This device described in this paper does not use silicon. It used unconventional materials and processing techniques.
Read and find out how the case has been made for miniaturization for this application. Examine Table 2 that compares different switches.
This paper addresses both the questions of this homework!

A HYBRID TECHNOLOGY FOR Pt-Rh AND SS316L HIGH POWER MICRO-RELAYS

F.M. Ozkeskin[1*] *and Y.B. Gianchandani*[1,2]
[1]Department of Mechanical Engineering, University of Michigan, Ann Arbor, USA
[2]Department of Electrical Engineering and Computer Sciences, University of Michigan, Ann Arbor, USA

ABSTRACT

This paper reports a hybrid technique to microfabricate relays from platinum-rhodium and stainless steel 316L bulk foil and to directly assemble them on printed circuit boards with gold coated copper interconnect for high power handling capability. Devices of 6mm^2 size serve as relays for DC current levels >1 A, and are suitable for circuits dissipating >250 W power.

BACKGROUND AND ADVANCES

The most commonly used processes for microsystem device manufacturing and assembly rely upon semiconductor technology and silicon based substrates. Although these processes are mature, the properties of silicon are seldom adequate for high power applications; additionally environmental limitations impose significant burden upon hermetic packaging of silicon based devices. Recent research reports have described device microfabrication on non-silicon substrates such as printed circuit boards (PCBs) and liquid crystal polymer to ease packaging and system integration [1-3]. Semiconductor based fabrication techniques typically provide very limited access to metal alloys, relying more on thin film sputtering [4-5], which limits the power-handling capability of the components. A hybrid technology by which hard metal alloy devices can be fabricated from bulk robust metal foils is of interest.

Micro-electrodischarge machining (µEDM) provides a lithography compatible manufacturing method for bulk metal foil based micro devices with feature sizes down to 5 µm. Both serial and batch mode machining have been developed and characterized in our group [6]. A µEDM'ed oscillating micro-relay on a glass substrate was also reported earlier [7]. This paper presents a hybrid technique whereby hard metal bulk foils such as platinum-rhodium (Pt-Rh) and stainless steel 316L (SS316L) are first µEDM'ed, then assembled on PCBs to demonstrate high power DC switching capability without compromising device footprint.

DESIGN

The central element of the device is an electrostatically actuated cantilever beam that is assembled on a power-rated PCB. The bulk metal foil cantilever (2400 µm x 950 µm x 40 µm) provides mechanical robustness and chemical resistance to corrosion. In particular, Pt-Rh prevents adhesion problems, and can withstand high temperatures without softening, alloying or microwelding to the contact surface. A lower cost alternative, SS316L, is used for benchmarking.

The cantilever beam is orthogonally placed with respect to the signal line, being suspended above a break in a PCB metal trace (Figure 1), and anchored by alignment posts that perforate it; these posts are positioned in blind vias on the PCB. A paddle at the distal end of the cantilever serves as an actuation (pull-down) electrode. Below it is a ground electrode, patterned on the PCB. The cantilever has two recessed zones: one over the ground electrode that is designed to prevent contact, and a shallower one over the signal line to ensure contact when it is actuated. This design also provides a protrusion that rests against stand-off bumps on the PCB, preventing contact between the pull-down electrode and the ground electrode.

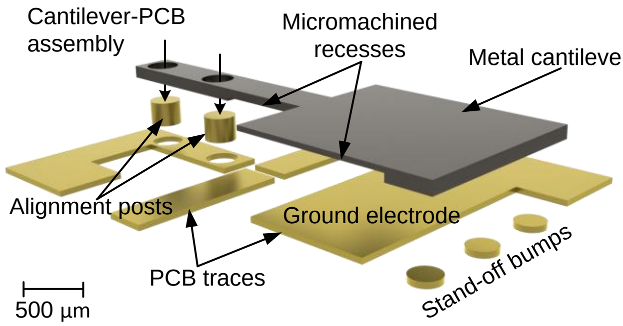

Figure 1: Exploded view of structure showing cantilever relay. Recesses are machined (2 µm across contact, 8 µm across electrodes) for DC-contact switching. Gold posts align and hold the cantilever over gold-coated copper traces on the PCB.

FABRICATION/ASSEMBLY

Micro-Relays

Micro-relays were fabricated in both Pt-Rh (80:20) and SS316L using 50 µm thick stock metal foils. The patterns were serially µEDM'ed. The lowest available discharge energy was used to ensure smooth surface finish. (Batch mode fabrication is also possible by using lithographically fabricated tool electrodes.) Perforations of 310 µm diameter were located in the anchor regions for subsequent alignment and attachment to the PCB. Machined hole diameters were slightly larger than the tool electrode diameter due to EDM discharge gaps of 5 µm in all directions.

PCB

A standard FR-4 with 1.6 mm thickness constituted the PCB substrate. Cu traces of 90 µm thickness were chosen for high current ratings (up to 4.5 A for 300 µm wide signal lines). In such PCBs, a 4 µm Ni layer is sandwiched between a Cu base layer and a 0.15 µm thick outer gold layer. Through holes formed by vias were positioned for subsequent assembly and electrical contact to the micro-relays.

Assembly

Alignment posts (1750 µm height; 300 µm diameter), were µEDM'ed as slices from gold wire. These were inserted as tight fits into the same diameter PCB vias by tweezers (Figure 2a). The length of the posts was designed to extend above the PCB trace by approximately 50 µm, to precisely accommodate the cantilever beam. The micro-relays were assembled into the posts by aligning over the posts (Figure 2b). A gold particle-filled conductive epoxy (Creative Materials, volume resistivity: 300 µΩ-cm) was manually applied through a syringe around the alignment posts (Figure 2c). Other techniques such as the use of solder balls are optional. The flatness of the cantilever beam was maintained during the assembly process by monitoring the height of the beam tip from a laser displacement sensor (Keyence LK-G) and adjusting to ensure that the cantilever tip is in contact with stand-off bumps during the epoxy curing. An assembled device is shown in Figure 3.

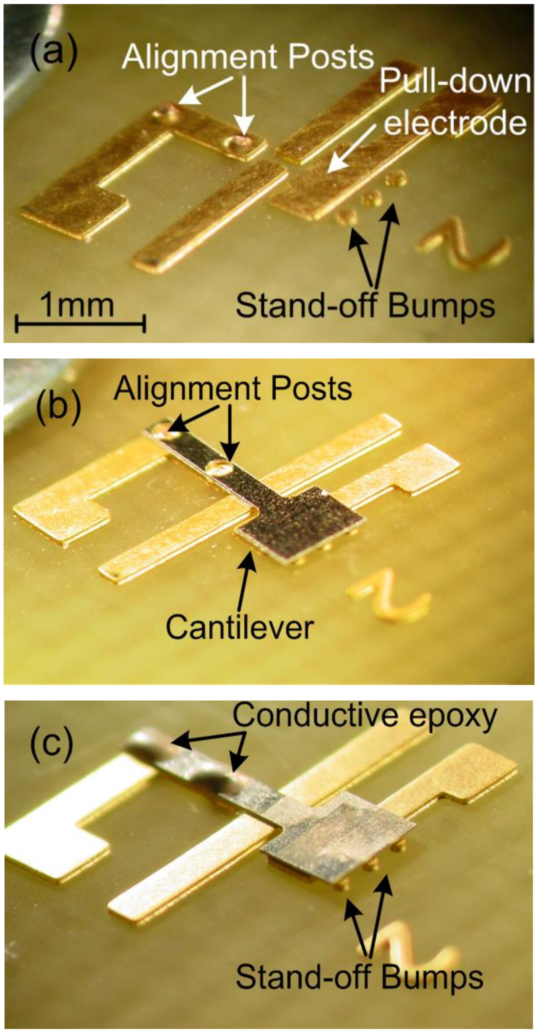

Figure 2: Assembly sequence for Pt-Rh and SS316L devices showing: (a) electrodes with alignment posts inserted. (b) The cantilever placed so that posts fit in vias in the thick foil. (c) Conductive epoxy applied for fixing.

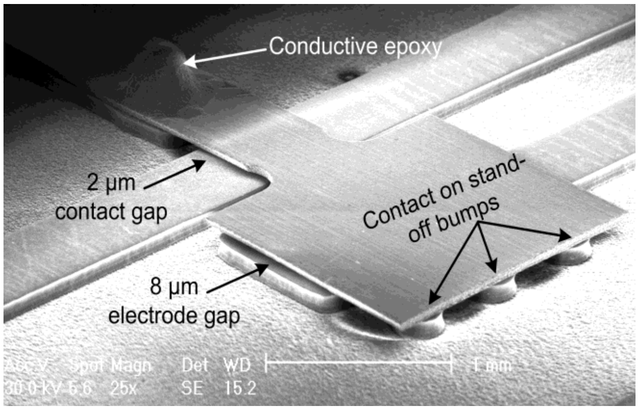

Figure 3: SEM image of the assembled device showing machined gaps, conductive epoxy and the stand-off bumps.

TESTING

The test circuit is shown in Figure 4a. It consists of a control voltage (V_{SS}) and two sets of power-rated load resistors: R_{L1} and R_{L2} along with a standard high value resistor to ensure that current pathway is on the signal line. Voltage values in boxes: V_S, V_D and V_G indicate measurements taken. V_G was always lower than 300 µV, indicating good switch isolation due to stand-off bumps. For testing, two different circuit configurations with different load resistors were used, as described in Table1. These configurations tested different voltage and current limits. In addition, tests were conducted both in air and nitrogen ambient. Nitrogen tests were conducted in a 0.2 Torr vacuum chamber. All the tests were repeated for both Pt-Rh and SS316L devices.

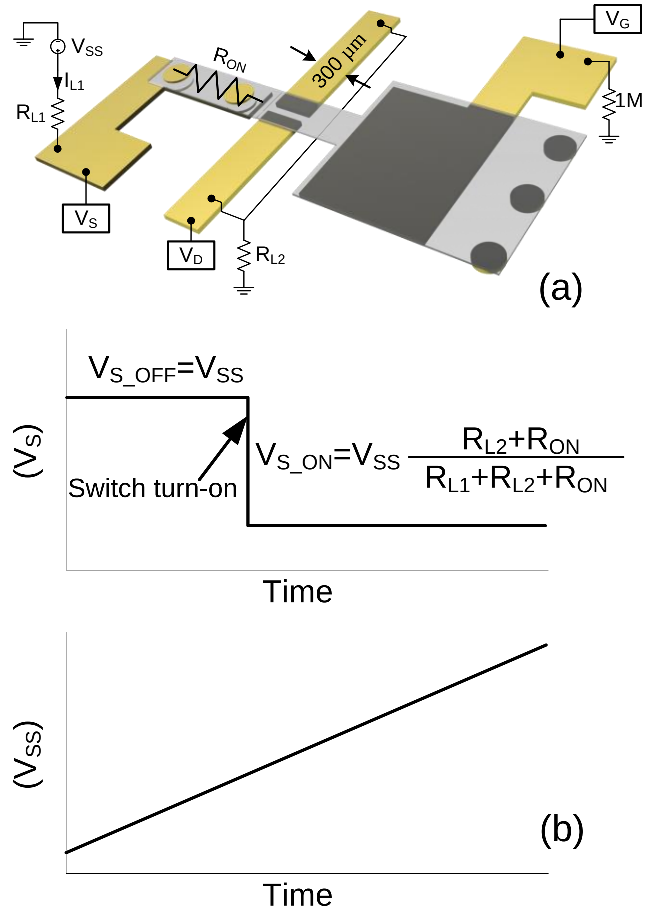

Figure 4: (a) Circuitry for testing; voltages in boxes are for measurements. V_D and V_S are used to determine ON-state resistance (R_{ON}). (b) The transient behavior of V_S as V_{SS} is progressively increased, showing V_{S_OFF} and V_{S_ON} conditions.

Table 1: Device test configuration details. Config1 provides higher voltage testing (>300 V) whereas Config2 is suited for high current (>1 A).

Configuration	Description
Config1	$R_{L1}=400\Omega,R_{L2}=125\Omega$, 0.6A max. allowed current
Config2	$R_{L1}=100\Omega,R_{L2}=83\Omega$, 1.34A max. allowed current

R_{ON} in Figure 4a is ON-state resistance and is a sum of the cantilever resistance and contact resistances at the epoxy transfer points. R_{ON} can be reduced with improved contact materials.

Figure 4b shows the transient response of V_S to a progressive increase of V_{SS}. When the switch is in OFF-state, V_S is the same as V_{SS} (denoted as V_{S_OFF}). When the switch is turned on and goes to ON-state, V_S is reduced sharply and is defined as a combination load resistors and R_{ON} during ON-state (denoted as V_{S_ON}).

RESULTS

Figure 5 shows R_{ON} as a function of series current in the circuit (I_{L1}) for 6 different test conditions that include the two types of relay materials, air and nitrogen environments, and the two different circuit load configurations presented in Table 1. In general, the Pt-Rh micro-relay offers the best overall performance, and in a nitrogen ambient, it can support >1 A DC current. The lowest recorded ON-state resistance was 2.8 Ω. The current handling capability of Pt-Rh devices was tested to the point of failure in Config2 and nitrogen environment. Device failure for this configuration occurred at approximately 1.2 A due to excessive heating of the contacts causing microwelding. The switch was operated around 600 cycles before failure took place.

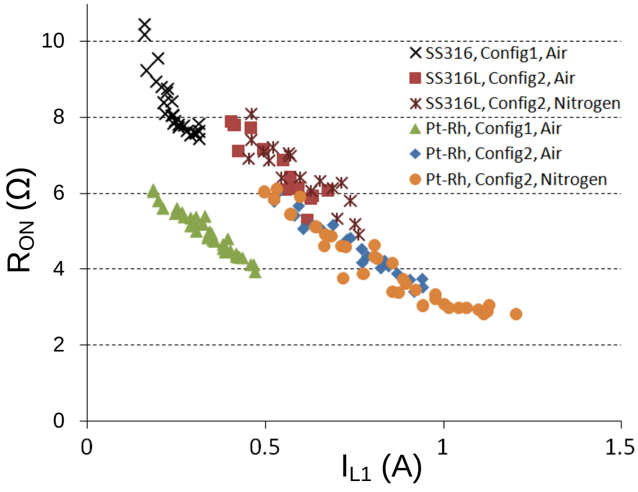

Figure 5: Switch ON resistance vs. series current. Highest current handling is for Pt-Rh in Nitrogen environment where R_{ON} is 2.8 Ω.

Figure 6 shows R_{ON} as a function of supply power (P_{SS}), which is the circuit dissipated power, for the same 6 conditions aforementioned, indicating that these micro-relays can be used in circuits that dissipate >250W power. The switch failure occurring at 1.2 A current translates to 332 W of DC power for Pt-Rh, Config2 and nitrogen ambient. P_{SS} is provided by $V_{SS}I_{L1}$, i.e. the total power dissipated in the circuit.

Figure 7 shows the voltage V_S at the anchor of the micro-relay when it is turned on (denoted as V_{S_ON}). This value is used to calculate the R_{ON}: $(V_{S\_ON}-V_D)/I_{L1}$.

Switch actuation voltage V_{SS} was designed to be 100 V. Test results, however indicate an actuation voltage of 107-110 V. Relatively small deviation (10% maximum) of experimental value from theoretical value can be correlated to structural inperfections or circuit parasitics. Note that the supply voltage can be increased past 300V for Pt-Rh switches.

Figure 8 shows the typical transient response of a Pt-Rh micro-relay. Typical turn-on/turn-of times are 30-40 ms. The device can actuate faster with perforations on the actuation electrode paddle which would decrease air damping, however a compromise could be made with increased actuation voltage due to decreasing electrode overlap area.

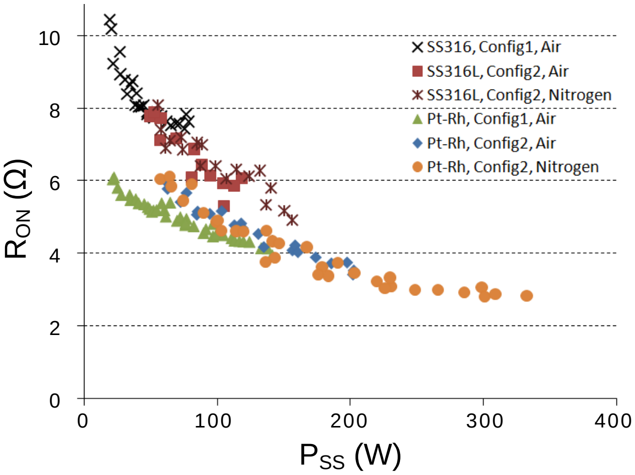

Figure 6: Switch ON (R_{ON}) resistance vs. supply power P_{SS} which goes up to 332 W for Pt-Rh switch. P_{SS} denotes circuit dissipated power.

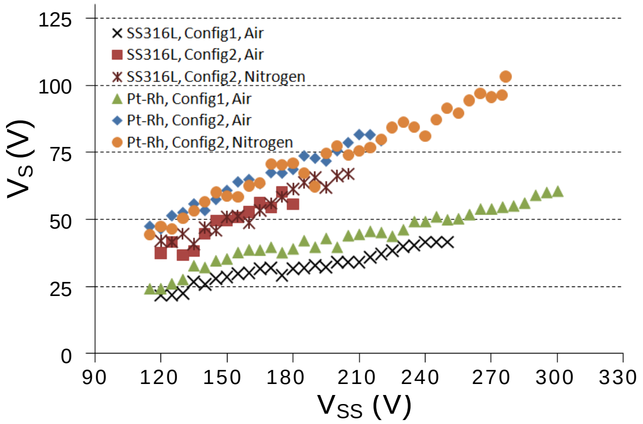

Figure 7: V_S measurement for control values of V_{SS}. This V_S is denoted by V_{S_ON} in Figure 4b.

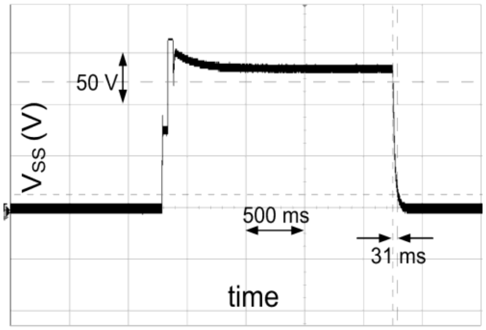

Figure 8: Switch response is shown for a V_{SS} of 135 V. The fall time measured is 31 ms and rise time is similar.

Table 2: Switch performance and size comparison to solid state and MEMS relays. Pt-Rh metal cantilevers provide high current carrying capability and small footprint.

Property	**Devices**					
	SKKD 57/08 Thyristor	ISL9V 2040S3S IGBT	SiC Schottky Diode	Omron MEMS Switch	Cronos MEMS Switch	**This Study (Pt-Rh and Config2)**
Footprint (mm²)	1302	112	303	15.6	36	**6**
Max current (A)	45	10	10	0.1	0.35	1.2
Current per mm² (A/mm²)	0.035	0.089	0.033	0.006	0.01	**0.2**
On resistance (Ω)	0.005	0.6	0.1-0.15	2	0.7	2.8
Actuation time (ms)	0.002	0.002	0.0001	0.02	10	30

Table 2 benchmarks this work to cross-technology (solid-state) options as well as in-technology (MEMS) relays. Commercial solid state alternatives include a high power thyristor [8], an insulated-gate bipolar transistor (IGBT) [9], and a high power SiC Schottky diode [10]. MEMS counterparts include a commercially available switch [11] and a research device [12]. It can be seen that solid state devices often have very fast actuation times and higher current ratings; however, these devices require compromises on footprint. Available MEMS devices have smaller footprint, but also low current ratings. While R_{ON} is larger for this work, the compactness is very competitive and the power handling is adequate for several applications.

CONCLUSIONS

A hybrid technology for fabrication and assembly of bulk foil hard metal high power micro-relays has been developed. Micro-electrodischarge machined cantilevers were directly assembled on PCBs with gold coated power rated traces, to facilitate system integration. Fabricated Pt-Rh devices demonstrated up to 1.2 A of current rating,for operation in circuits dissipating >250 W of DC power. The micro-relays have a footprint of $6mm^2$ and provide high current rating per area compared to solid-state and MEMS counterparts.

ACKNOWLEDGEMENT

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CONTACT

*F.M. Ozkeskin, tel: +1-979-218-1087; ozkeskin@umich.edu