Miniature Biomimetic Acoustic Sensors

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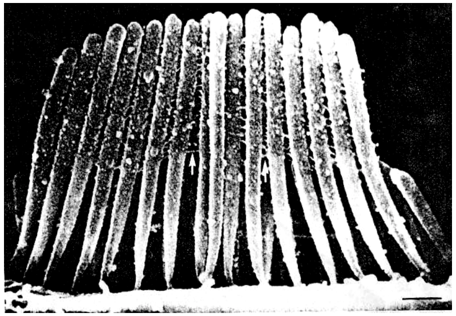

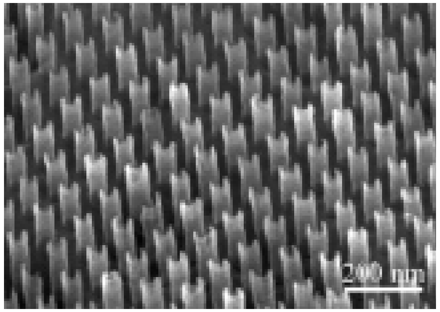

[1] New appointment: DARPA (MEMS program)

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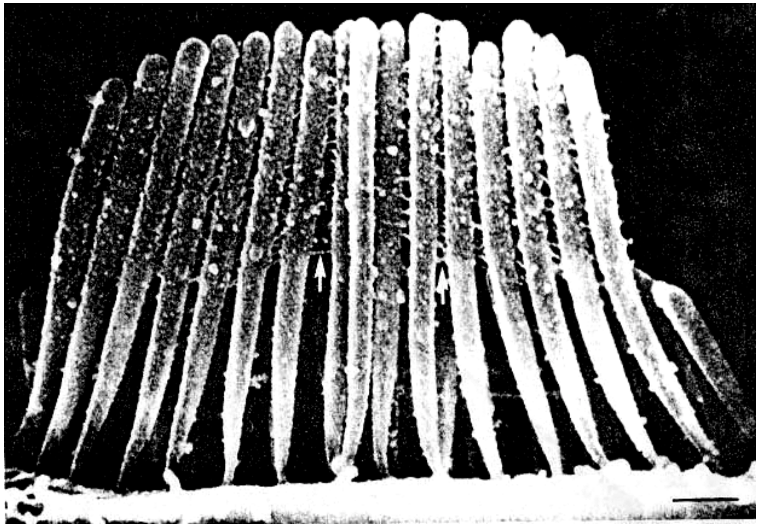
Stereocilia

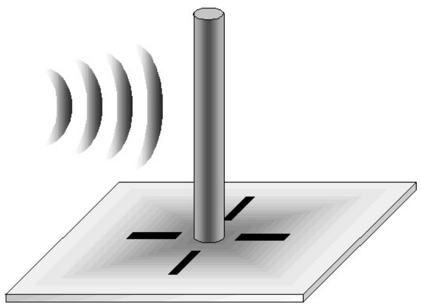
- ***Stereocilia***, Nature's fundamental acoustic sensors ***found in all hearing living systems***, are located on hair cells in the cochlea. Deflection of stereocilia, induced by shear in the endolymphatic fluid, generates neural impulses.



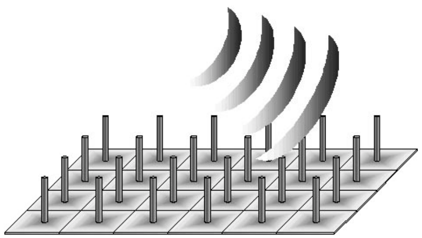
Bundle of stereocilia protruding from an inner hair cell of the guinea-pig cochlea. Scale bar: 500 nm (Pickles 1988).

- Stereocilia are also found in the ***lateral line of fish*** for water flow detection.
- Even in non-hearing organisms (hydra, jellyfish, sea anemones), stereocilia may be present as ***mechanoreceptors for swimming prey detection*** (plankton).

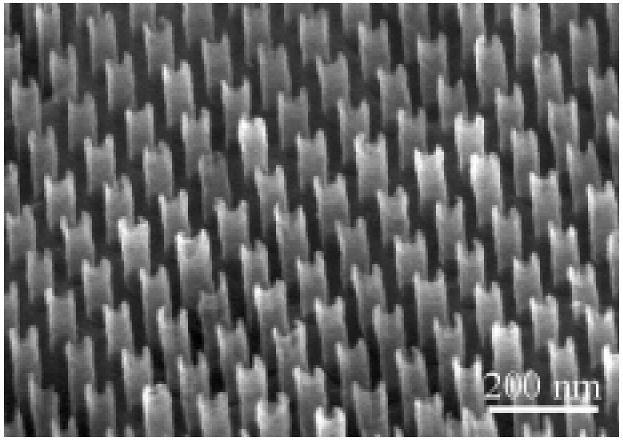
Micro/Nano-Fabricated Stereocilia



Schematic diagram of micromachined stereocilia mounted on a membrane, with piezoresistive strain sensors to measure deflection due to microflows (W. Tang).



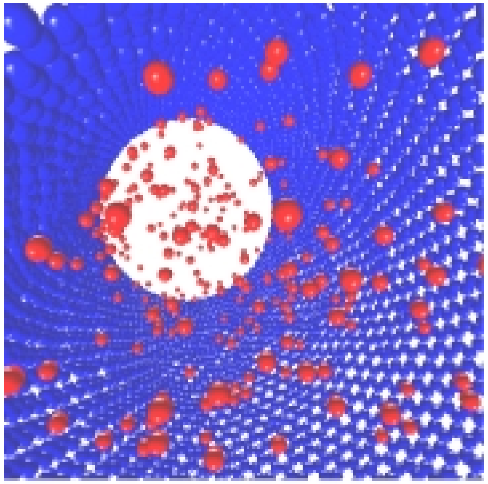
Array of micromachined stereocilia.

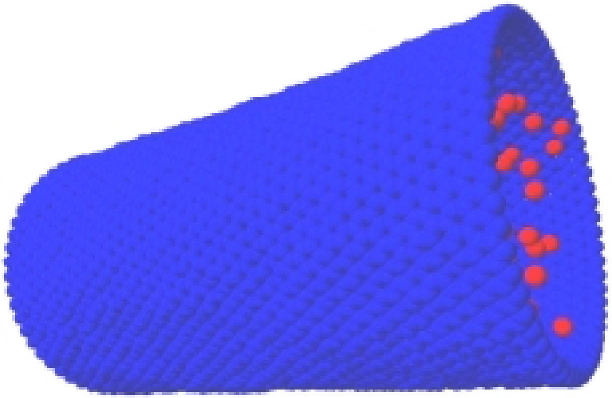


Highly ordered arrays of parallel carbon nanotubes were grown by pyrolysis of acetylene on cobalt within a hexagonal close-packed nanochannel alumina template at 650 °C. The nanotubes are characterized by a narrow size distribution, large scale periodicity and high densities. Using this method ordered nanotubes with diameters from 10 nm to several hundred nm and lengths up to 100 μm can be produced. Scale bar: 200 nm (from Li *et al. 1999*, courtesy J. Xu,).

Flows around Nano-Stereocilia

- Nanotube ***internal gas flows*** have already been computed at the Center for Computational Astrobiology (NASA Ames)





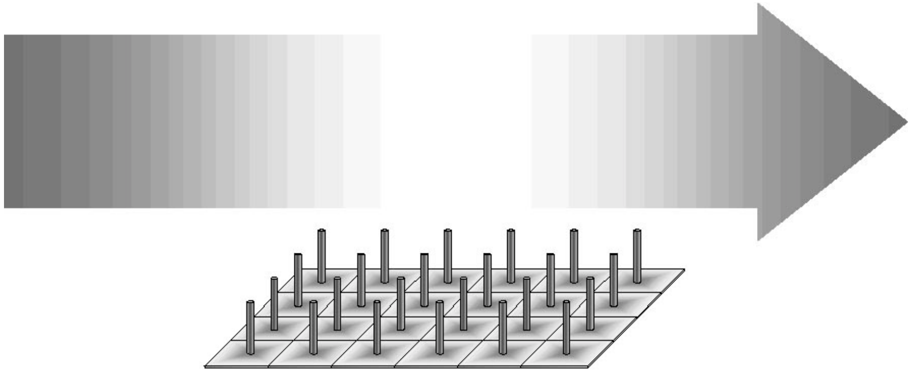
Inside view (left frame) and side-view (top frame) of computed argon molecular flow within carbon nanotubes (Koumoutsakos & Walther 1999).

- A JPL-Ames collaborative effort is in place to compute ***external water flows*** around nanotubes (using water-graphite intermolecular potentials).

Stereocilia as Acoustic Transducers

How?

- Stereocilia may be able to measure ***microflows*** associated with ***pressure waves***.
- Stereocilia deflection is expected to be ***coherent*** over the whole nanotube array (even at frequencies of several MHz).



Features:

- Array geometry can improve ***signal-to-noise ratio*** by averaging the incoherent thermal noise.
- Arrays could have ***directional*** sensitivity.
- The submicron diameter typical of stereocilia provides extreme ***sensitivity*** to small signals.
- Because fluid is free to flow through the array, stereocilia-based transducers would probably have ***low impedance***.
- Stereocilia could allow the ***miniaturization*** of acoustic sensors, without loss of sensitivity.

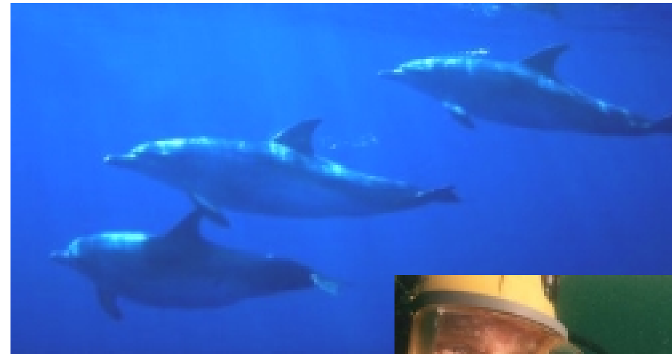
Stereocilia - Challenges

Issue	Nature	Fabricated
Medium	- liquid (endolymphatic, marine water)	- liquid - gas??
Contamination	- enclosed (ear cochlea) - cupula (fish lateral line)	- ??
Sensing	- deflection opens ion channels (tip links)	- optical - piezoresistive (membrane, integrated) - ??
Brownian motion	- array averaging - stochastic resonance	- array averaging - ??

Stereocilia - Applications

Stereocilia as sensors

- ***Miniature microphones/hydrophones***
- Miniature acoustic ***imaging arrays***
- Micro-flow detectors
- Shear stress micro-sensor
- Microscale ***bio-sound detectors***

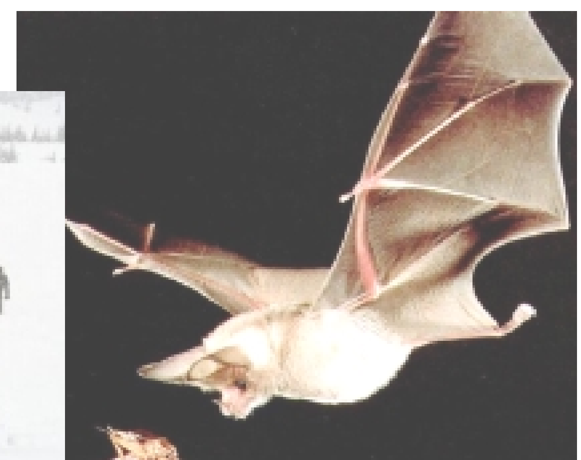


Handheld Sonars

Stereocilia as actuators ?

- Similar to crustacean/insect ***stridulatory pegs***
- ***Micro-Sonar/Sodar*** emitting arrays

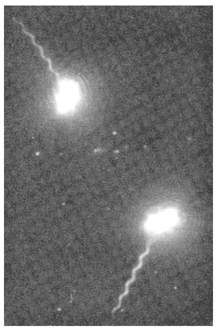
Air-Coupled
Acoustic Sensors



Microscale Bio-Sounds

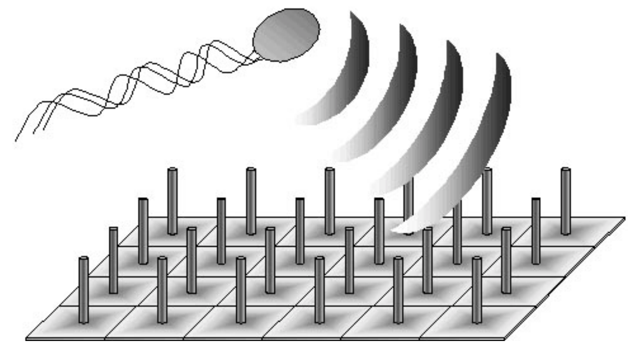
Listen to the ***sounds*** produced by microscale cellular or biomolecular events

- Detect and identify ***acoustic signatures of microscopic life*** to search for life on other planets

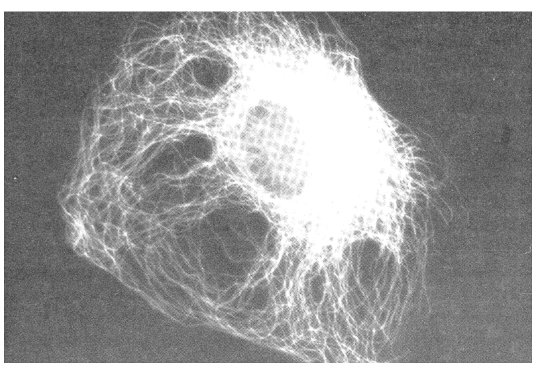


Swimming bacteria

Cellular motility



- Record the ***sounds and real-time dynamics of biomolecular systems*** at scales unreachable with conventional methods.



Internal cell movements (metabolite flows)

Biochemistry

Biochemical reactions (replication)