National Kaohsiung First University of Sci. & Tech.

微致動器二

Microactuators-2

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Magnetostrictive Microactuators
磁變致動器

CED

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Motion Principle and Its Properties

- 磁變致動器尚未產品化，因其材料製造成本高，控制困難。
- 而一般磁變材料的居里溫度（失去鐵磁性的溫度）低，也降低其實用價值。
- 磁變(Magnetostriction)：正常狀態下，Weiss' Domain有不同的極化分佈而相互抵銷，在外加磁場將導致該材料的尺寸變化。
- 在低溫下，磁變材料可產生0.1%的相對長度變化，但體積則無明顯改變。
- 鋱鐵 (terbium-iron) 與鋱鏑鐵 (terbium-disprosium-iron,又稱為 Terfenol-D) 為主要研究材料。其磁變性佳，長度變化為 0.15~0.2%。與PZT比較，其遲滯小，居里溫度約380 °C。

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Motion Principle and Its Properties

- 磁變材料的主要優點
  - 磁變材料由電流控制，所需電壓低，線路簡單
  - 能量密度為PZT的20倍以上，故適用於高出力、快速機動反應與短距離高精度定位上
  - 不需可移動式電極或高電壓
- 磁變材料的主要缺點
  - 位移量小
  - 靜態作業仍須加上電流，造成歐姆損失
  - 且其磁變效應不能直接可逆。
  - 微觀元件製造不易
- 主要應用在線性馬達的控制元件、主動式吸振元件，或定位裝置

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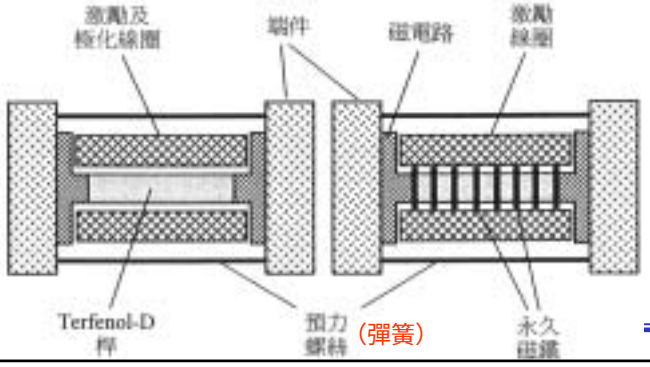
典型桿狀Terfenol-D致動器

- 兩種典型桿狀Terfenol致動器的設計，因Terfenol-D的拉伸強度差，為避免受磁時伸長造成破壞，需加以預壓應力。
- 右圖設計增設永久磁鐵，以增加Weiss‘ domain間的對準，來增進磁變的線性。



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雙態(Bimorphic)磁變懸臂樑

- 相較壓電式的懸樑，磁變懸樑的位移量大，且不需要直接的電接觸。

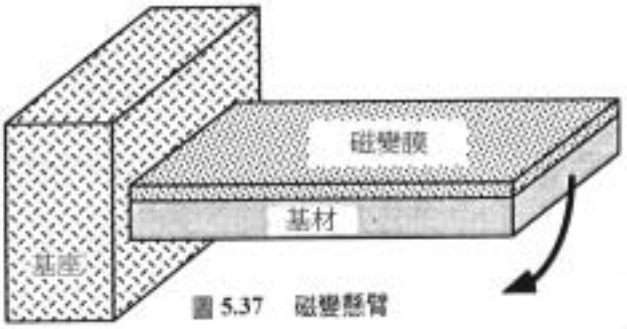

圖 5.37 磁變懸臂

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Fluidic Switch

- 薄膜式的磁變材料較桿式亦整合於微機電中，且成本較低。
- The cantilever arm is 2 mm long, 1 mm wide and has a layer of 20 μm (Si) and 5 μm (TbDyFe).

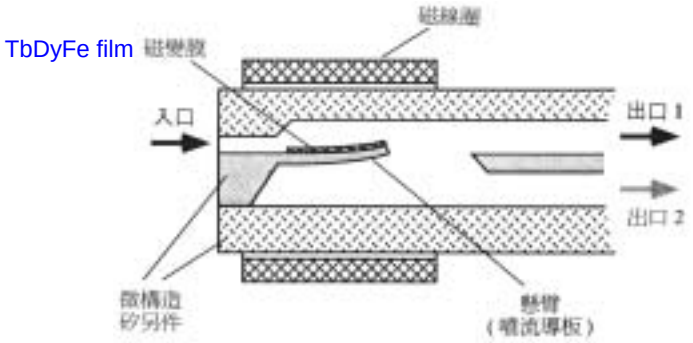

圖 5.39 磁變流體開關。根據 [Flik 94]。

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Membrane-type Microvalve

- The valve consists of an external coil, a bimorphic magnetostrictive membrane actuator, two inlets, an outlet and the valve seat.

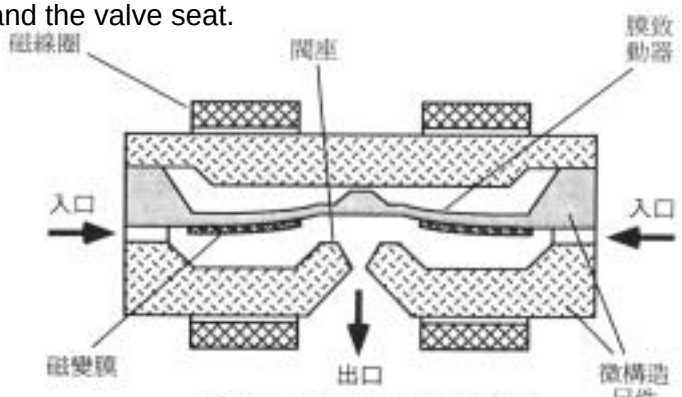

圖 5.40 磁變閥。根據 [Flik 94]。

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Electromagnetic Microactuators
電磁致動器

CED 9

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電磁微致動器的性質

- 典型的應用包括電動馬達與致動器，運用LIGA製出（因為可製造將磁能轉換成力與力矩的材料如鎳）。
- 但以平版法同時產生帶電線圈與磁通元件有困難。因此磁石與線圈常需以導線黏和的介面技術來整合。
- 電磁致動器的有效性決定於材料性質與磁石體積，因此也是微小化的限制取決於所需整合的磁石體積。

CED 10

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運動原理

- A reluctance type stepping motor
  - Consist of a serrated stator and a magnetic rotor consisting of three magnetic subsystems to produce a sliding motion according to the magnetic bearing principle.

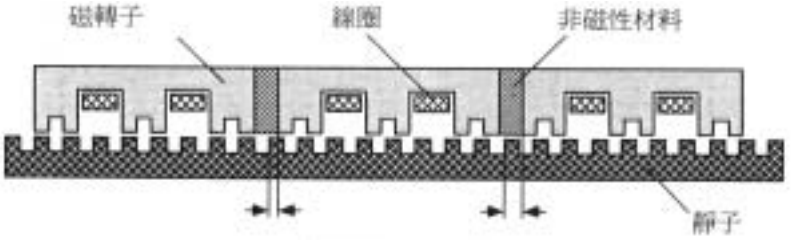

圖 5.41 線性步進馬達。根據 [Lehr 92]。

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運動原理

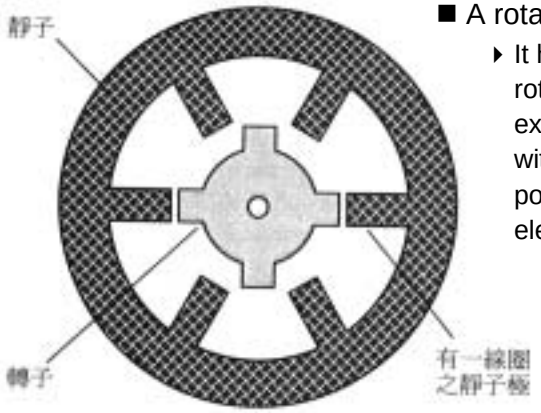

圖 5.42 旋轉磁阻馬達

- A rotary reluctance motors
  - It has a permanent magnet rotor with externally extended poles and a stator with internally extended poles; around the stator the electrical coils are wound.

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Rotational electromagnetic micromotor with gears

- 以SLIGA製造高100μm的鎳製金屬構造，馬達軸與轉子間隙僅500 nm。
- The coil windings of the stator pole are made of an aluminum alloy wire using wire bonding

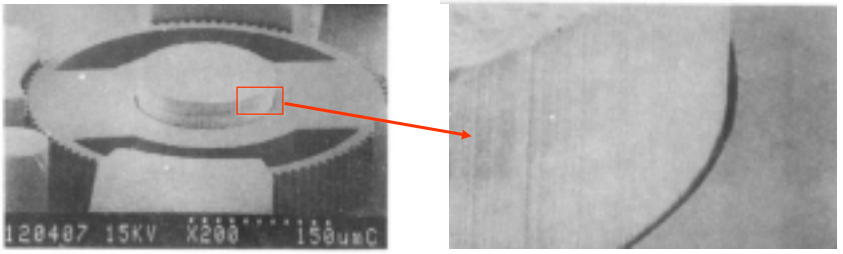

圖 5.43 電磁微馬達。感謝 the University of Wisconsin-Madison (Department of Electrical and Computer Engineering)

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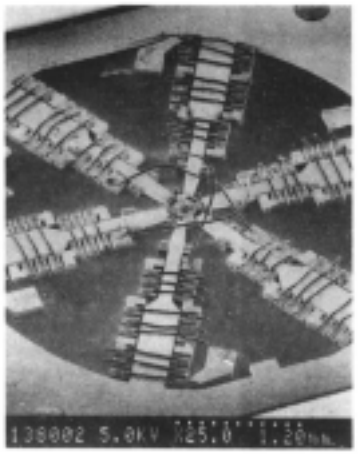
Micro-stepping electromagnetic motor



- A 3-phase variable electromagnetic reluctance micromotor having six stator poles and four rotor poles.
- Stator height 300 μm
- keeping the rotor relatively thin as compared with the stator to reduce the friction between rotor and substrate.

圖 5.44 微步進電磁馬達。感謝 the University of Wisconsin-Madison (Department of Electrical and Computer Engineering)。

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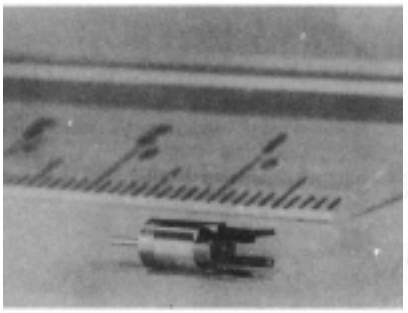
Micromotor Using a Rare Earth Rotor

- The rotor, a magnet made of rare earth metal alloy (SmCo), has an inner diameter of 0.5 mm



一電磁直流馬達之原型。感謝 the Toshiba Corporation.

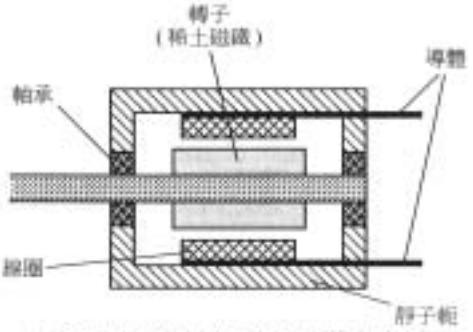


圖 5.48 電磁直流馬達之剖面。根據 [Itoh 93]。

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以微細加工法製造線圈的原理

- 導體圍繞在一彎曲的磁化體上，減少了微細製造時整合的困難。

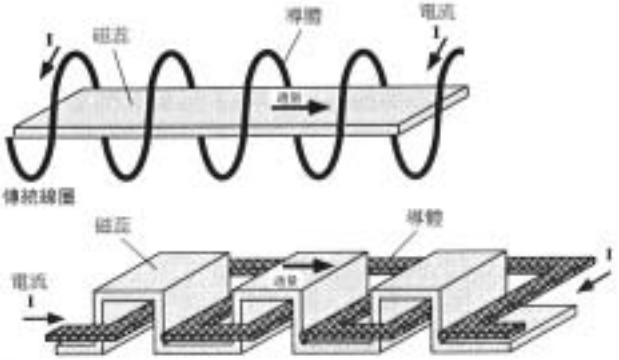

圖 5.49 以微機械加工法製造線圈之原理。根據 [Ahn 93]。

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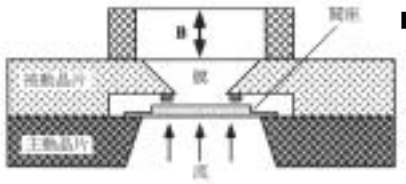
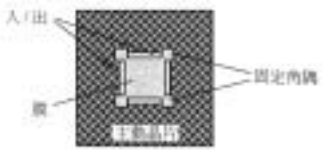
Microvalve



a



b

圖 5.50 電磁閥門之構造。(a) 剖面圖；(b) 主動晶片之上視圖。根據 [Lock]。

- The valve was manufactured using UV exposure and galvanic deposition together with new PR material (AZ4000 from Hoechst).
- The lower active chip has a 2 x 2 mm^2 square membrane made of a galvanically deposited FeNi alloy.

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Microswitch

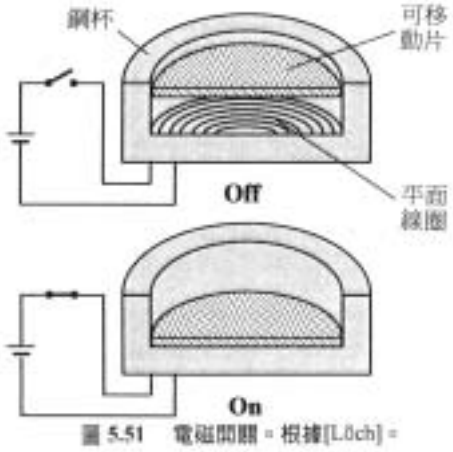

圖 5.51 電磁閥門。根據[Loch]。

- A miniaturized electromagnetic switch with a planar magnet coil
- The plate moves back to its original position by means of a spring (not shown).
- The actuator has a diameter of 12 mm and is 2.5 mm high; its plate lift is 0.3 mm.

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Linear Micromotor

- Due to the height limitation of about 20 mm in the silicon technology, the forces that can be produced are very weak.
- A linear motor with a sliding rare earth magnet using planar coils. (24 cm/s)

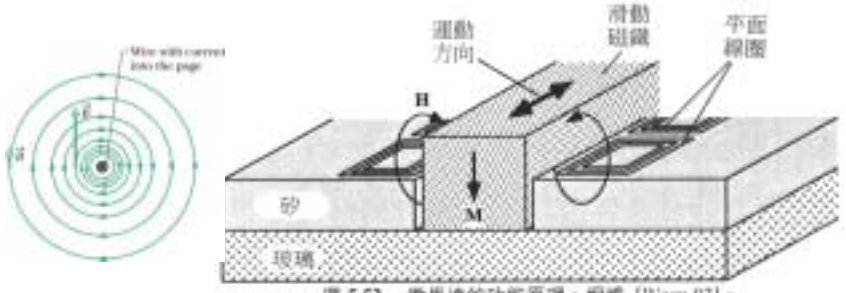

圖 5.52 微馬達的功能原理。根據 [Wagn 92]。

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Linear Micromotor Prototype

- The coils opposite one another are driven sequentially with a current of the same magnitude so that a traveling perpendicular magnetic field (parallel to the magnetization of the permanent magnet) is produced.

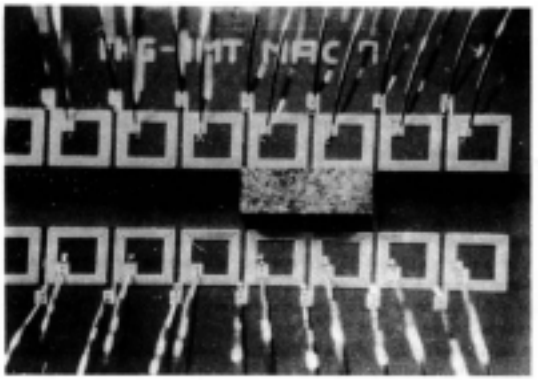

圖 5.53 線性馬達的原型。感謝 the Fraunhofer Institut für Silizium technologie (ISIT), Itzehoe。

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SMA(Shape-Memory Alloy) Microactuators
形狀記憶合金致動器

CED 21

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SMA的性質

- The SMA transforms from the austenitic state into the martensitic state as the temperature sinks under the critical temperature.
- The shape of the SMA can be deformed by up to 8% (as for NiTi-alloys. （超過時將會有永久變形）
- In the low temperature state, the SMA keeps the desired deformed shape until it is exposed to a higher temperature.
- Characteristic for actuators that use SMA are their low complexity, light weight, small size and large displacement.

CED 22

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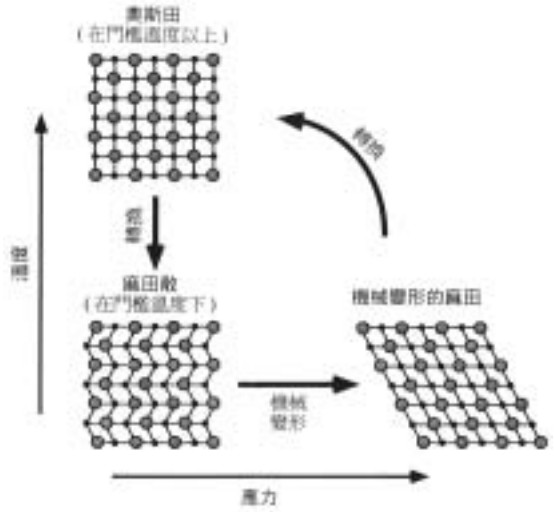
SMA運動原理



CED

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SMA運動原理

- In this (martensite plateau) temperature range, the alloy can be deformed considerably under constant stress .

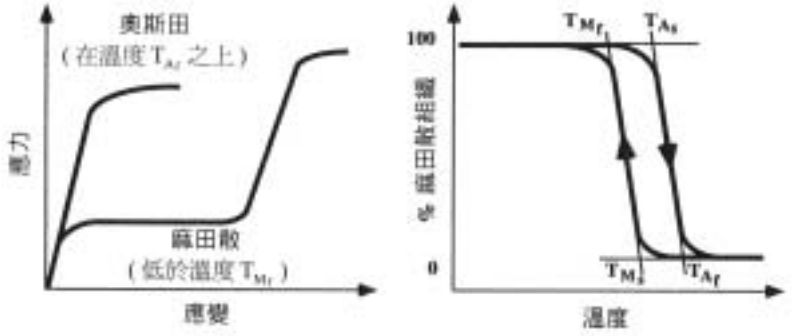

圖 5.55 應力—應變圖(左)及 SMA 遲滯曲線(右)。根據 [Stock 92]。

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SMA材料特性

- One-way effect.
- The two-way-effect offers more application possibilities, especially for microactuators, but it is of less magnitude as the one-way effect (max. 5% for NiTi-Alloys)
- NiTi alloys have their critical temperature between -100°C ~100°C. Small switching temperature range (about 10-20°C) limits the application.
- NiTiPd alloys which have a higher transformation temperature of about 200°C.
- Disadvantage: relatively long reaction, hysteresis.

CED 25

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Expansion and Compression Springs Using SMA

- When heated the spring transformed into an austenitic structure, it lifts the weight up to a certain height. By cooling the SMA spring under the "switching point", the weight deforms the "softened" martensitic spring.

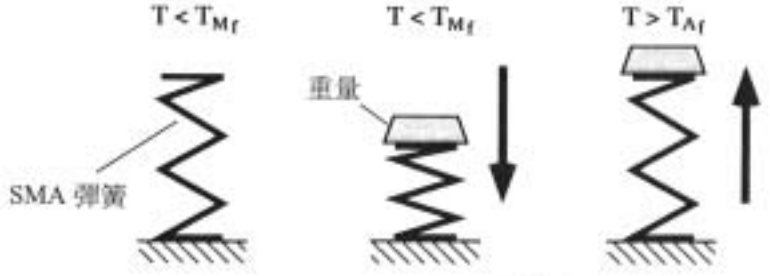

圖 5.57 形狀記憶合金彈簧工作原理。根據 [Humb 94]。

CED 26

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Active Endoscope Using SMA Spring

- The prototype is 215 mm long, has a diameter of 13 mm and consists of 5 active segments.

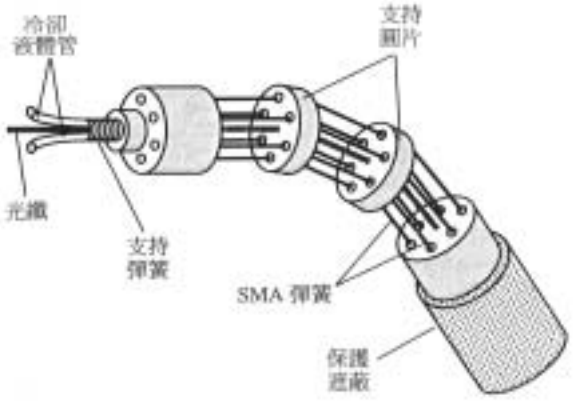

圖 5.59 使用形狀記憶合金之主動內視鏡。根據 [Esashi 93]。

CED 27

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Catheter Design Using SMA

- The SMA contract when heated by electric current. The direction of motion of the endoscope and its angle of the bend can be controlled by selectively applying electric voltage to each of the three wires.

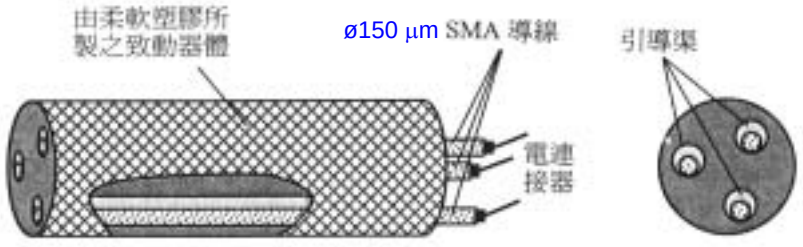

圖 5.60 MAC 致動器之示意表示。根據 [Fuku 93]。

CED 28

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Micro Grippers

- Two successive lithographic and three wet etching steps to produce the microstructure. A 5 μm thin NiTi film was deposited using the sputter technique.

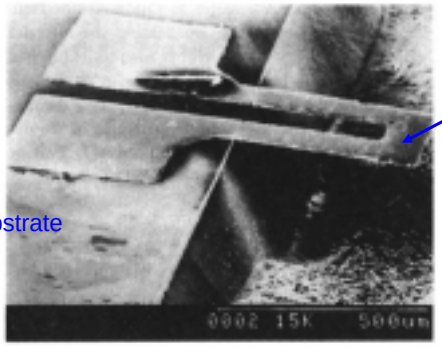

圖 5.61 NiTi 製之 SMA 微機械人的臂。感謝 the Yamaguchi 大學 (Faculty of Engineering)。

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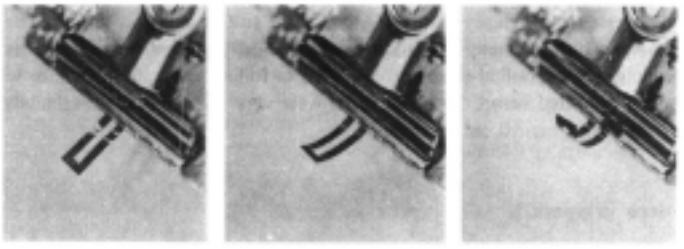
SMA Microarm

- By heating above T_{Af} =57°C, the SMA actuator returns to its original curved shape; when the temperature is lowered, the microarm straightens out. If the temperature falls below T_{Mf} =-9.1°C, the material bends in the opposite direction. (SMA two-way effect)



CED

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Thermomechanical Actuators
熱機械致動器

CED 31

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Working Principle

- Based on the principles of a change of the shape or the volume of a material which takes place when heat or cold is applied to it.
- Bimaterial actuators: made of layers of different materials which have different thermal expansion coefficients.
- Another type of thermomechanical actuator uses the thermal expansion of gases or the liquid-gas transformation to produce an actuation.
- Disadvantage: Miniaturized thermomechanical actuators have short response times. However, the actuator's ability to exert a force is also reduced.

CED 32

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Bistable Cantilever Actuator

- Consists of a U-shaped three-layered thin-film cantilever beam (polysilicon - silicon dioxide - polysilicon), a tension band (silicon nitride) and a three-layered anchor structure (polysilicon - silicon nitride - polysilicon)

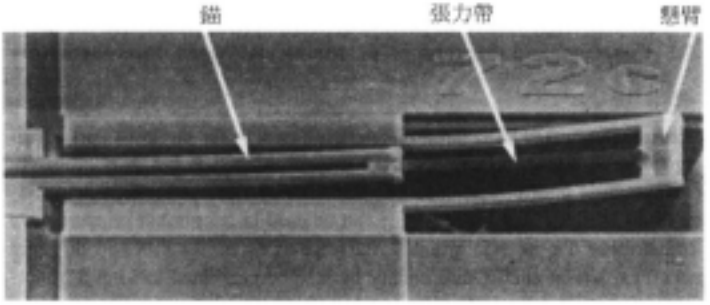

圖 5.63 一雙穩態致動器的掃描電子顯微鏡照片。感謝 the Sharp Corp. (Precision Technology Development Center), Nara。

CED 33

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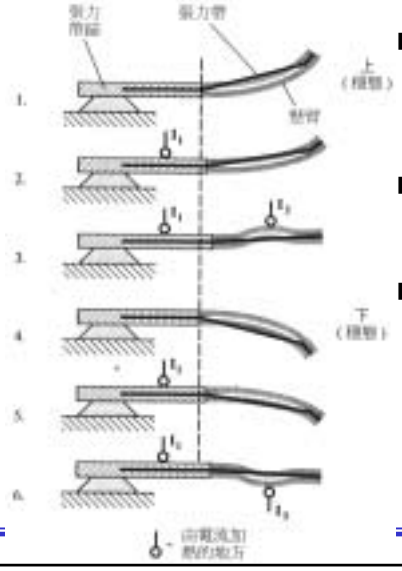
Principles of Bistable Cantilever Actuator



- A current I_1 can be applied to the anchor and I_2 and I_3 to the upper and lower polysilicon layers.
- Upper to Lower stable state: I_1 + I_2 and off
- Lower to Upper stable state: I_1 + I_3 and off

CED 34

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Ciliary Microactuator System for Locomotion

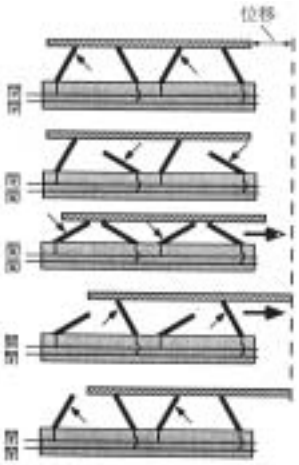

圖 5.65 使用纖毛運動原理造成關節運動之整材料微致動器原理。根據 [Fuji 93]。

- Consists of a multitude of flat bimaterial microactuators forming an actuator array that moves smoothly according to a coordinated motion principle.
- Particular interest is the low friction.

CED 35

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Ciliary Microactuator System

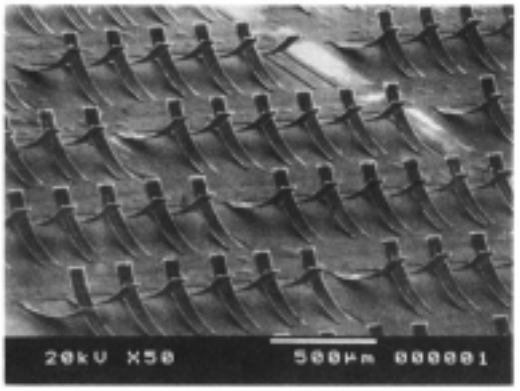

圖 5.66 關節運動的纖毛微致動器系統之照片。感謝 the University of Tokyo. (Institute of Industrial Science)。

- A micro-heating element is embedded between its two polyimide layers.
- 512 elements were arranged on a 1 cm^2 substrate.
- Silicon plates weighing 2.4 mg moves at a speed of 27 μm/s and an operating frequency of I Hz.

CED 36

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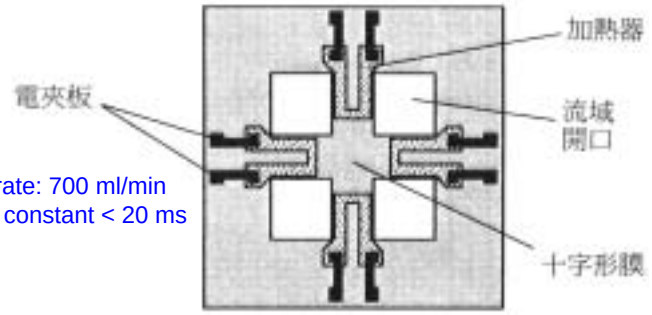
Microvalve

- There are four n^+-doped, 600 μm wide cliplike polysilicon heating strips bonded to the membrane.
- Produced by seven lithographic steps, including wet and plasma etching and galvanic deposition.



Flowrate: 700 ml/min
Time constant < 20 ms

CED 37

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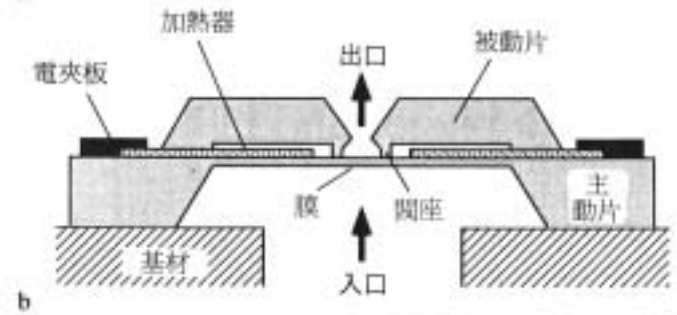
Microvalve

- When a current is applied, the polysilicon heating strip and silicon membrane are heated up causing the membrane to buckle downward and to open the valve.



b

圖 5.67 微致動閥示意圖。(a) 膜片之上視圖；(b) 閥剖面。根據 [Lisec 94]。

CED 38

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Principle of Thermopneumatic Actuators

- The thermal expansion of gas or the thermal transformation from liquid to gas or vice versa can be used to drive micropumps and valves.

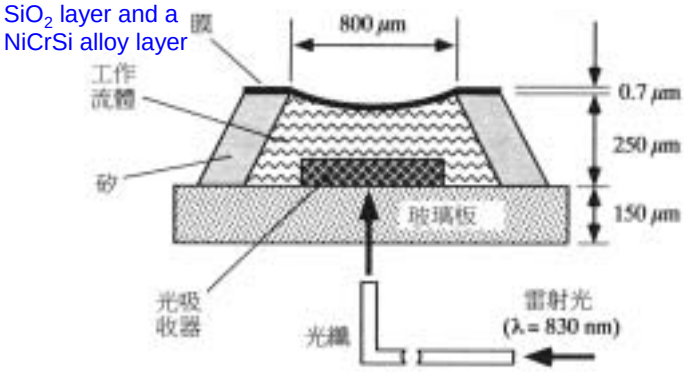

圖 5.68 光致（作業）微致動器。根據 [Mizu 93]。

CED 39

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Pressurized Membrane

- The light absorber heats the liquid, the inner cell pressure increases and the membrane is pushed outward.

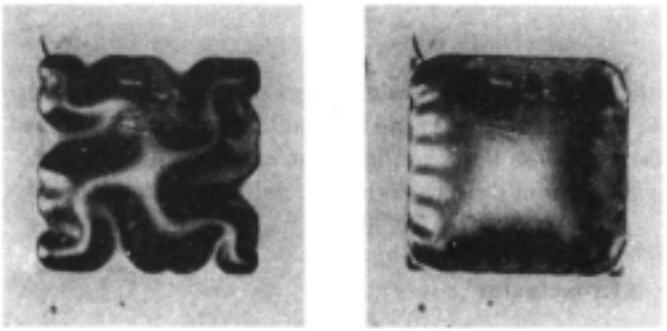

圖 5.69 膜的兩狀態。感謝 the Asia Cosmos R&D Co. (Electronic Field), Tokyo。

CED 40

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Micropump Using Worm-like Motion

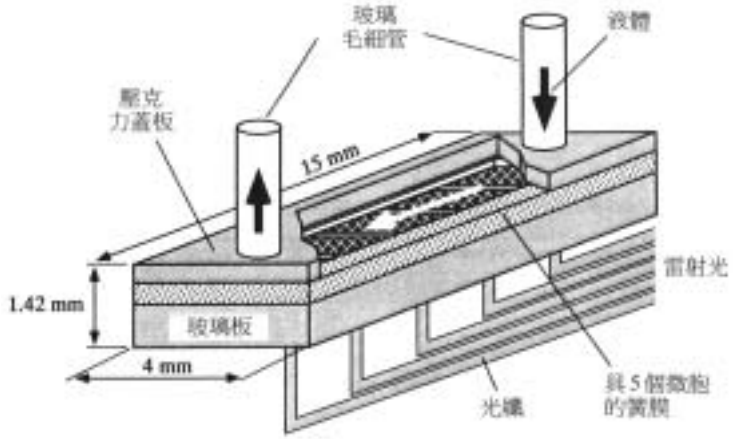

圖 5.70 由 5 個微致動器驅動的幫浦。根據 [Mizu 93]。

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Thermopneumatic Micropumps

- The pump consists of two passive valves and a polyimide membrane between two plastic substrates (made from polysulfone using LIGA molding).

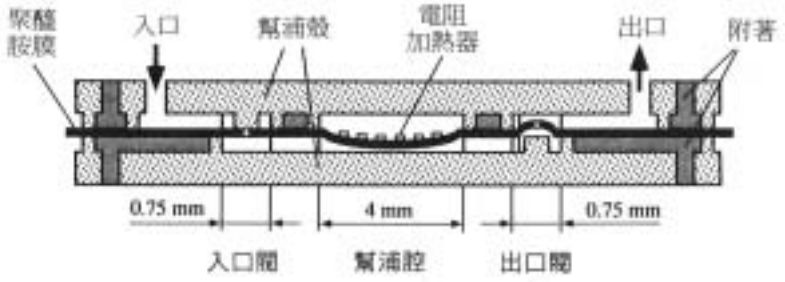

圖 5.71 微幫浦的示意表示。

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Thermopneumatic Micropumps

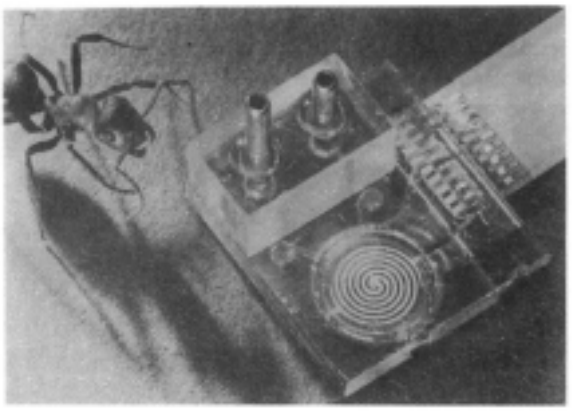

圖 5.72 微幫浦與一隻螞蟻的尺寸比較。感謝 the Karlsruhe Research Center, IMT。

- With a pumping frequency of 30 Hz and an operating current of 100 mA, the pump was able to pump 220 μl/min of air.

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Microdosing System

- When the two pumps are combined with a detector and a mixer, a dosing system can be built to be used for chemical analysis.

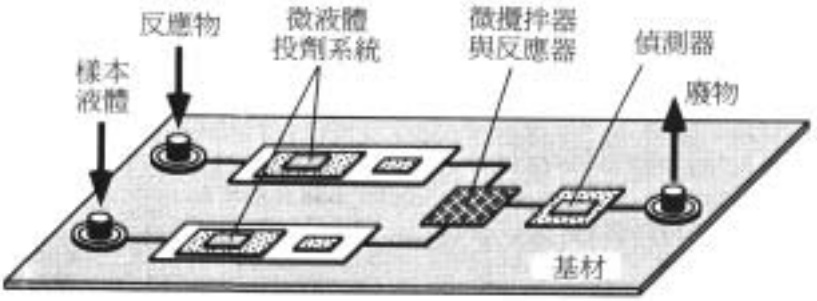

圖 5.73 化學分析儀。根據 [Lamm 93]。

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Thermally Actuated Micropump

- Consists of two passive valves, a pump chamber and a pump actuator, which is provided with an air chamber and an integrated heating element.

50 μl/min at 3-5 Hz

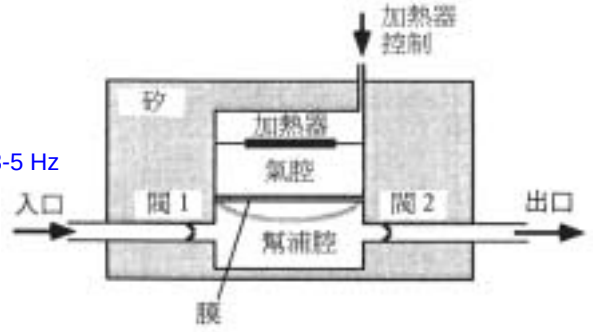

圖 5.74 熱致動微幫浦。根據 [Lamm 93]。

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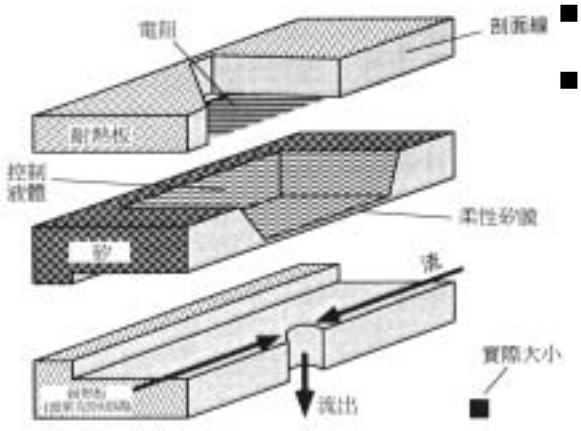
Thermopneumatic Microvalves



- Normally open.
- When the resistors are activated, the liquid in the closed chamber expands and the diaphragm bulges out to decrease or stop the flow.

圖 5.75 常開熱致微閥之設計。根據 [Zdeb 94]。

CED 46

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Thermopneumatic Microvalves

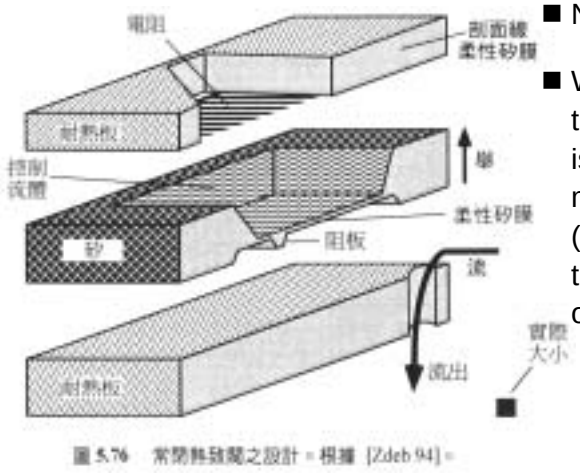

圖 5.76 常開熱致閥之設計，根據 [Zdeb 94]。

- Normally close.
- When the liquid in the valve chamber is heated, the right membrane support (pedestal) lifts off the valve seat and opens the outlet.

CED 47

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Electrorheological Actuators
電流變致動器

CED 48

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Electrorheological Liquids

- Electrorheological liquids change their flow properties under the influence of an electric field.
- An electric field can solidify the Electrorheological liquid to a plastic body by increasing its dynamic viscosity, and the process is reversible.
- 今日使用材料由懸浮固體非金屬親水(hydrophilic)粒子所組成，如矽酸酐(silicone acid anhydrides)或金屬氧化物於非導電性油中（如變壓器油或石蠟paraffin）。

CED 49

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Electrorheological Liquids

- The electrorheological liquids consisting of polymer particles (15~50%) and silicone oils.

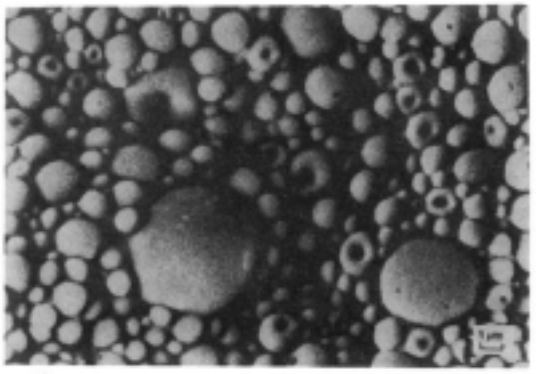

圖 5.77 固體質點在電流變液體中之電子掃描顯微鏡照片。感謝

CED 50

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電流變效應的模型

- The viscosity increase is caused by the polarization of the solid particles when an electric field is applied.

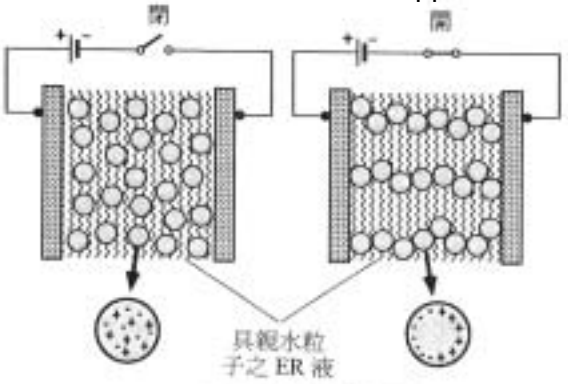

圖 5.78 電流變效應之簡化模型。

CED 51

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流動阻力與外加電場的關係

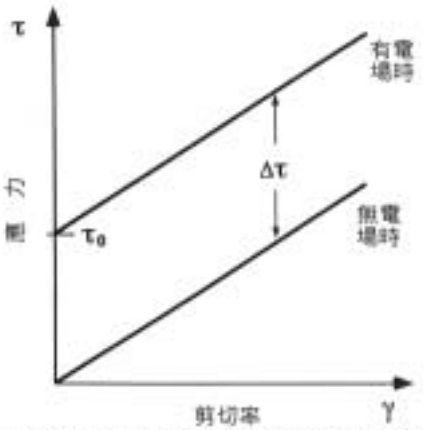

圖 5.79 電流變流體之典型的流動性圖。根據 [Block 92]。

- The transition of a Newtonian liquid to a Bingham body under the influence of an external field.
- Both τ_0 - the static yield stress and $\Delta\tau$ - the field induced stress increase due to the external field.

CED 52

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電流變體的特性

- Not desirable to have a large amount of solid particles in the liquid; usually the amount is kept at about 40% by volume.
- The switching times that can be reached are in the range of a few milliseconds with an applied voltage in the kilovolt range.
- The great advantage of clectrorheological actuators is their simple design compared with other actuators.

CED 53

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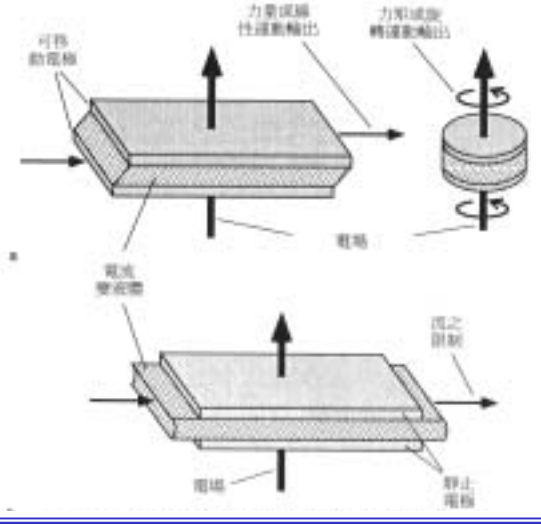
電流變致動器驅動的方式



- 剪力原理：應用於旋轉離合器
- 流動限制原理：應用於閥門的限流器

CED 54

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A Rotational Clutch Shear Principle

- The device must be relatively long in order to create a large contact area between the liquid and the rotor, and to avoid the inertia effect.

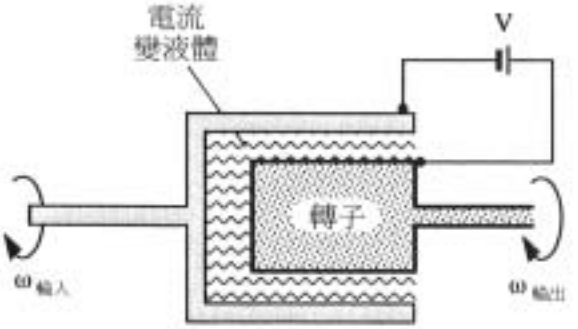

圖 5.81 電流變耦合系統。根據 [Hoss 92]。

CED 55

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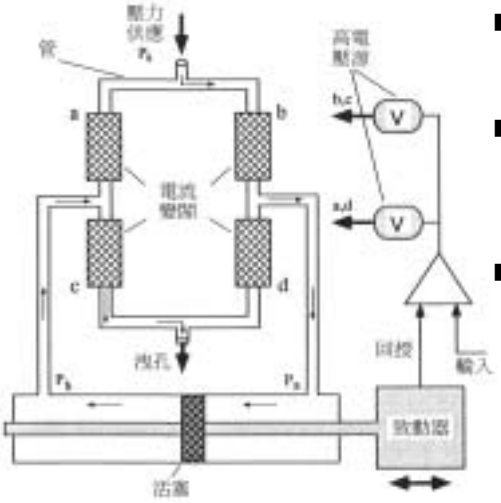
The 4-valve Bridge



- 四閥門加相同電壓：活塞不動
- b, c閥門電壓下降，a, d閥門電壓增加：活塞向左移
- a, d閥門電壓下降，b, c閥門電壓增加：活塞向右移

CED 56

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Hydraulic and Pneumatic Actuators
液壓與氣壓致動器

CED 57

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Flexible Rubber Microactuators

- Expand along its longitudinal axis when the pressure is increased equally in all three chambers.
- Bends in the opposite direction If the pressure is only increased in one chamber.

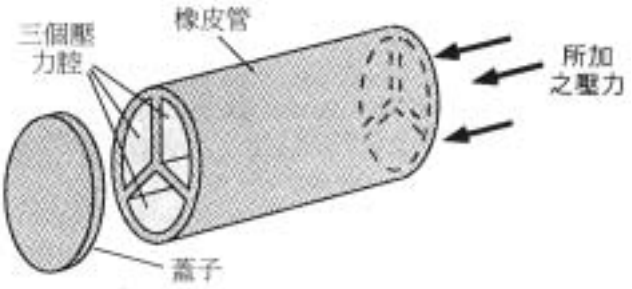

圖 5.83 氣動柔性微致動器之原理。根據 [Suzu 91]。

CED 58

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Robot Hands and Walking Machine

- The four-fingers (Ø12 mm) hand and the 6-legs (Ø2 x L12 mm) walking robot.

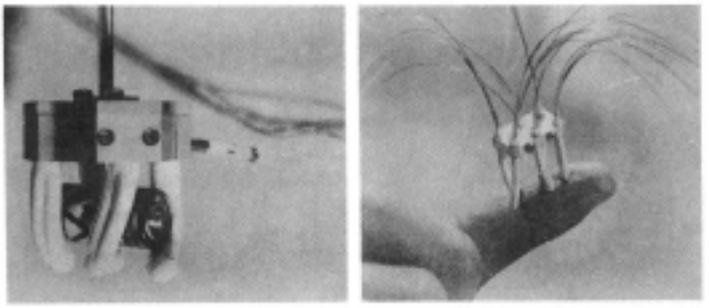

圖 5.84 機械人之手（左）及走路機械（右），兩者均基於柔性微致動器設計。感謝 the Toshiba Corp. (Research & Development Ceneter), Kawasaki。

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Pneumatic Multiactuator Microsystem

- Allows flat objects to be lifted, transported and positioned by air currents coming from several microjets.

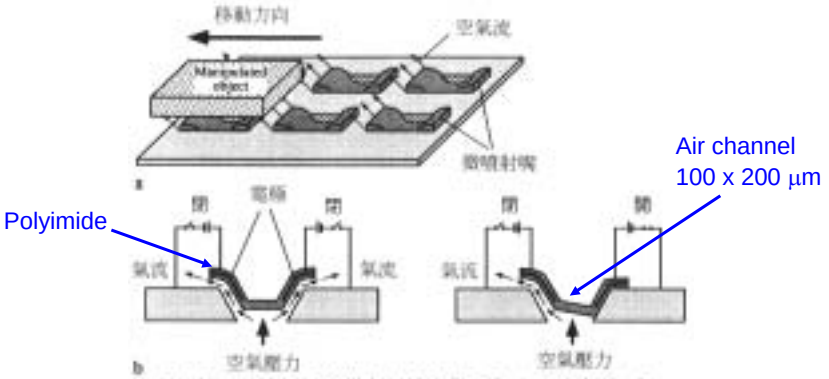

圖 5.85 物體定位及輸送之複致動器微系統。(a) 系統構圖；(b) 功能原理。根據 [Fuji 93]。

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