APPLICATIONS OF SHAPE-MEMORY ALLOY THIN FILM

A.D. Johnson, V.V. Martynov

TiNi Alloy Company, San Leandro, CA, 94577 USA

ABSTRACT

Diverse applications for TiNi film are being realized. Devices combine sputter-deposited SMA thin film with silicon substrate, using MEMS fabrication technology.

Pneumatic valves are in limited production, finding applications in analytical instruments and medical instruments. Mass flow controllers and pressure regulators are at prototype stage.

We have prototyped liquid control valves of two types: direct control via force of actuator and control of membrane using pneumatic pressure. Advantages are low internal dead volume and compatibility with corrosive or sensitive liquids. Applications exist in process control and drug discovery.

A microactuator for spacers in flat panel displays is being developed. This is a true microactuator mechanism, with components a few microns wide. These microdevices, which combine SMA with polysilicon, are fabricated using CMOS processes.

OVERVIEW

In the last five years research and development at TiNi Alloy Company has become focused on microactuators employing sputtered titanium-nickel film combined with silicon substrates. Fabrication techniques are adapted from microelectronics manufacture to microelectromechanical systems (MEMS) processes, which include application, exposure, and development of photoresist to create microlithographic patterns. Devices combining TiNi thin film with silicon substrates are fabricated by chemical milling using etchants of silicon, silicon oxide, and metals. All of these processes are carried out in our own laboratory. Production and sales of miniature pneumatic valves has been accomplished, and other products are under development. This paper reviews the status of valves for liquid and gases, and out-of-plane hinged micro spacers for use with field effect displays.
Why should we develop shape-memory microdevices?

Micromachines have a limited repertoire of actuation technologies. Electromagnetic devices do not scale down well to the sub-millimeter domain.

TiNi microactuators, on the other hand, can be fabricated down to micron dimensions and still produce a lot of force and displacement compared to other mechanisms.

There are several market forces which drive development of micromechanical devices. Some valves must be small and lightweight to make the machines portable. Other valves must have minimal dead or unswept volume in order that microliter samples can be processed. Devices such as the spacer must be small enough to hide between the pixels of a TV picture.

TiNi shape-memory thin film is proving to be a versatile means of actuation for a wide variety of small (tens of microns) to medium size (hundreds of microns) mechanisms. The advantages of shape memory microactuators include small size, large force and displacement, and compatibility with TTL level voltages.

**VALVES**

An overall drawing of a TiNi-actuated pneumatic valve is shown in Figure 1. The valve consists of a silicon orifice die, an actuator die with a poppet controlled by a TiNi shape-memory alloy 'microribbon', and a spring bias which holds the poppet against the orifice thus forming a normally-closed valve. When an electric current of 50 to 150 ma flows in the TiNi actuator it contracts and lifts the poppet from the orifice, opening the valve: proportional control is achieved through feedback. Dimensions of the assembly are 5 mm by 8 mm by 2 mm. This assembly is enclosed in a PEEK plastic enclosure for in-line connection or for bolting to a manifold.

The principal component of this valve is the actuator shown in Figure 2.

This device, less than one half a square centimeter, produces displacement of a poppet of more than 100 microns with a force of one-half newtons. Flow through the valve is roughly proportional to current, so that with feedback it may be used to control flow. A sensor measures the flow (or differential pressure) in a system, and this is compared to a set-point. A feedback loop increases or decreases flow to bring the measured flow into equality with the set-point. This is incorporated in a low-cost, digitally operated flow controller. Pulse-width modulation is used to produce partial actuation. Response time is a few milliseconds.

The layout of TiNi microactuators is such that several valves may be placed on a square centimeter of silicon substrate. This enables us to make multiple valve systems for microfluidic applications.
Figure 1
Pneumatic valve with enclosure

Figure 2
Detail of valve actuator mechanism
Figure 3 shows a drawing of a liquid control valve which has been prototyped. The advantages of this valve are its very small dead volume, and that liquid is not subjected to heat or to materials which would contaminate it. This valve functions as a pneumatic pilot valve controlling pressure above a membrane. When the pneumatic valve is closed, the pressure above the membrane is sufficient to flatten the membrane, closing the two orifices. When the pneumatic valve opens the pressure is released and the membrane responds to liquid pressure which causes flow in and out through the orifice die. Applications include drug discovery and equipment for preparation and analysis of DNA.
We are currently developing what we call an Out-Of-Plane microactuator. Typically all microdevices are fabricated in the surface of a substrate of silicon by deposition of layers and removal of sacrificial layers. This sequence of processes had its origin in work done at U.C. Berkeley by Kurt Peterson and has since evolved into a major technology called MEMS.[1]

We are applying this technology to a need which arises in the manufacture of large flat panel displays. Flat panel displays will take up less volume and weigh less than conventional cathode ray tubes (CRT) used for computer output. To be acceptable these must be inexpensive, bright, and mechanically robust.

One strong candidate is the field emitter display (FED) which uses tiny (one micrometer size) cones, several cones per pixel. The problem which arises in manufacture is that FEDs require high vacuum, so there must be a means of holding apart two flat planes against atmospheric pressure.

The solution we have posed is to place a large number of miniature spacers across the surface. If these spacers are fabricated in the same plane as the field emitter cones and erected just before joining of the front and back panels of the envelope, then they may survive the other manufacturing processes.

These spacers must be small so as not to interfere with evacuation, and must not get in the optical path. The devices we are fabricating are small enough to disappear between the pixels.

The solution we are testing consists of many miniature hinged levers [2] lifted out of plane by shape-memory thin-film microactuators. The concept is illustrated in Figure 4.

![Figure 4](drawing.png)  
**Figure 4**  
Drawing showing concept for microactuated spacer
Fabrication of the hinged lever mechanism has been done at MCNC, using CMOS compatible processes, from layouts done for us by Ezekiel Kruglick.[3] One cm square dies come back to us after separation. An example is shown in Figure 5.

![Image of cantilevers on die, showing first and second polysilicon layers, and hinge structures. Note scale: Smallest features are micron size.]

We deposit TiNi on the surface. This is patterned to conform to the shape of the actuator. Microribbons are created by selective etching of TiNi. TiNi as deposited is amorphous, so it must be heat-treated to produce the SMA crystal structure. This heat treatment creates stress in the film due to differential thermal expansion of TiNi versus silicon, and is relieved during cooling to room temperature.

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