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Microrelay

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Our goals in this project were to (1) develop a new design concept for a high reliability microrelay, (2) build a prototype, and (3) demonstrate high force relay closure in the prototype.

During FY1999, we designed a microrelay to meet commercial specifications: 3 g (or 0.03 N) closure force and 30-mA actuation current at less than 0.5 V. Our microrelay not only occupies less than 1 mm^3—about 1% of the volume of the smallest commercial part—but also its fabrication takes advantage of semiconductor processing, which has the potential to automate microrelay production.

Conventional relays are fabricated by assembling many discrete parts. The process includes a number of nonautomated assembly and inspection steps, which increase fabrication cost and limit possible size reductions. Microrelays based on electrostatic forces can be fabricated by thin-film techniques employed in the semiconductor industry; however, the voltages required to make reliable electrical contact in an electrostatic relay significantly increase the cost of the driver. Microrelays based on electromagnetic forces, on the other hand, provide reliable contacts at low voltage.

Reliable metal-to-metal contacts require sufficient contact force to plastically deform contact surfaces at asperities—thereby increasing the contact area. On the other hand, contact metallurgy and the gaseous environment must be controlled to prevent contact welding, contamination, oxidation, and other effects that change contact resistance over time. A contact force of 3 g is commonly used with gold/gold-alloy contacts in a sealed relay (e.g., a reed relay). In this way, more than 10 million closures can be achieved with a resistance of less than 100 mΩ. Our prototype relay preserves the contact metallurgy of commercial relays.

The fundamental innovation in the fabrication of our microrelay is the use of a 3-D lithographic process to create a "winding" around a discrete magnetic core. To achieve sufficient inductance to generate the desired contact force, we chose a discrete core of substantial cross section (about 0.3 mm^2). Because of the core thickness, thin films deposited on it cannot be patterned by conventional lithography but can be patterned by our 3-D process.

The microrelay is formed on a single substrate so that critical core-to-armature distance can be precisely defined using a thin sacrificial layer. The initial separation of the core and armature is about 10 μm. The issue of greatest significance to the performance of the relay is the dimensional precision of relay closure - the electrical contacts must touch when the armature and the core (which define the magnetic circuit) are separated by only 1 μm. Defining a manufacturable process which can achieve this goal has been the triumph of this year's development effort.

To define the design of our prototype microrelay, we performed both 1-D analytic and 3-D numerical modeling. Photos of the prototype in fabrication are shown in Figure 1. The prototype differed in a number of ways from the design due mainly to problems in fabricating the iron core . The prototype served its purpose, however, verifying the design concept and demonstrating the closure forces required. Measurements of the force generated by the microrelay, as a function of the separation of the armature from the pole pieces of the core are shown in Figure 2. Particles in the contact region could not be eliminated in the environment of the experiment so there is approximately ±3 μm uncertainty in the separation. The flatness of the surfaces was approximately ±1 μm. To get good data out to large separations we used 0.5A actuator current. The data are consistent with a force of 3 gm at a separation of 1 μm using 0.03 A with the larger core of the design. This force can also be achieved at larger separation by increasing the number of turns in the winding.

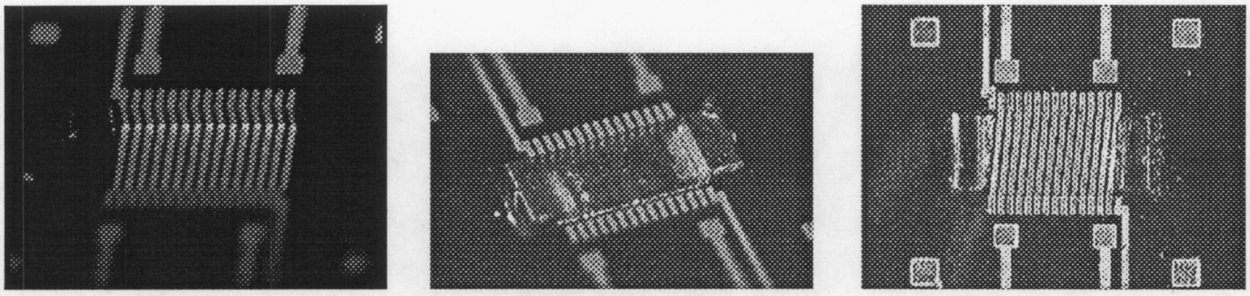

Figure 1: The relay actuator is fabricated in a cavity etched in a silicon substrate. The photo on the left shows the copper lines which have been patterned on the bottom, walls and top of the cavity. In the second figure shows the core has been bonded into the cavity. The length of the core is 2.1 mm. In the final photo the core has been encapsulated and copper lines patterned across the top of the core to complete the actuator winding. The core pole pieces are visible on either side of the winding.

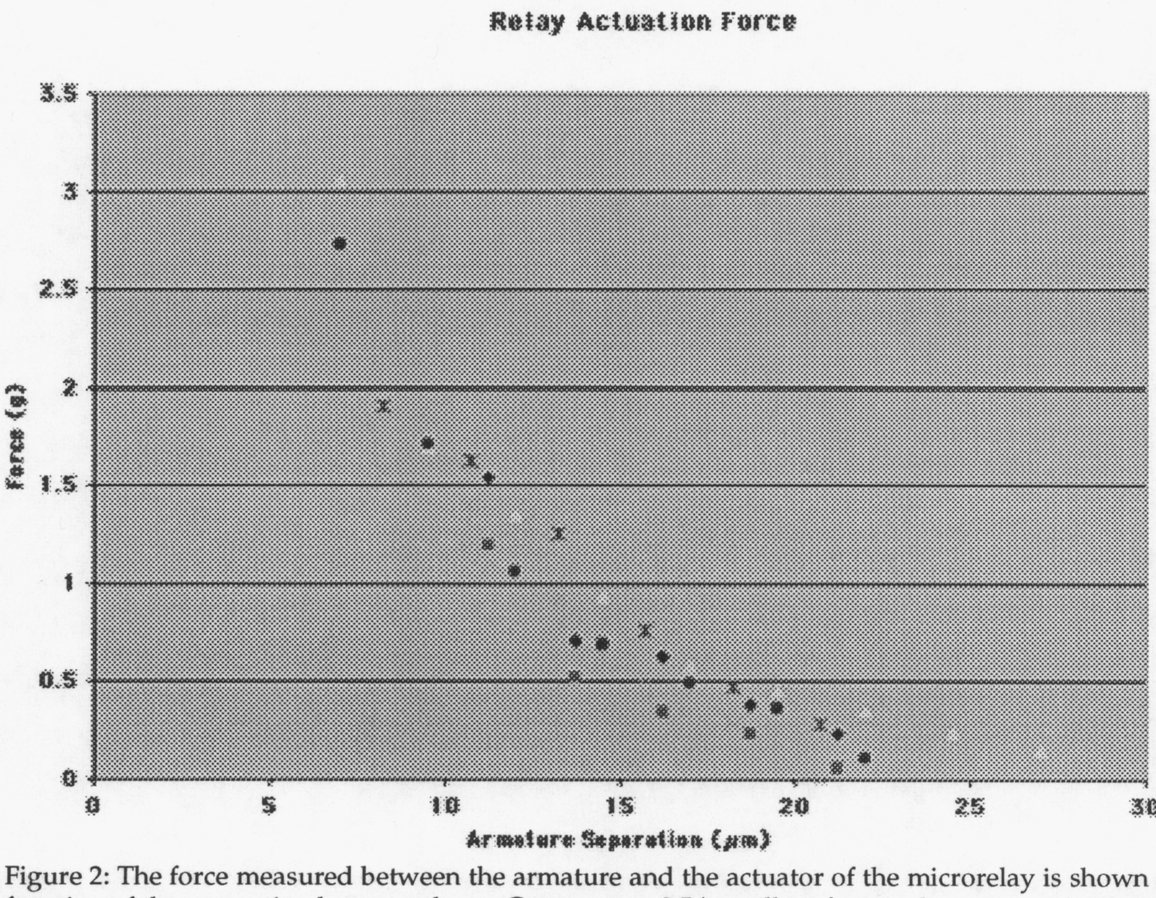

Figure 2: The force measured between the armature and the actuator of the microrelay is shown as a function of the separation between them. Current was 0.5A to allow force to be measured at large separation. Uncertainty in position is ±3 μm due to the presence of particles preventing perfect contact. Surface flatness was approximately ±1 μm. The data are consistent with a contact force of 3 gm at a separation of 1 μm using an actuation current of 0.03A with a larger core.

In conclusion, we have designed a microrely which meets commercial specifications and can be sufficiently reliable for weapons applications. We fabricated a prototype which verifies the design. The fabrication process produces the required micron-scale tolerances in the separation of the armature and the core in a process which lends itself to simultaneous fabrication of thousands of microrelays on the same substrate.

Publications

No publications