Advantages of using MEMS Approach

1. No manual assembly

2. Integration of multi-function
   Electronics, Mechanics, Optics, ...
   (example) Analog Devices' Accelerometer

3. Mass production

4. Small size
Merit of Mass Production by MEMS

----- In Production ------
Mass production of the identical design

--- low cost

----- In R & D ------
Mass production of different design in a single lot
= simultaneous trial & error (design annealing)

--- fast development

After just one trial process...

OK, This is the Best design!
Only Disadvantage of Mass Production is ...

When Supply > Demand

Pressure Sensor

1 mm x 1 mm

18,000 pcs / wafer

x Yield (?? %)

\[ \Phi 6'' \text{ Si wafer} \]

Now that I have done my task of this year ONLY by this single wafer...

Taken from TI (http://www.ti.com/), Modified by H. Toshi
The right method in the right place

Durable Devices
- Optical Switch
- Projection Display
- Ink jet Printer Nozzle
- Hard-disk Head

Automobile Applications
- Accelerometer
- Gyro
- Pressure Sensor
- Packaging Technique

High Tech MEMS
- Expensive Processing Equipment
- Long Processing Time
  with Integrated Circuits

$1@ ...?$

Low Tech MEMS
- Batch Process
- No Circuits

(Simple)

Disposable Devices
- Biomedical Filter
- Injection Capillary
- μTAS (micro Total Analysis System)

H. Toshiyoshi Hiroshi@ee.ucla.edu
Merits of Downsizing by MEMS

- cost performance improved
- **vibration** tolerance improved
- **shock** resistance improved

\[ m^{\text{small}} \cdot a^{\text{given}} \Rightarrow F^{\text{small}} \Rightarrow k^{\text{given}} \cdot x^{\text{small}} \]

- **thermal expansion** tolerance improved

\[ \rho_{\text{expansion}}^{\text{given}} L^{\text{small}} \cdot T^{\text{given}} \Rightarrow \Delta L^{\text{small}} \]

- parallelism
Bridging between nm and mm through μm

Conventional Mechatronics
Steppers, IR Spectroscope etc.

MEMS
STM, AFM, Atom craft etc.

Atom Molecular Cluster
LSI Cell Insects
Beyond the Limit of Photolithography

Twin Probes for Nanoscale Material Research


Twin Probes

< 100 nm (Controllable)

Silicon

1.5 μm

R ~ 50 nm

Silicon

Supported by Core Research for Evolitional Science and Technology, JST
Combination of TEM and MEMS TS

TEM : Transmission Electron Microscope
TS : Tunneling Spectroscope

Sample Holder

Micro Tools for Nanoscopic Phenomena

Too large for TEM chamber
Thermal drift due to
- large size
- different material
Vibration sensitive
Alignment difficulty

Small size ~ 2 mm
Less thermal drift thanks to
- small size
- single material
Vibration tolerance
Pre-aligned tips
Micromachined Tunneling Gap Controller

- Through hole
- Comb-Drive Actuators
- Tunneling Tips
- 0.5 mm
- 2.4 mm

H. Toshiyoshi  Hiroshi@ee.ucla.edu
TEM Image of Nanoprobe Tip

Tip radius 10nm

Silicon lattice

J. Endo 1999
Multiple Probes and Actuators

Four Probe Measurement

Resistivity

Response

H. Toshiyoshi Hiroshi@ee.ucla.edu
Actuator is Energy Converter

Some Missing Links between Energies

- Radiation
- Joule Heat
- Pertie Effect
- Thermal
- Electric Actuator
- Thermal Actuator
- Chemical Reaction
- Chemical
- Biochemical
- Optical
- Photoelectric Effect
- Solar Cell
- Photonic Actuator
- Luminescent
- Mechanical
- Electrophysically Controlled Surface Energy (Surface Tension)
- Electrical
- Photostrictive
- Muscle
- Boltanic Effect (Battery)
- SMA
Electrostatic vs. Electromagnetic

Electromagnetic Energy

Max. $9 \times 10^5 \text{ J/m}^3$

Limited by Magnetic Flux Saturation

$\sim 1.5 \text{ T (iron)}$

Electrostatic Energy

Limited by Electrostatic Break Down

$3 \times 10^6 \text{ V/cm}$

$4 \times 10^5 \text{ J/m}^3$

Representative Size

Energy Density $\text{J/m}^3$

$\mu\text{m}$

$\text{mm}$

$m$
Micro Actuators for Precise Position Control

Performance of Electrostatic Actuator

Voltage Resolution: \( \frac{10\text{mV}}{100\text{V}} \times \frac{1}{256} = 4 \times 10^{-7} \)

Typical Stability of Voltage Power Supply: \( \sim 10^{-5} \)
For More Precise Positioning

CONVENTIONAL

2-Stage Actuator

Coarse

Fine

OUTPUT

V_{coarse} V_{fine}

Analog

Feedback Control

Noise

THIS WORK

Digital-to-Analog Converter of Displacement

LSB

MSB

b_4 b_3 b_2 b_1

OUTPUT

1 0 1 1

Open Loop Control

V_{DC} N-bit Digital
D / A Converter of Displacement

\[ X = A \left( \frac{1}{2} x_1 + \frac{1}{4} x_2 + \frac{1}{8} x_3 + \frac{1}{16} x_4 \right) \]

C-2C Suspension Network

H. Toshiyoshi, et al., TRANSDUCERS 99, Sendai, Japan
Micro Electro Mechanical Digital / Analog Converter

4-bit MEMDAC

H. Toshiyoshi  Hiroshi@ee.ucla.edu
4-bit MEMDAC Output

Merits of Downsizing by MEMS

- cost performance improved
- vibration tolerance improved
- shock resistance improved
- thermal expansion tolerance improved
- parallelism

Capacitor & Switch

x 64 Million =

Fujitsu
http://www.fujitsu.co.jp
Quantity Changes Quality

Capacitor & Switch

\[
x \times 64 \text{ Million} =
\]

Mirror

\[
x \times (1280 \times 1024) =
\]

Cantilever

\[
x \times \text{Array} =
\]

Nanocantilevers for AFM Data Storage

Conclusions

1. MEMS technology provides us with new & wide range of manufacturing methods for precision engineering:
   - assemble free
   - batch fabrication
   - quick R & D
   - integration of more function
   - small size
     - vibration tolerance
     - shock resistance
     - less thermal drift

2. MEMS has open up a new approach in mechatronics: "Quantity changes quality"