ELECTRICALLY ACTUATED MICROMECHANICAL SWITCHES WITH HYSTERESIS

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The need for hysteretic devices capable of high temperature operation arises in several areas of industrial process control. These devices could be incorporated in the circuit design for sensors and actuators, or could be used as memory elements which serve to identify the equipment in which they are employed.

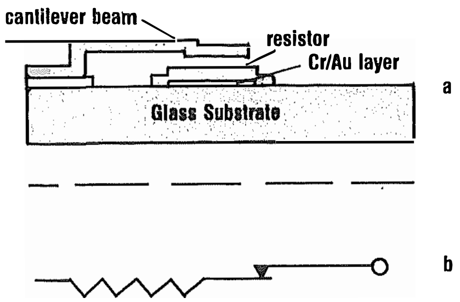

Figure 1

In Figure 1, a candidate device called an H-switch (hysteretic switch) is shown in a cross section view along with an equivalent circuit diagram. The conception of the H-switch was greatly influenced by the work of Nathanson [1] and Petersen [2]. As can be seen, an H-switch is a metal cantilever beam suspended over a thin film resistor. Metallization provides electrical contact to the base of the switch and to the lower side of the intercontact resistor. The resistor plays the important role of providing the device with hysteresis. With a small voltage applied to the contacts, an electric field is established between the cantilever and the surface of the resistor. This field exerts a force on the beam, deflecting it toward the resistor. An equal but opposite restoring force is provided by the elastic properties of the cantilever itself. As the applied voltage is increased, the electric field increases, deflecting the beam further. The electrostatic force increases inversely with the square of the distance between the beam and the resistor, while the restoring force varies linearly with the displacement of the beam from its equilibrium position. As the voltage is increased further, a critical point is reached where the spring force exerted by the beam is no longer able to overcome the electrostatic force. The beam suddenly closes on the resistor, making electrical contact. At this point, the voltage required to hold the switch closed is far exceeded by that applied. Therefore, to reopen the switch, the voltage must be lowered considerably.

The ideal H-switch current-to-voltage (I/V) characteristics are illustrated in Figure 2. The voltage at which the switch closes, Von, is determined by the geometry of its design. For example, a switch with a longer cantilever beam will close at a lower voltage if all other parameters are held constant. The voltage at which the switch will reopen depends, among other things, on the thickness and dielectric constant of the intercontact resistor.

Ideal I/V Characteristics

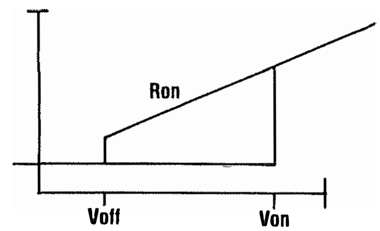

Figure 2

While a two-terminal device has conceptual simplicity, the same I/V characteristics can be achieved with a three-terminal device, such as shown in Figure 3. In this case, the function of the intercontact resistor is replaced by an external resistor connected between the field plate and the contact. In this way, fabrication difficulty is significantly reduced and reliability is increased.

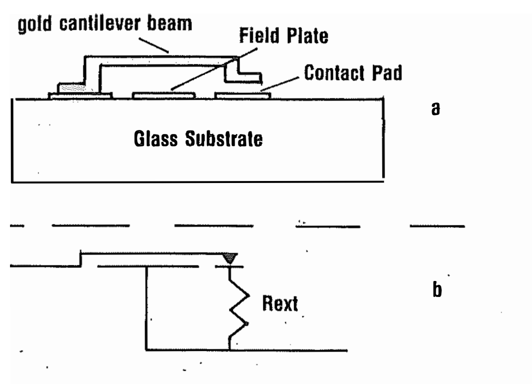

Figure 3

H-switches have been fabricated on glass substrates using the following process steps. A chrome/gold (500A/2000A) layer is E-beam evaporated on a Corning 0211 Glass Substrate and subsequently patterned and etched. The resistor layer is deposited and patterned so as to cover the counter electrode completely. Sputtered films of silicon and evaporated films of germanium make suitable resistor layers. The layers must be thick enough to withstand the electric field that will be applied when the switch is closed. In most of our work, we found that one or two micron layers were more than adequate. Next, a "spacer" layer of between one and four microns of nickel or copper is deposited. After patterning, the spacer layer is etched to open holes through to the base contact region. Finally, the wafer is patterned to the plating mask with a positive resist (AZ1350J, for example). In our experience, we found that positive resists worked well with acid gold plating solutions, and have successfully used products manufactured by Technics, Inc., and Transene Company, Inc. After the resist has been stripped, the spacer layer is etched out from under the beams, leaving them freely suspended over the resistor layer and counter electrode.

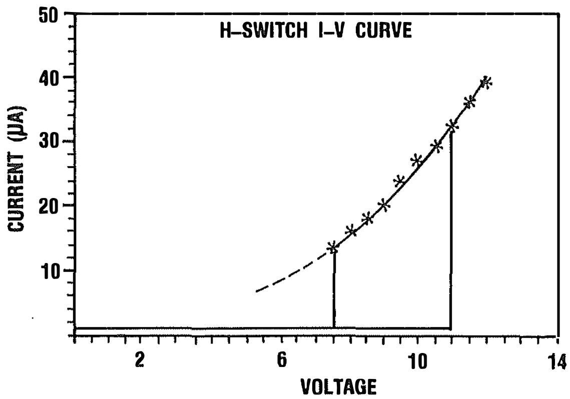

Figure 4

The I/V characteristics shown in Figure 4 are typical for H-switches with silicon resistors. The nonlinearity of the "on resistance" is expected because the contact between the switch and the silicon is a purely mechanical one. The turnon voltages of the beams we tested were, in general, higher than would be expected from a mathematical model. Close observation showed that the beams tended to curve away from the substrate slightly over their length.

References

[1] IEEE Transactions on Electron Devices, Vol. Ed. -14, No. 3, March 1967.

[2] International Electron Devices Meeting, IBM Corp., San Jose, California, pp. 100 - 103, 1978.