Microorganism as MEMS

Xiaorong Xiong
MEMS Group Meeting

Nov 18, 2004

Outline

- Motivation and background
- Microorganism (MO) for MEMS:
  - Material synthesis
  - Special structure formation
  - Functional devices
  - Integrated systems
- Challenges

Motivation and Background

Goal:

Bio-integrated micro/nanosystems

- Understanding the working mechanism of different MOs.
- Development of bio-friendly process. Using MOs as devices and systems at the cell level.

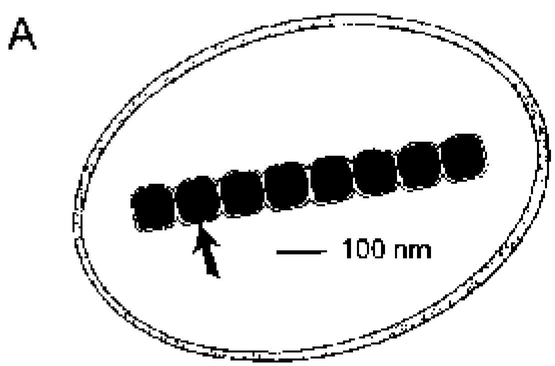
Material Synthesis

- Magnetic materials:
  - magnetite (Fe_3O_4)
  - greigite (Fe_3S_4) called ‘‘magnetosomes’’
- Metals

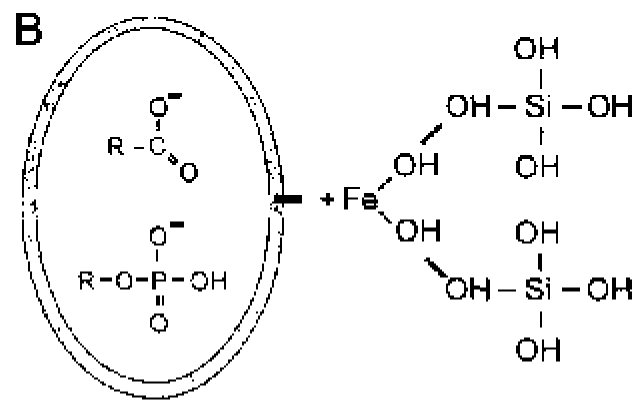
  Au, Ag, CdS and ZnS
- Semiconductor, carbonate materials and other materials
  - Silica, carbonate materials, Selenium

Biomineralization Mechanism

Intracellular



Extracellular

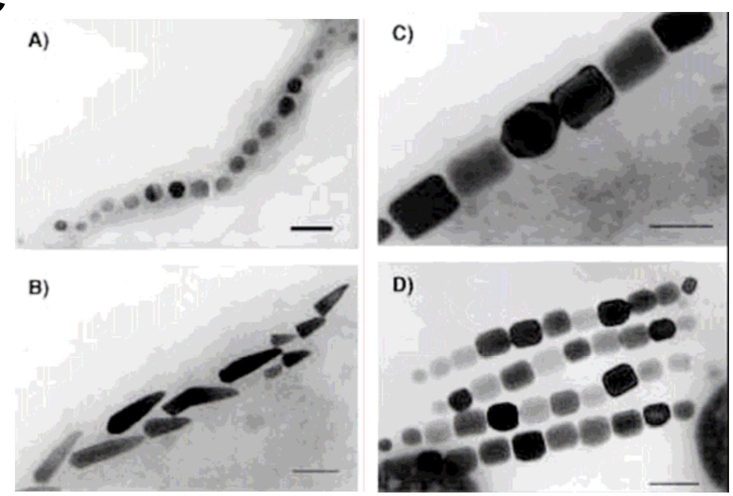


[Konhauser, Earth Science Review, 43 (1998)]

Bio-synthesis Magnetite (I)

Intracellular Properties:

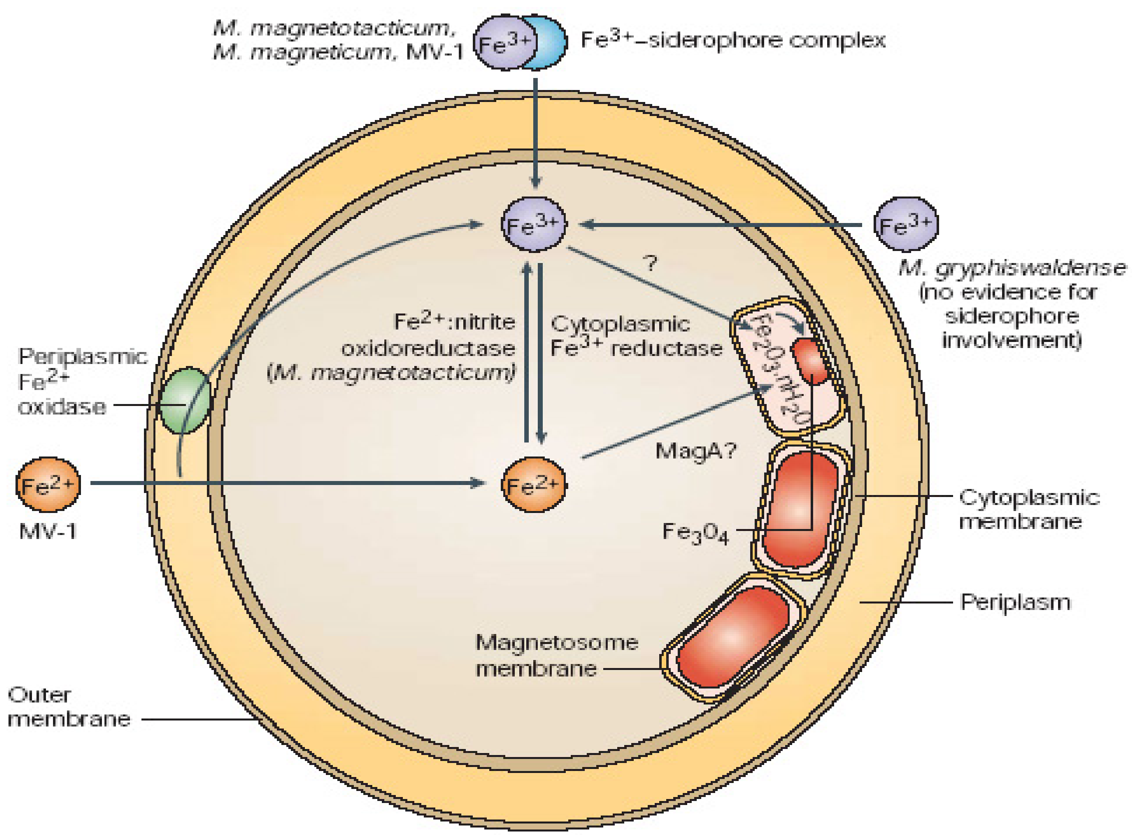
- Controlled size-range (single domain);
- Chemical purity;
- Crystallographic perfection;
- Unusual morphology;



100nm

[Bäuerlein, Angewandte Chemie, 42, (2003)]

Intracellular Biomineralization

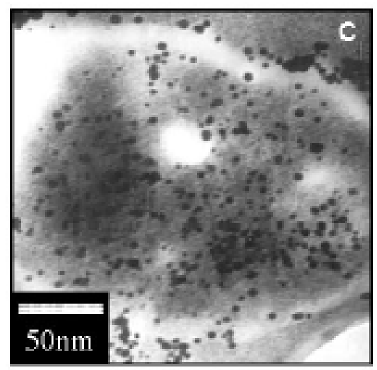


[Bazylinski, Nature reviews microbiology, 2, 2004]

Bio-Synthesis Metal

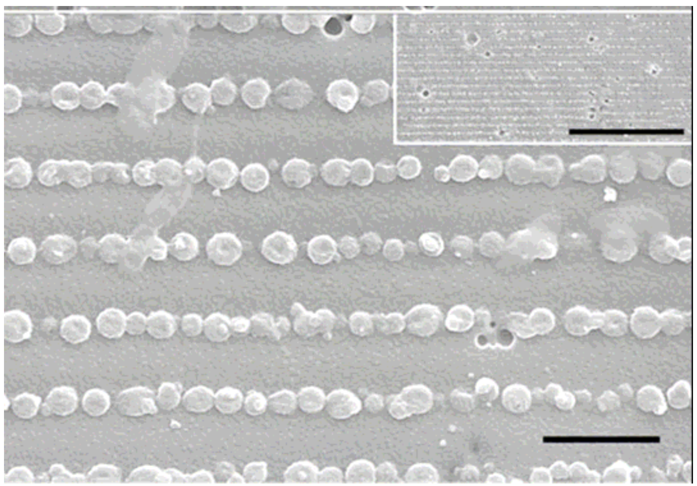
Au, Ag and CdS by prokaryote and eukaryote:

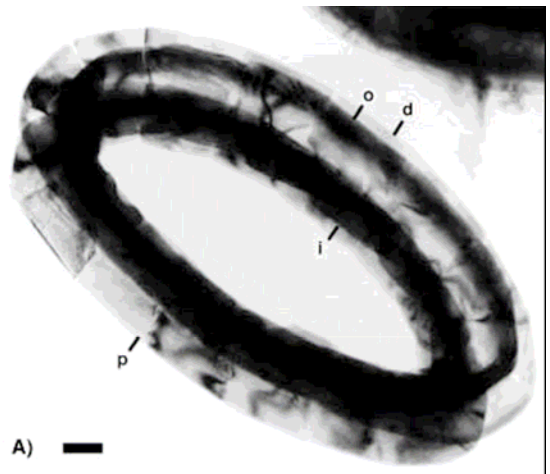
Ahmad et. al. Nanotechnology 14 (2003)



Au particles made by *Rhodococcus* (24h)

Semiconductor and Carbonate Materials





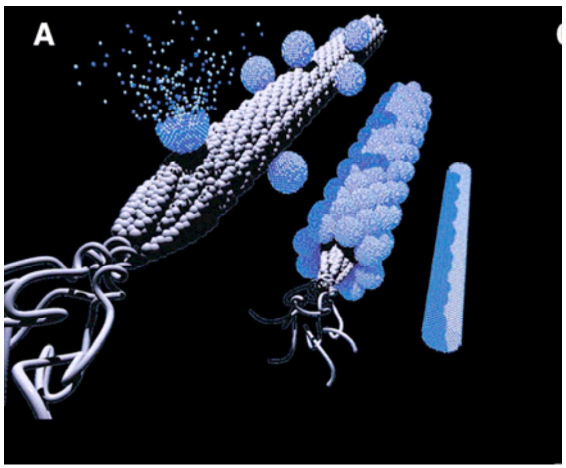
2μm **100nm**

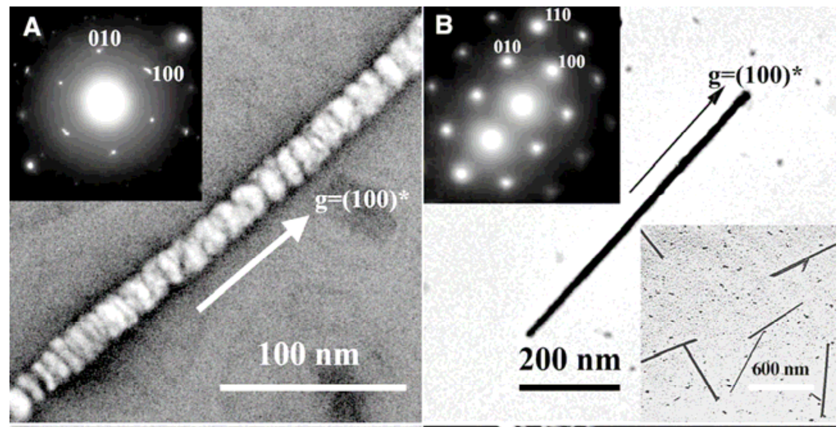
the biosilica nanostructure created by reacting the silane with a peptide-polymer

A TEM image of an isolated mature coccolith from *Pleurochrysis*.

Special Structure Formation (I)

1D nanostructures (Intracellular)

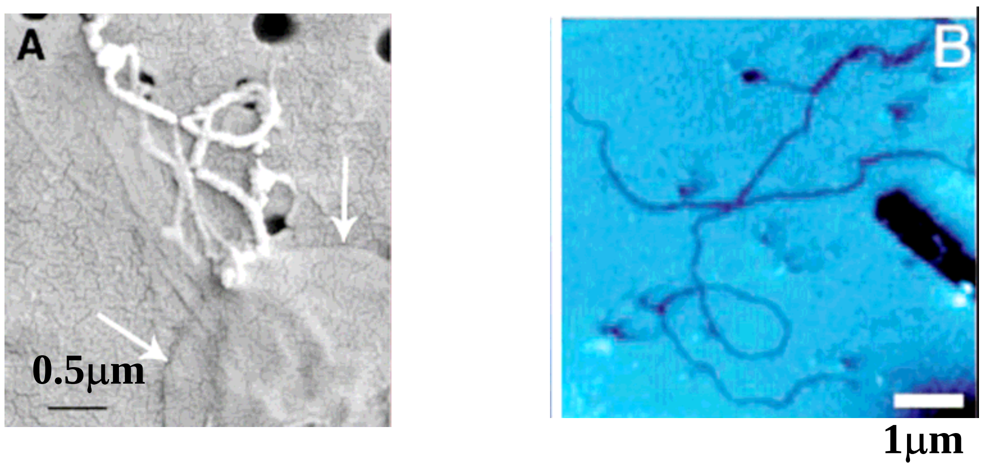




Virus on peptides template [Mao et. al., Science 303, 2004]

Special Structure Formation (II)

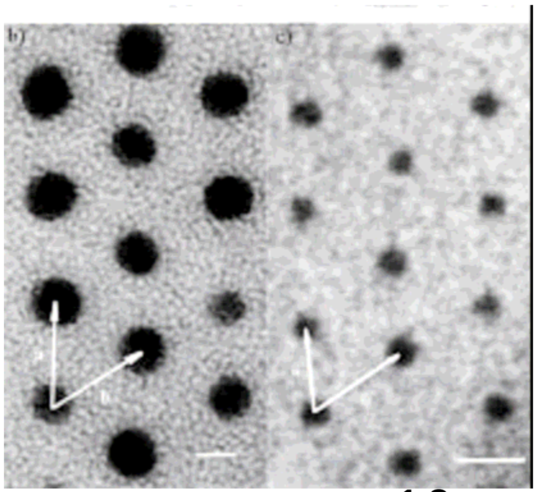
1D nanostructures (Extracellular)



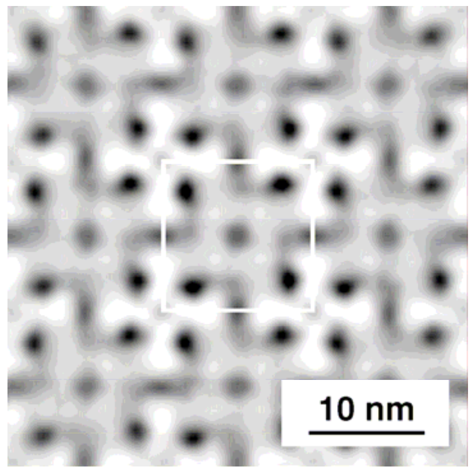
FeOOH on Polysaccharides
[Chan, et. al., 303 (2004), Science]

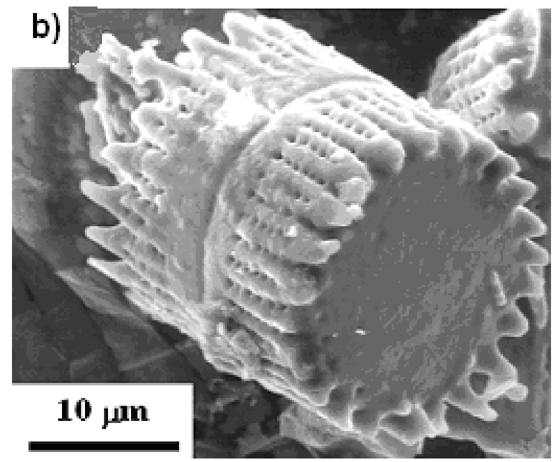
Special Structure Formation (III)

2D and 3D structures (bio-template)



7nm 10nm





2D arrays of Au and Pt nanoparticles [Engelhardt et al. Eur. Phys. J. D 9 ,(1999) , CHEMPHYSCHEM 3, (2001)]

Epoxy structures from diatom frustule [Gaddis and Sandhage , J. of Mat. Res., 9 (2004)]

Biomineralization Summary

Bio

- Low-temp process
- Regular morphologies
- High purity
- Long time (days)
- Unique crystal Structures (bio-sign.)
- Small size range

Lab

- Low-temp process
- Irregular morphologies
- High purity/high temp
- Or impurity with low T
- Fast process
- Multiple crystallines
- Large size range

Functional devices

- Biological sensors
- Actuation
- Bioluminescent
- Energy conversion

Microbial Biosensors (I)

Advantages:

- Quick response time
- Not sensitive to environments
- Easy to operate and control
- Multiple analytes
- Genetically Engineered microbial biosensors
- Low-cost

Microbial Biosensor (II)

Applications:

- Environmental monitoring
- Food monitoring: glucose, alcohol, bacteria, yeast etc.
- Monitoring of biology properties: growth of microbial.

Energy Conversion

Microbial Fuel Cell

- Microbial bioreactors producing H_2 for conventional fuel cells.
- Integrated microbial-based biofuel cells producing electrochemically active metabolites in the anodic compartment of biofuel cells.
- Microbial-based biofuel cells operating in the presence of artificial electron relays.

Challenges and Some Solutions

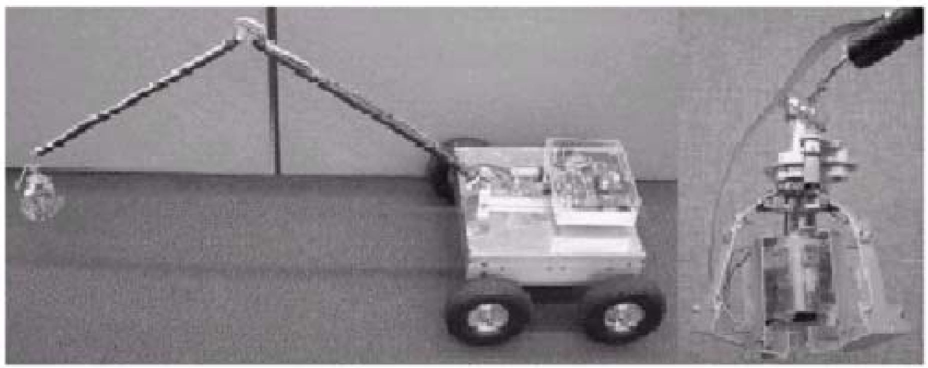
Challenges:

- Partially oxidize their organic substrates
- Transfer a portion of these electrons to electrodes
- Low power

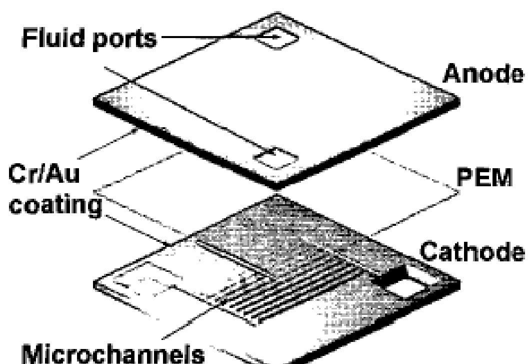
Solutions:

- Soluble mediator compounds added to facilitate electron transfer
- Layered design and special materials for the electrodes
- Immobilization of the microbial on the electrode*.

Microbial Fuel Cell Applications



[www.robotics.usc.edu]



Chiao, M., K.B. Lam, and L. Lin. IEEE MEMS. 2003.

Challenges (I)

What??

- What's the best choice of MOs to use for MEMS and NEMS?

Challenges (II)

- How??

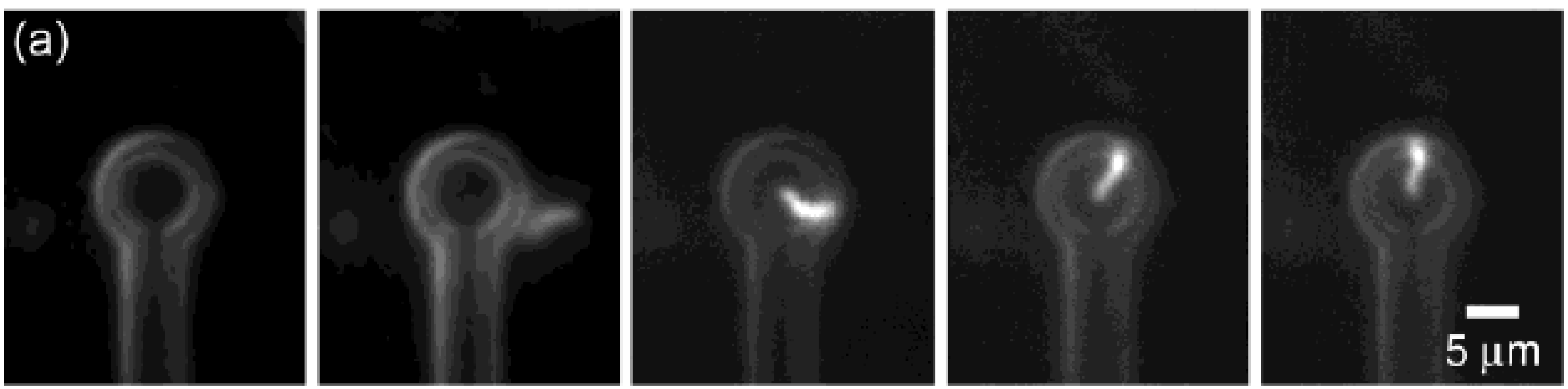
  Development of the bio-friendly process with bio-compatible materials.

Challenges (III)

Fits to the scope of the biological developments at molecular level.

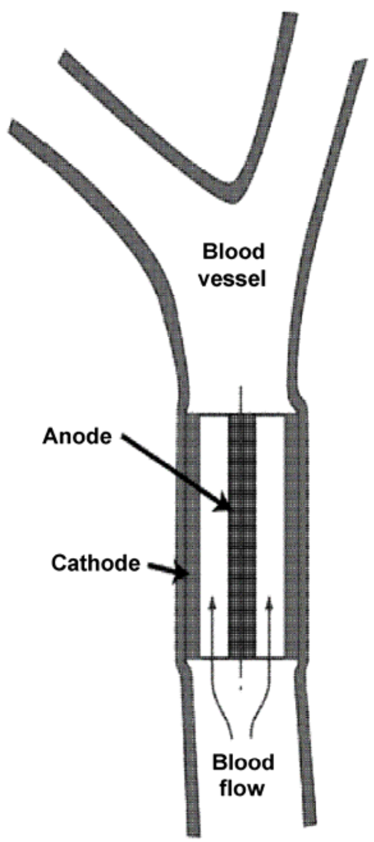
Examples

Controlled Assembly of Magnetic Nanoparticles from Magnetotactic Bacteria Using Microelectromagnets Arrays



Lee, et. al. NANO LETTERS 4, (2004)

Reality ??



BioMEMS integrated with a bacteria using the whip-like motion of their flagella to move about a microfluidic pump. Steve, Tung, U of Arkansas

The End

Thank you!