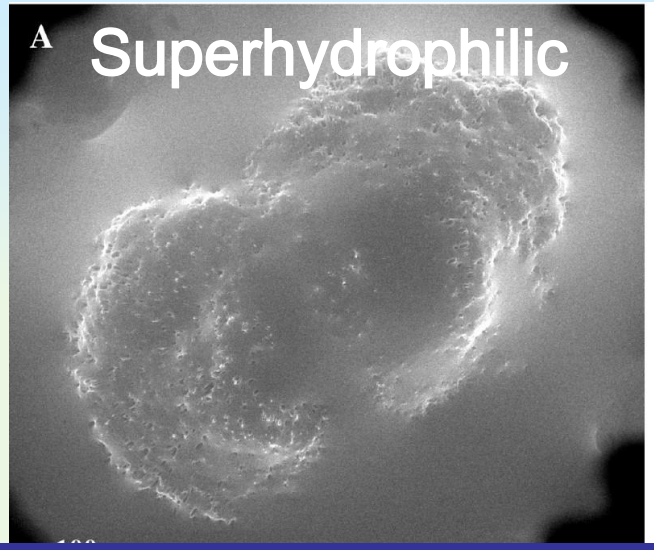


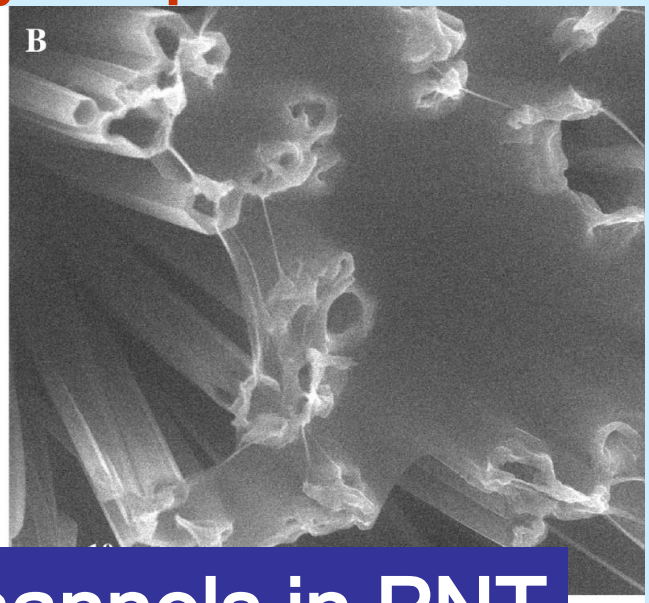


Biomacromolecules, 2011

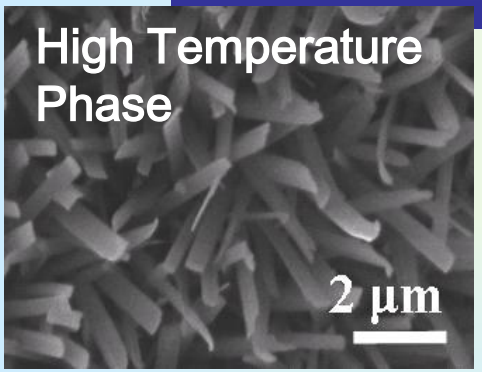
Phase Transition: Wettability Properties

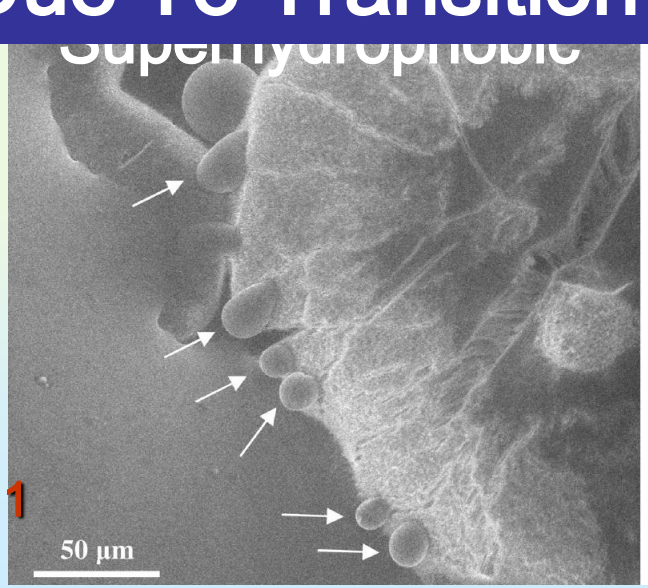


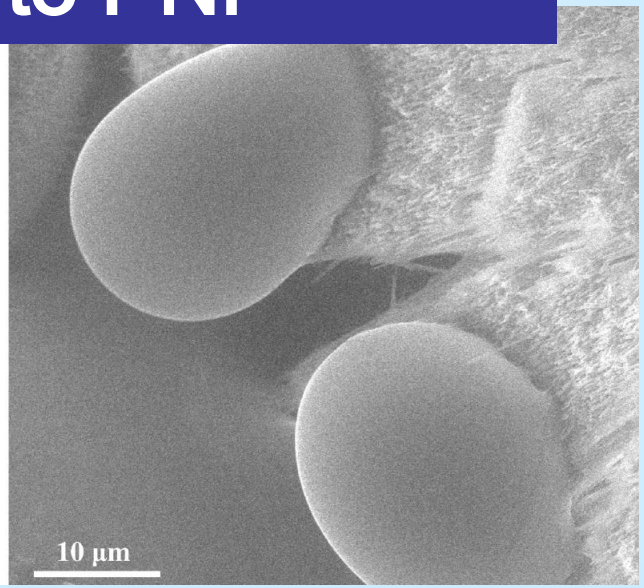




Total Collapse of Nanochannels in PNT Due To Transition to PNF



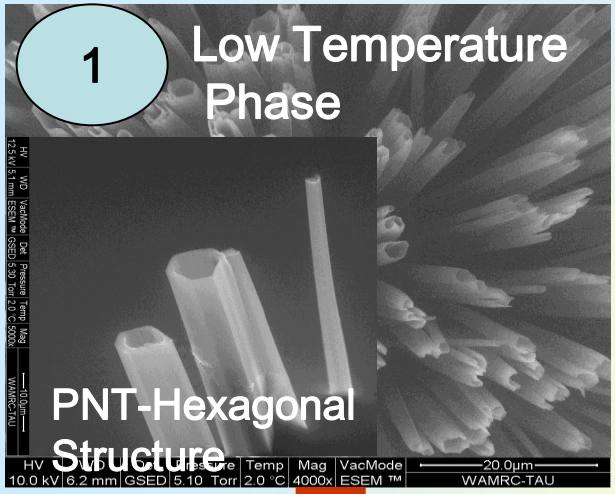




Biomacromolecules, 2011

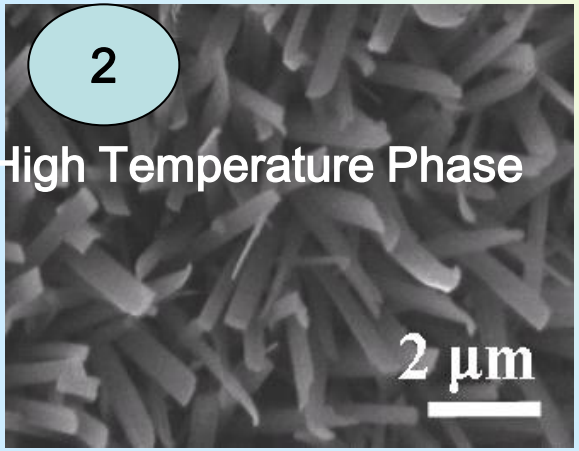
Peptide Nanotubes Structural Transformation

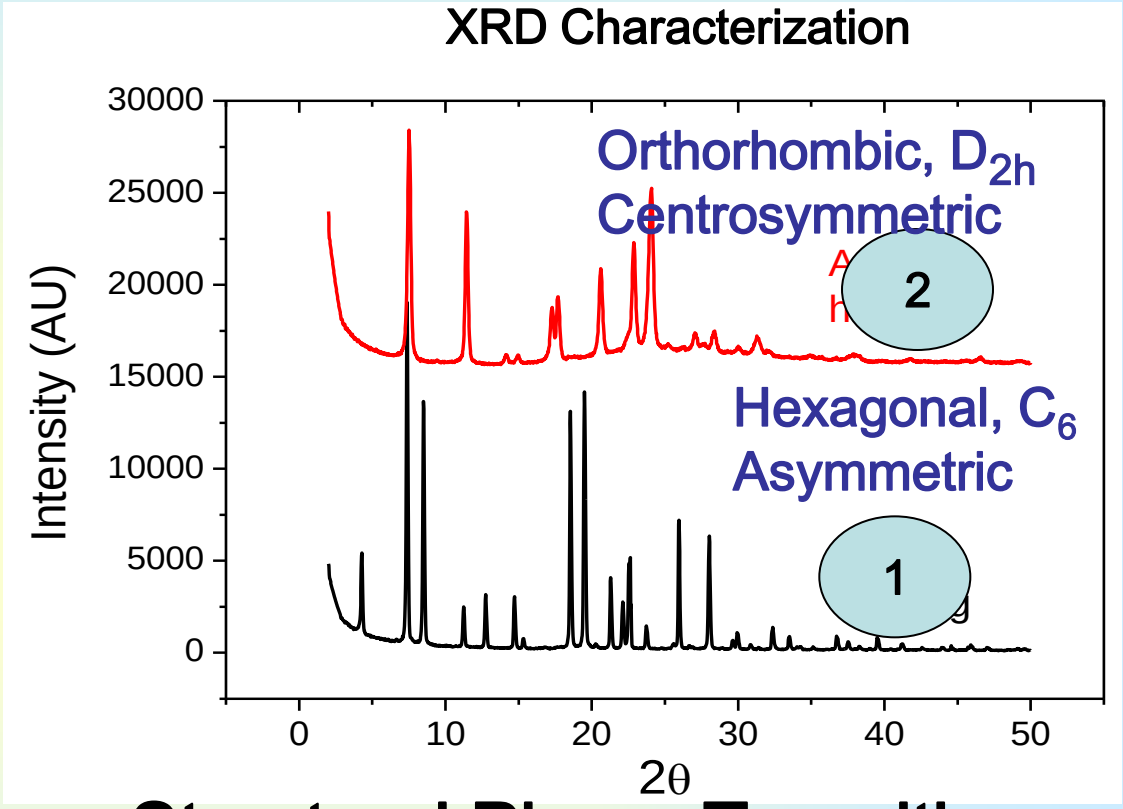
Asymmetric Structure, Class C_6



T~150C

Centrosymmetric, Class D_{2h}





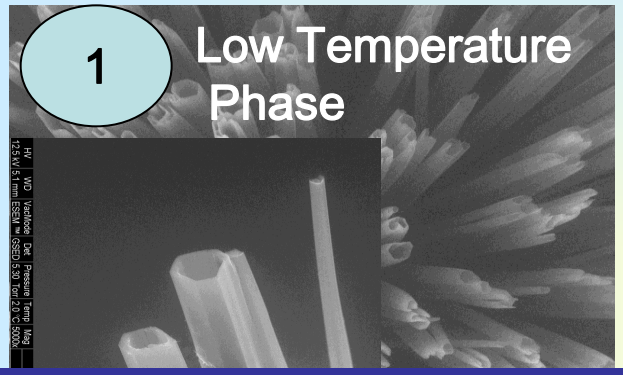
Structural Phase Transition, T~150 C

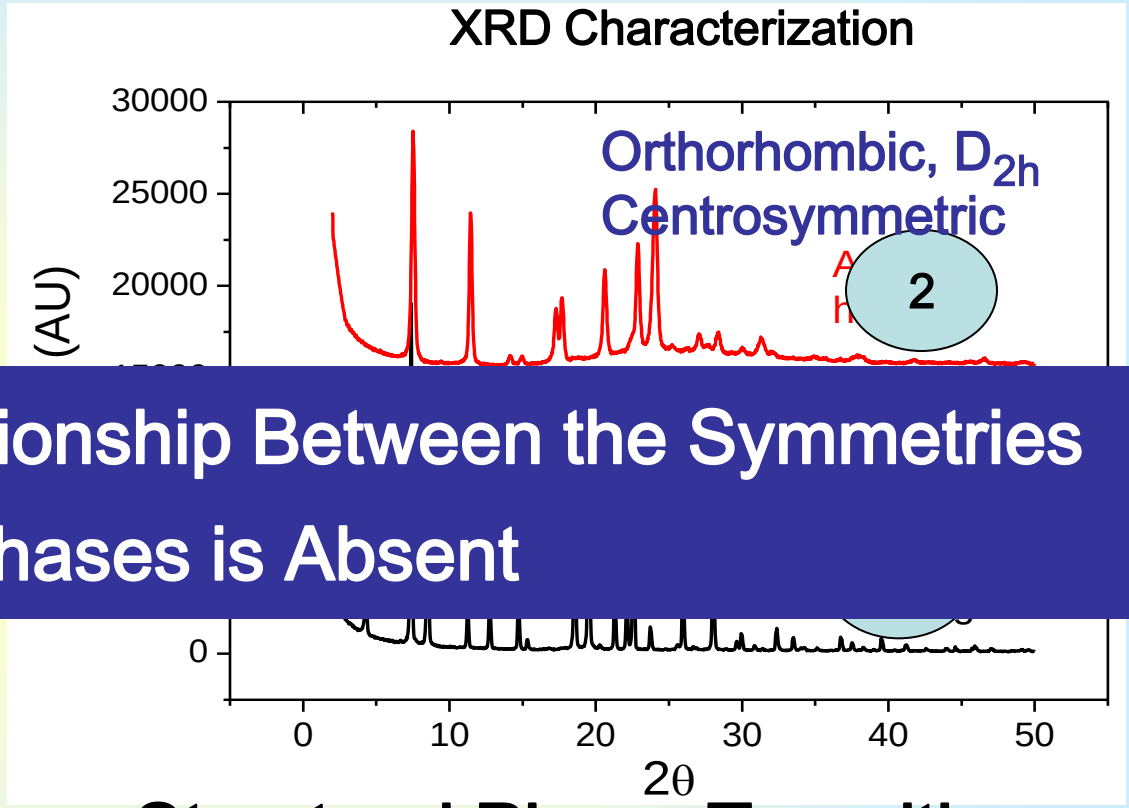
Phase Transition: Symmetry C_6 to D_{2h}

Asymmetric Structure to Symmetric One

Peptide Nanotubes Structural Transformation

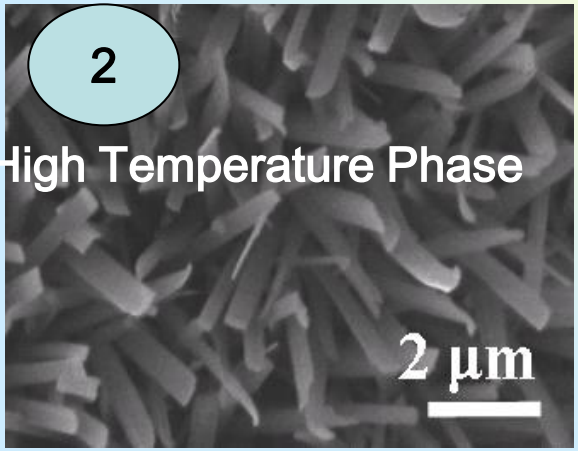
Asymmetric Structure, Class C_6





Group-Subgroup Relationship Between the Symmetries of the Phases is Absent

Centrosymmetric, Class D_{2h}



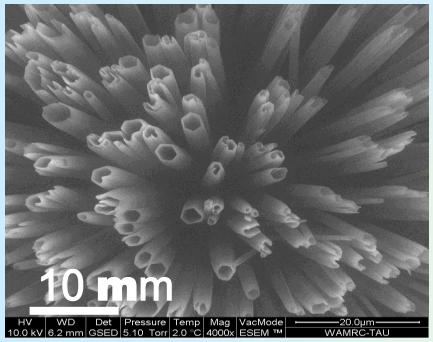
Structural Phase Transition, T~150 C

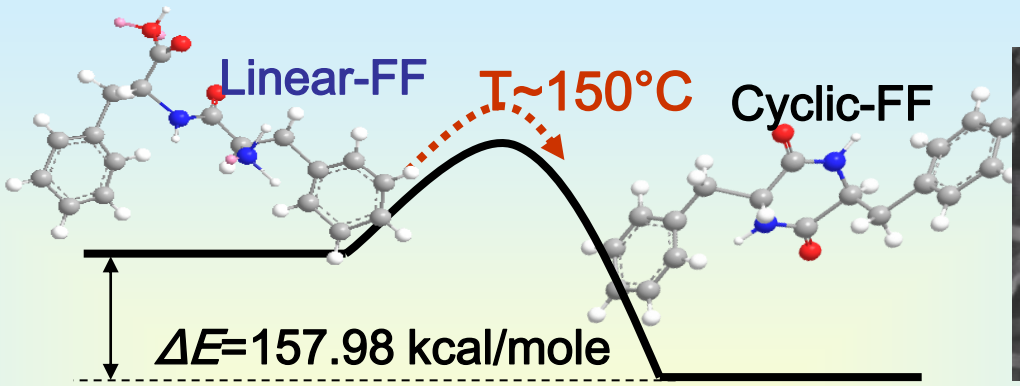
Phase Transition: Symmetry C_6 to D_{2h}

Asymmetric Structure to Symmetric One

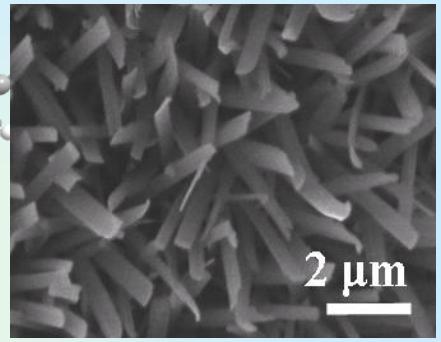
Phase Transition: Molecular Transformation

Linear-FF



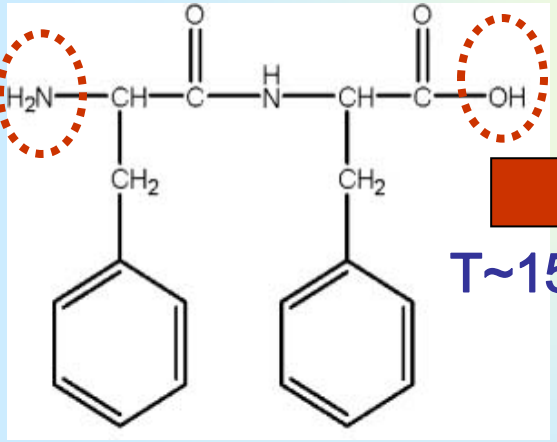


Cyclic-FF



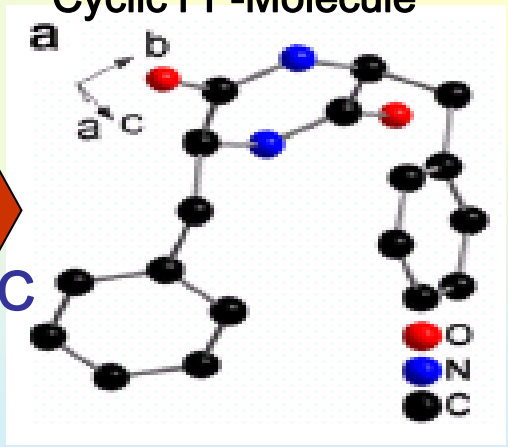
J. Pept Sci, 2011
J. Biomacromol., 2011

Linear FF-Molecule

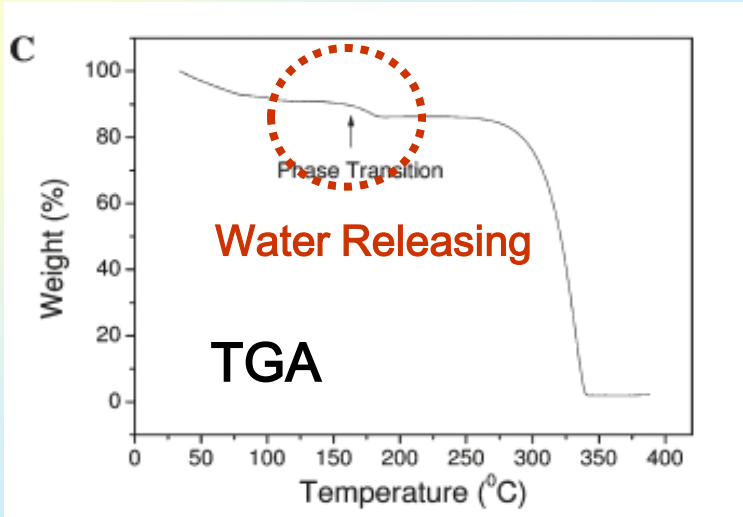


T~150 C

Cyclic FF-Molecule

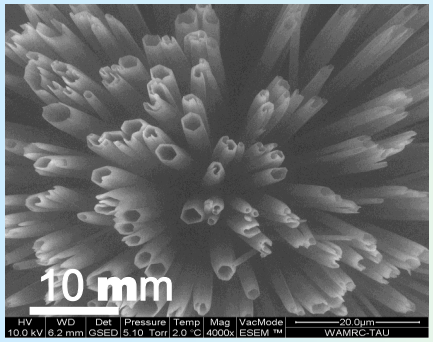


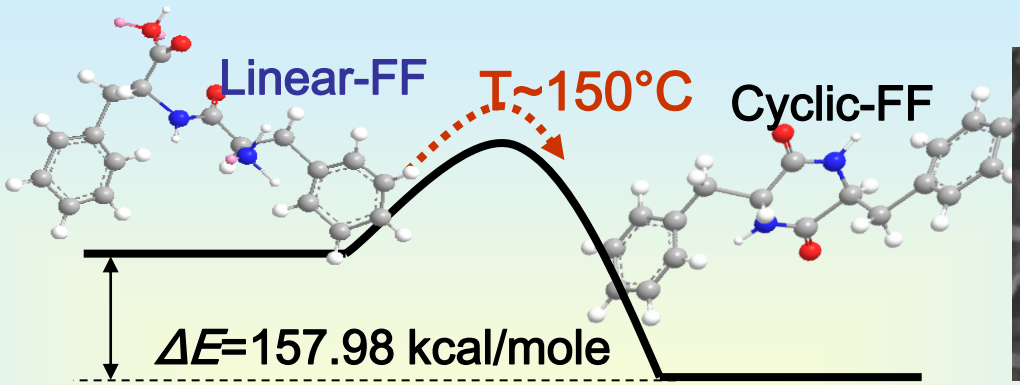
K. Joshi,Tetrah. Lett. 2008



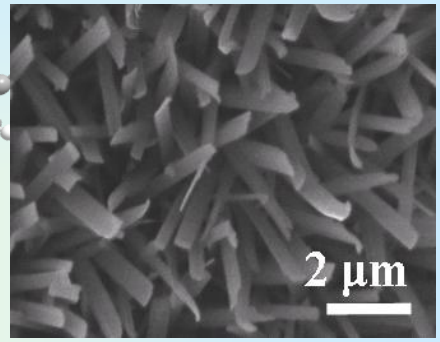
Phase Transition: Molecular Transformation

Linear-FF





Cyclic-FF



J. Pept Sci, 2011

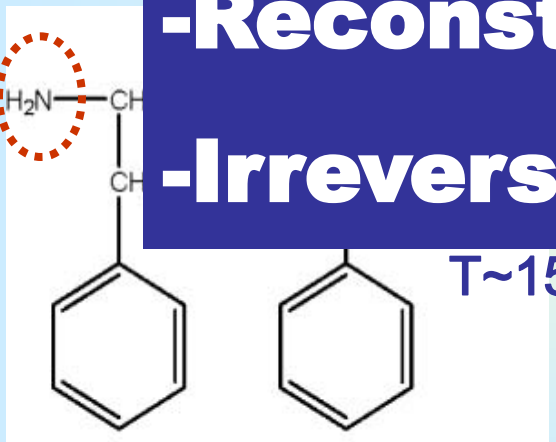
J. Bio

Phase Transition:

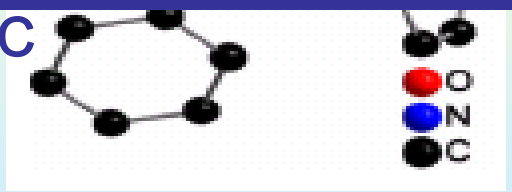
-Reconstruction of Covalent Bonds

-Irreversible Phase Transition

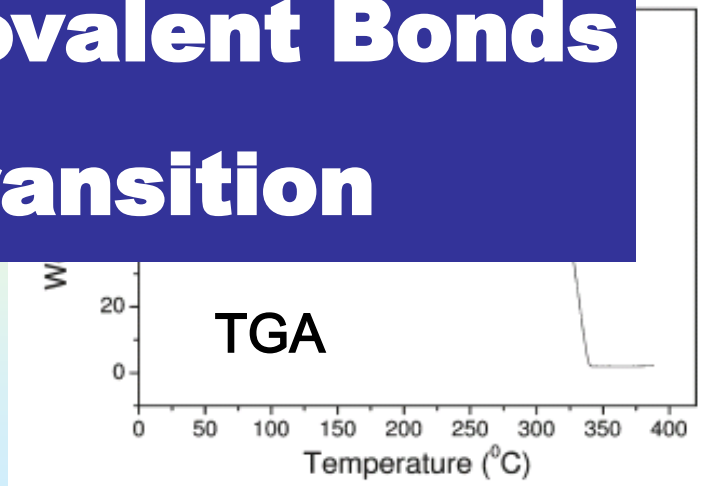
Line



T~150°C

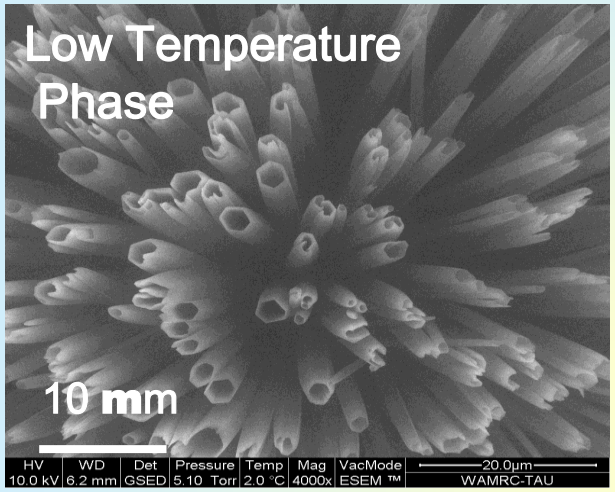


K. Joshi,Tetrah. Lett. 2008



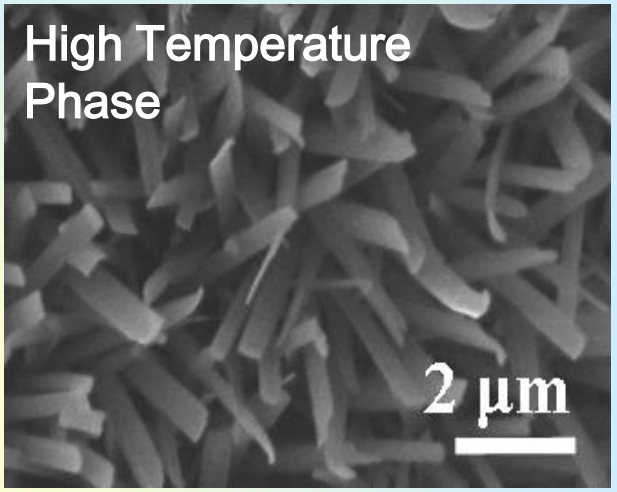
Phase Transition
In Bioinspired FF-Peptide Nanostructures

Hollow Nanotubes



T~150C

Nanofibers



1. The transition is based on breaking of chemical bonds
2. Group-Subgroup relationship between the symmetries of the phases is absent
3. The transition is strongly first order

Reconstructive Phase Transition

APPLICATIONS OF BIOINSPIRED MATERIALS:

a.Nanophotonics

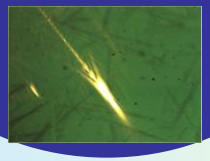
b. Nanobiopiezotronics

c. Energy Storage Devices

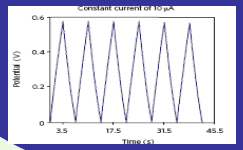
d. Medical Technology

NANOTECHNOLOGY

Nanophotonics
LED, Bio-Lasers



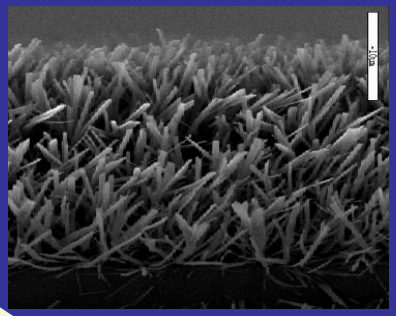
Energy
Storage Devices



NANOTECHNOLOGY

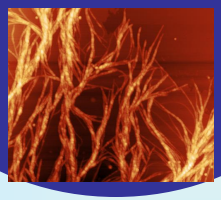
Nano-Bio-
Piezotronics
IJS, Electronic Ceramics
Prof. M. Kosec

Bioinspired Peptide
Nanostructures

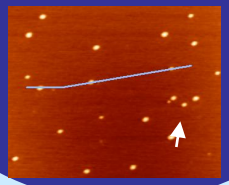


NANO-BIO-MEDICINE

Diagnostics of
Amyloid Diseases

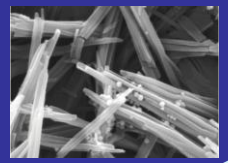


Nano-Bio-
Markers



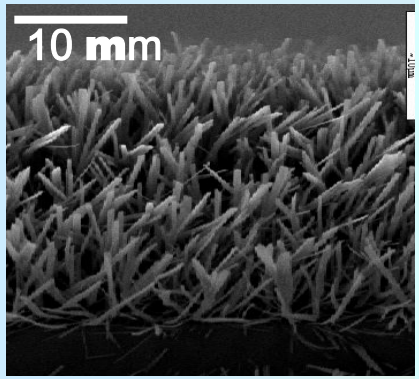
NANO-BIO-MEDICINE

Orthopedic
Coatings



Peptide Nanotubes-Nanoordering and Nanostructure

FF-peptide nanotub



Nano Lett., 2009

Self Assembly Process:

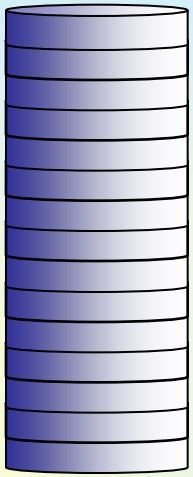
PNT of 10 μm length:

10,000 QW in dozen of seconds

QW structure in PNT is intrinsic structure for Lasers

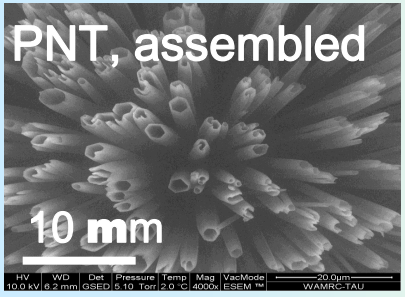
Quantum Well Structure

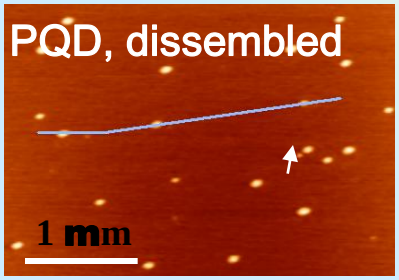
Δ~13 Å

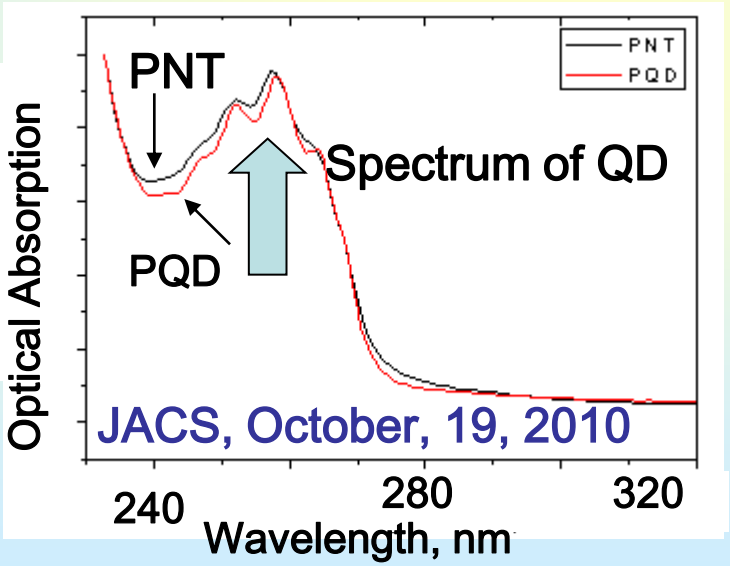


Wavelength, nm

FF-peptide nanotubes (evaporation from solutions)

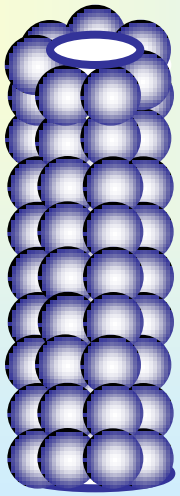


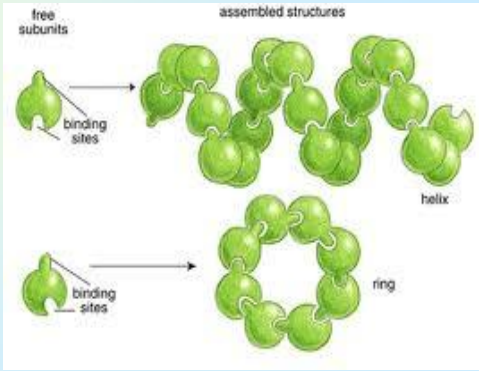




Quantum Dot Structure

Δ~15 Å

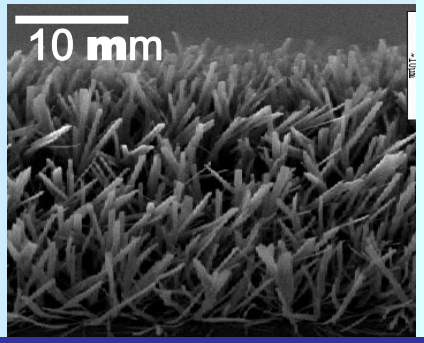




Nature, 468, Nov 25, 2010

Peptide Nanotubes-Nanoordering and Nanostructure

FF-peptide nanotub



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Quantum Well Structure

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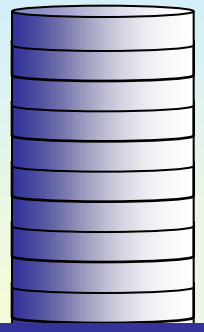
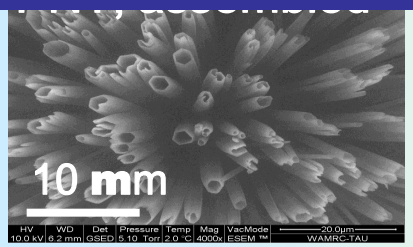
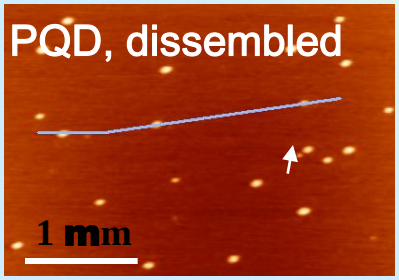
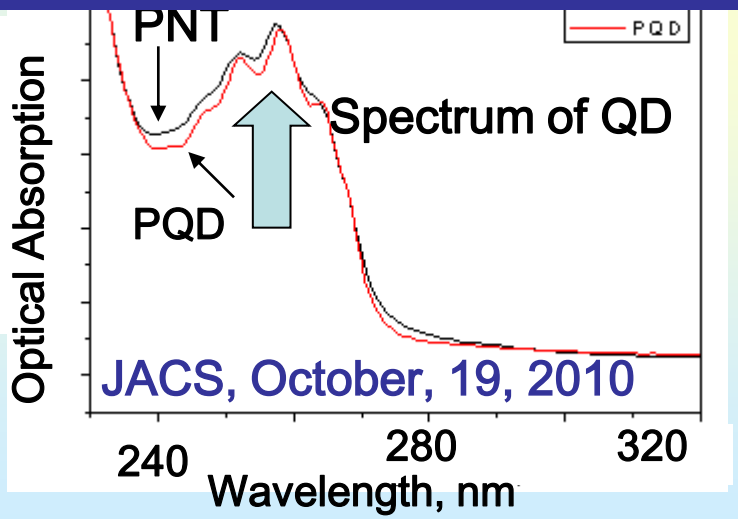


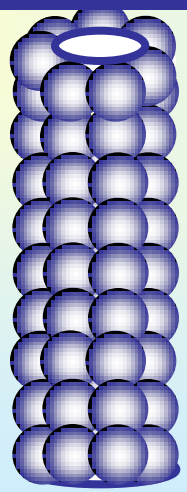
QW- and QD-Bio-Laser

Bio-LEDs

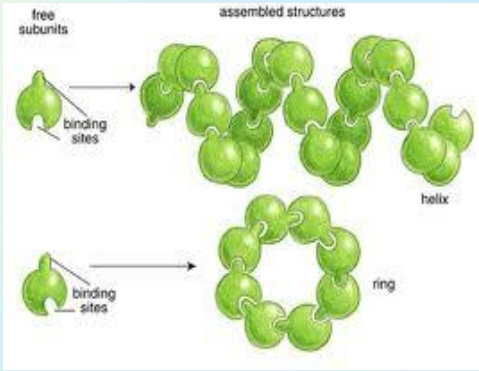








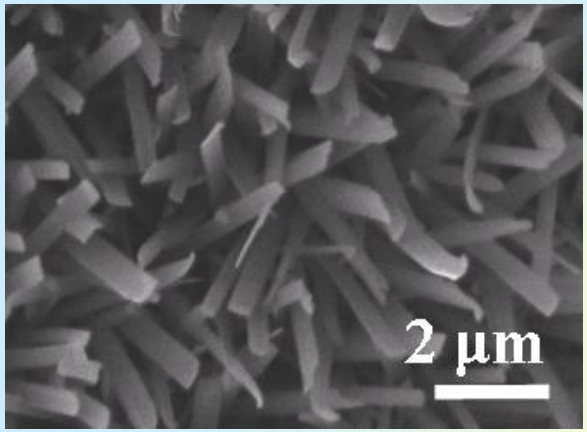
Δ~13 Å

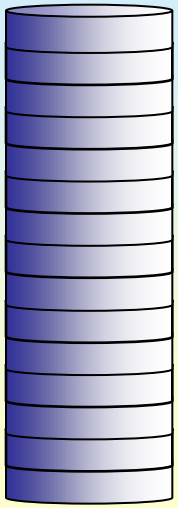


Nature, 468, Nov 25, 2010

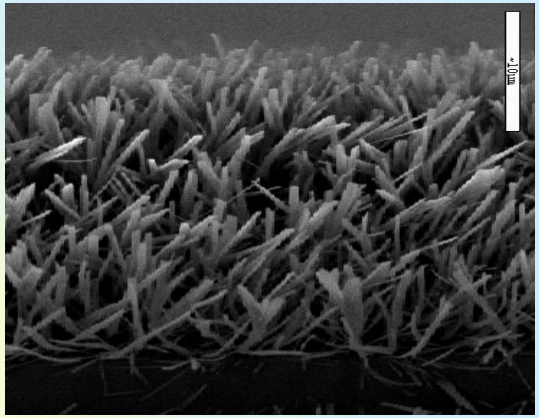
PNT-Nanophotonics

Heat-treated PNT evaporated from organic solutions



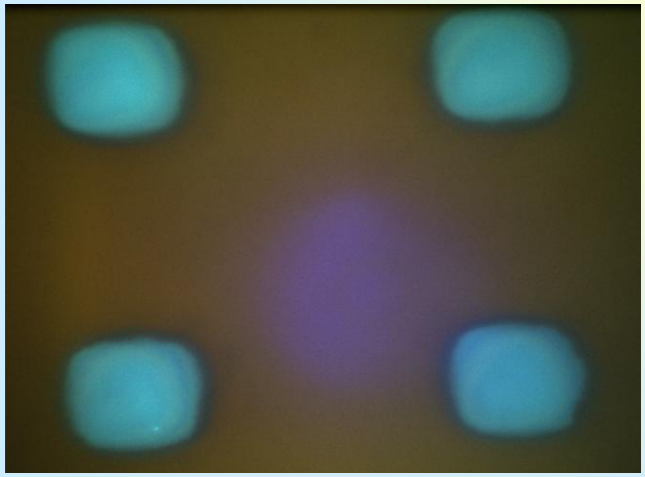


Vapor Deposited PNT

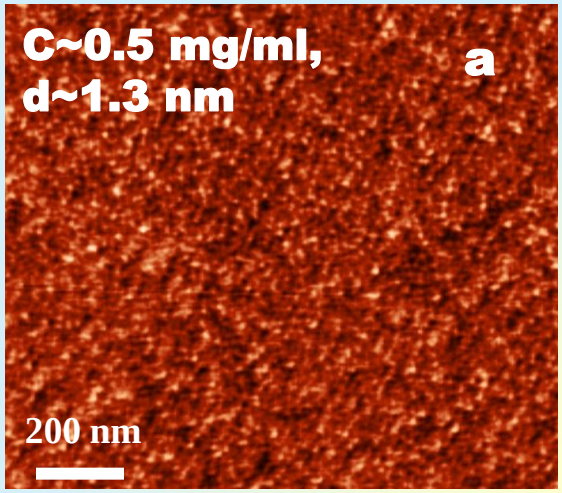


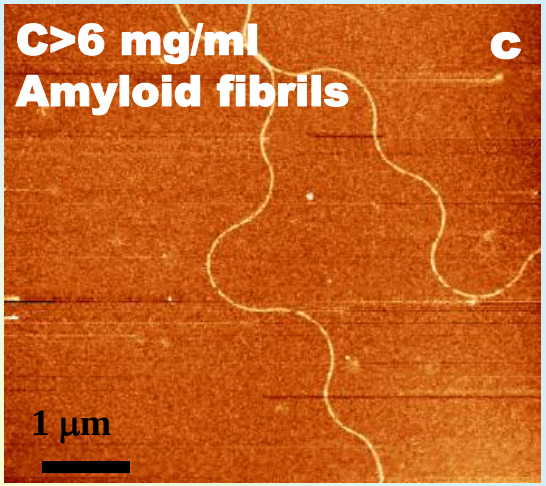
Light Emitting Devices

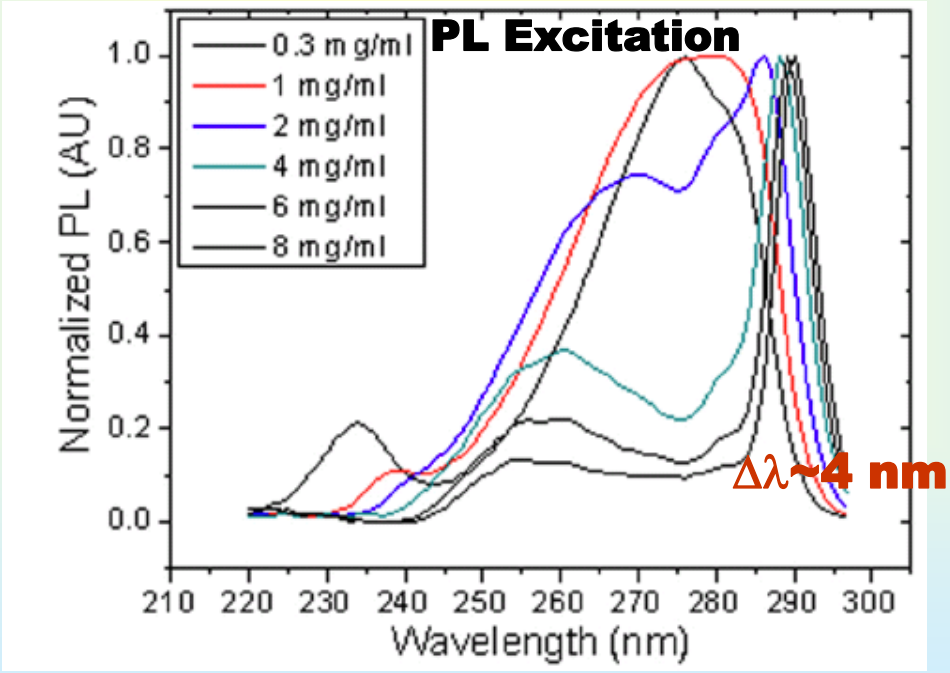
PNT- LED



Nanophotonics-Insulin Amyloid Fibrils







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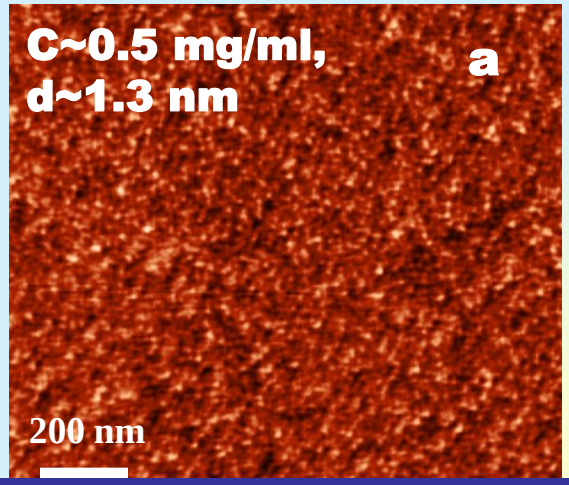
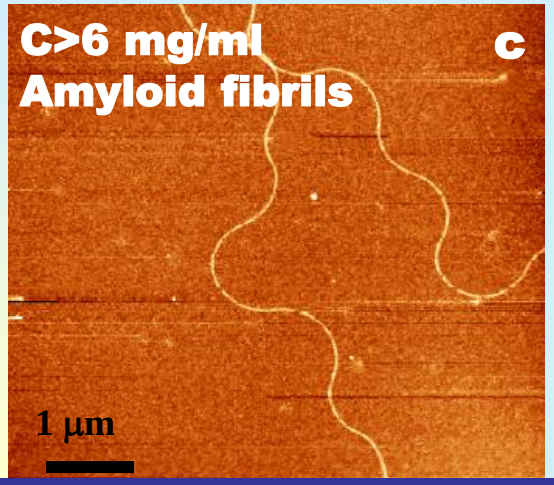
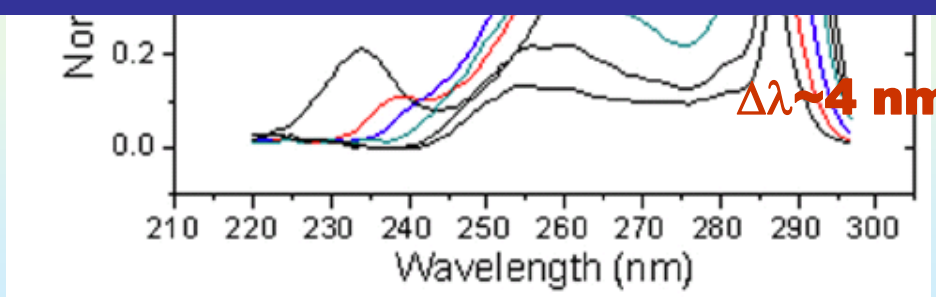




Could Self Assembly Bioinspired Peptide Nanostructures Be a Model of Biological Materials?

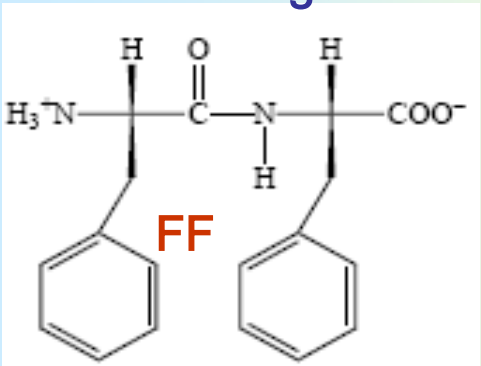


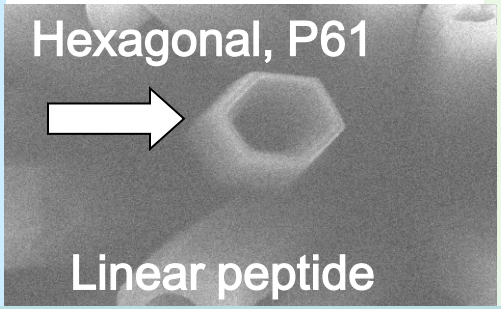
Bio-Nano-Piezoelectrics

Could we speak about New Class of Ferroelectrics- Supramolecular Ferroelectrics of Biological Origin?

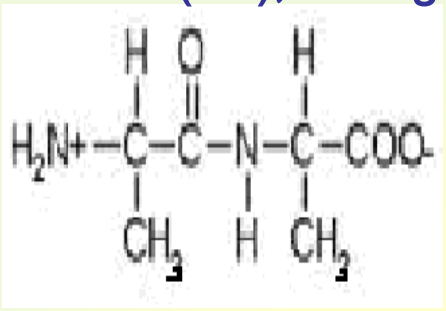
Asymmetric Peptide Structures (J. Pept. Sci, 2011)

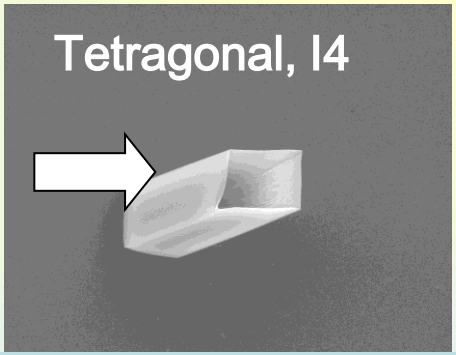
FF-Hexagonal



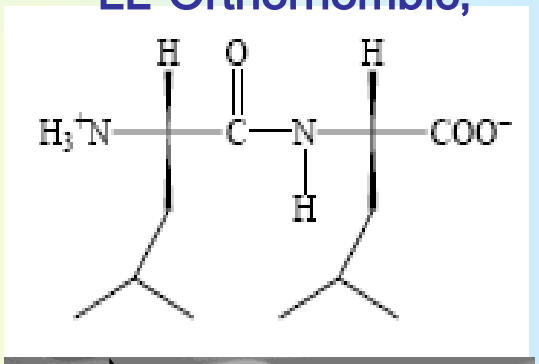


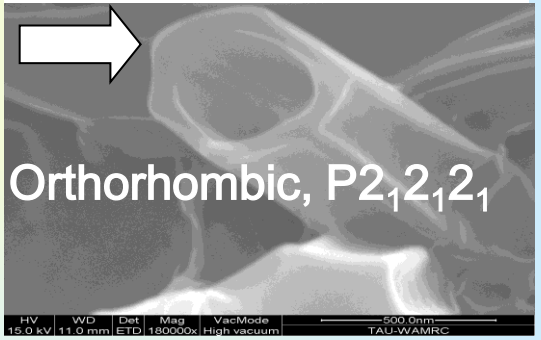
Ala-Ala (AA), Tetragonal





LL-Orthorhombic,





- -Piezoelectric Properties
- -Second Harmonic Generation
- -Spontaneous Electrical Polarization
- -Pyroelectric Effect?

Bio-Nano-Piezoelectrics

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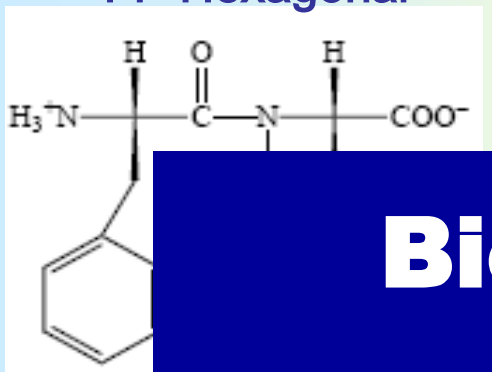
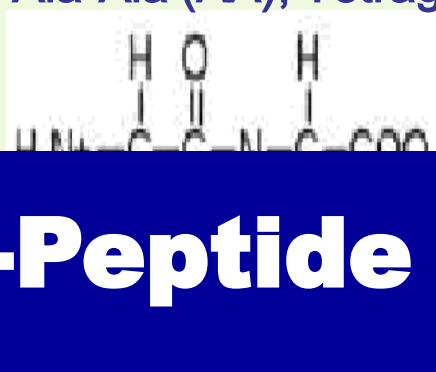
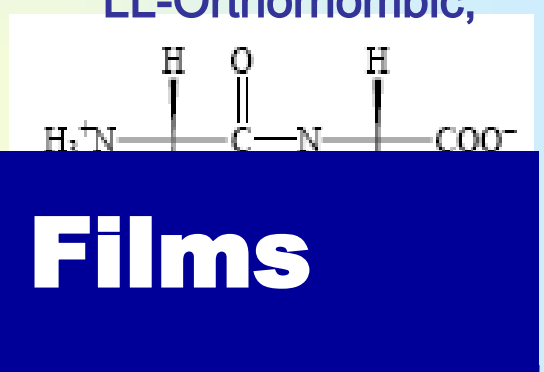
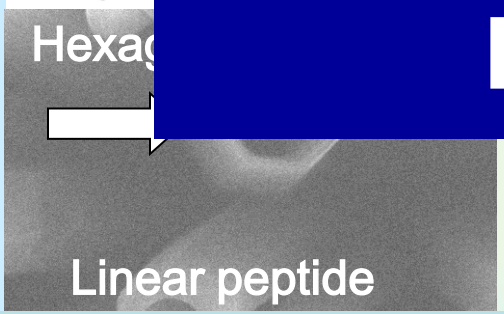


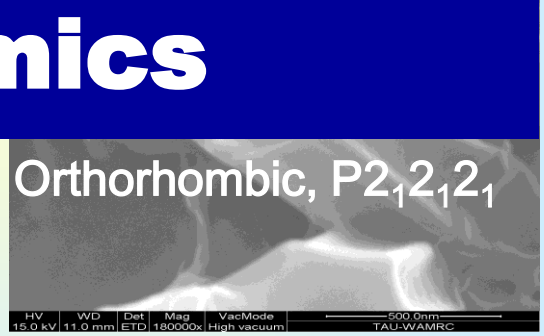




Bio-Peptide Thin Films

Bio-Piezoceramics





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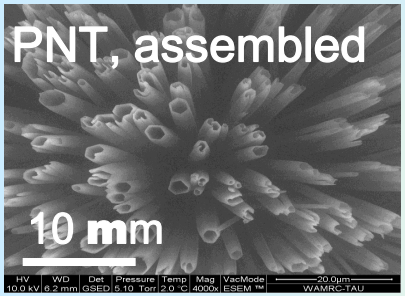
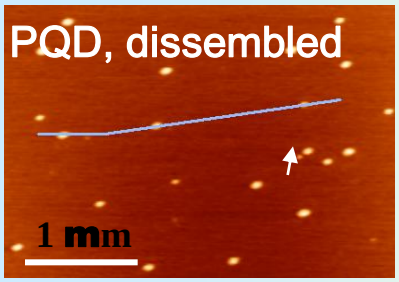
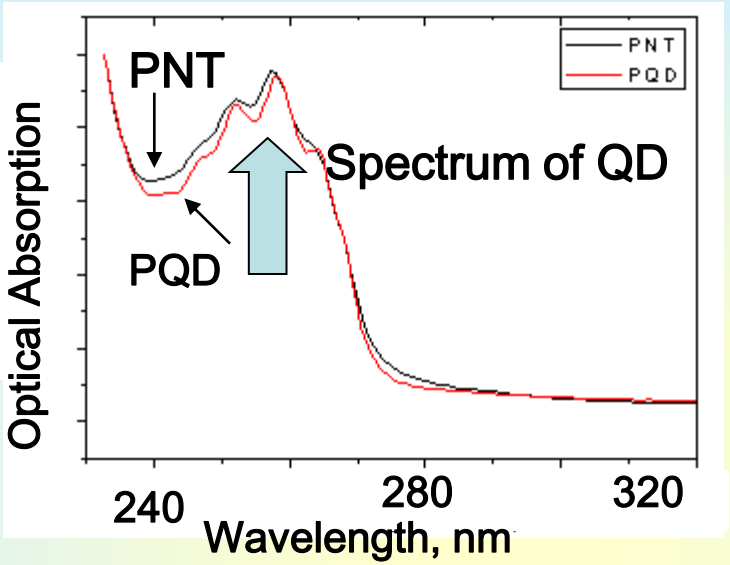
Nanotechnology of Elementary Building Blocks

JACS, 2010

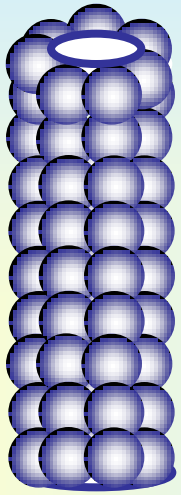






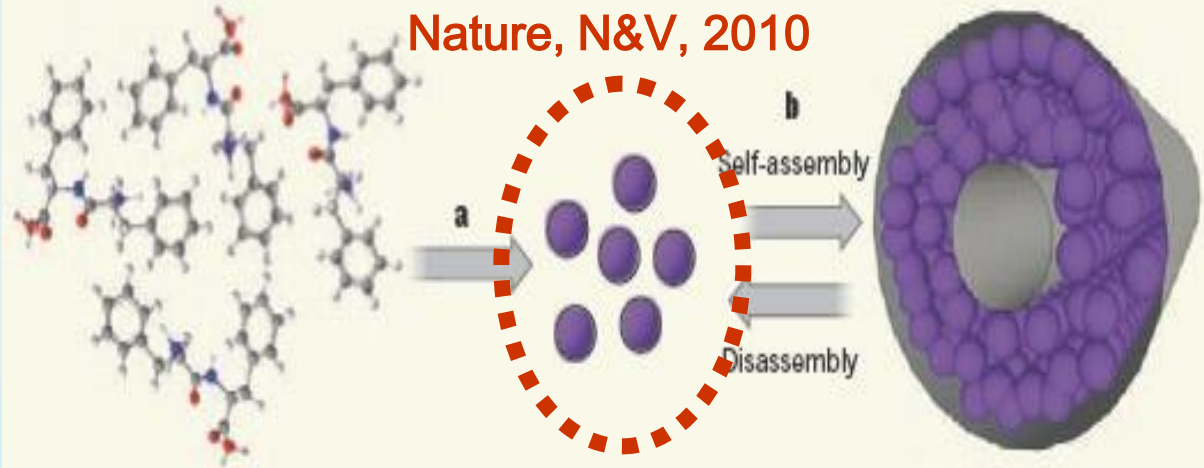
Quantum Dot Structure

Stacked Balls



Δ~15 Å

Nature, N&V, 2010



Nanotechnology of Elementary Building Blocks

JACS, 2010

Elementary Building Blocks of Nanometer Size:

-Quantum confinement:

QD-Biomarkers and Quantum Dot Lasers

-Asymmetric Structure And Ferroelectric Properties:

FE memory

NanoPiezo Devices

-Organic Charge Storage Memory For flexible Electronics

Acknowledgments

-Prof. M. Molotsky-Theoretical support

-Prof. E. Gazit –Life Science Faculty, TAU-Bionspiration

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-PhD student Peter Beker-Electrochemistry, Energy Storage Devices

-MSc. student Itai Koren-Bio-Ferroelectricty

-MSc. student Becky Bank-Bio-Molecular Vapor Deposition -

-PhD student Ilia Torchinsky-Surface Modification

-MSc Maya Yevnin-Wettability

Piezoelectric studies

Dr. A. Kholkin, University of Aveiro, Portugal

Prof. A. Gruverman, University of Nebraska-Lincoln

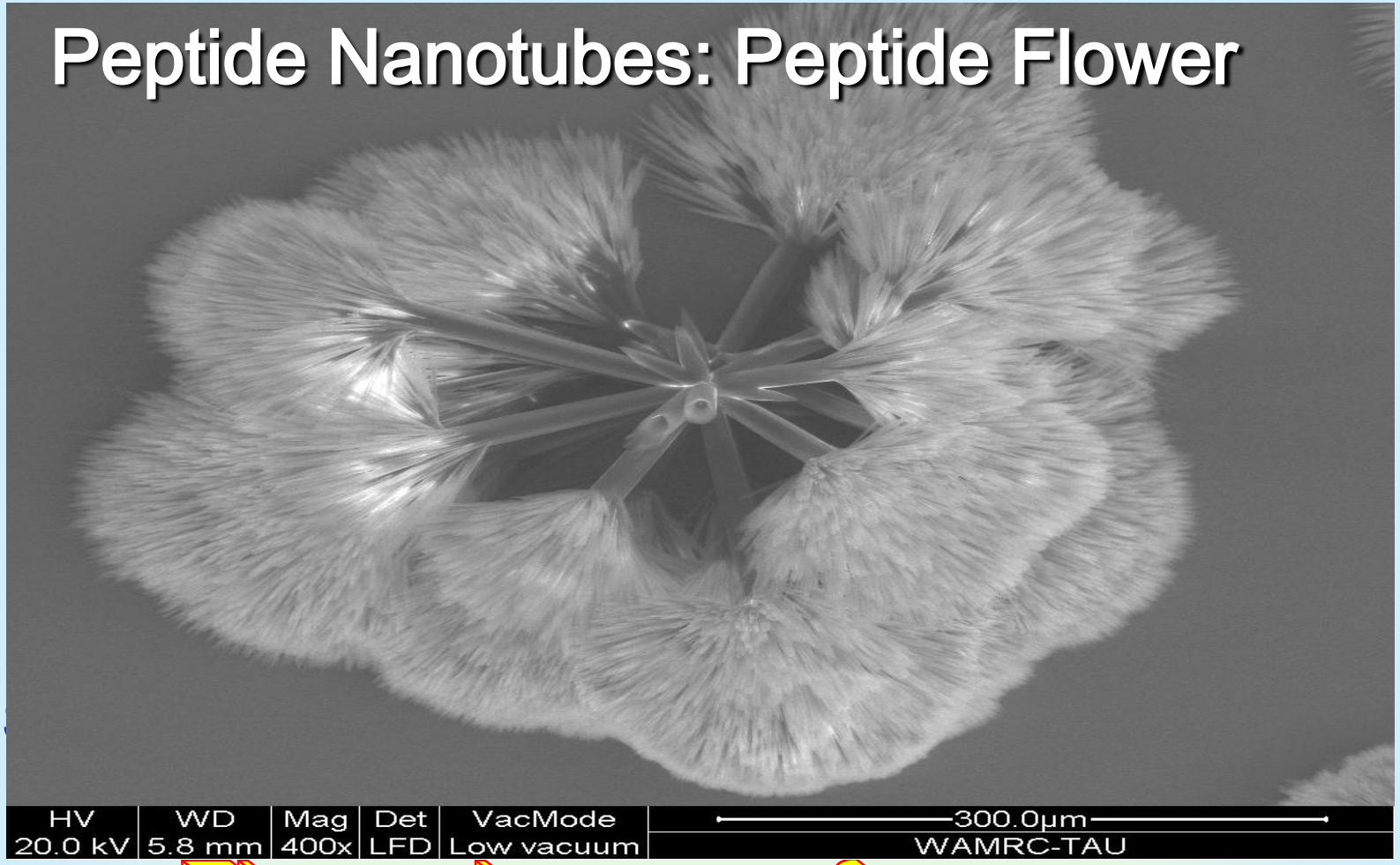
Optical studies (SHG)

Prof. E. Mishina, MIREA, Russian

Prof. T. Rasing, Radboud University, The Netherlands

This research was supported by the Ministry of Science & Technology, Israel & the Russian Foundation for Basic Research

Peptide Nanotubes: Peptide Flower



Thank you for your attention