A DC-POWERED HIGH-VOLTAGE GENERATOR USING A BULK PT-RH OSCILLATING MICRO-RELAY

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Abstract: This paper reports a high voltage generator formed by the hybrid assembly of a micromachined relay and a wound-wire inductor or transformer. The relay is micro-electrodischarge machined from Pt-Rh bulk metal foil, and consists of a normally-closed switch that is part of a DC-powered electrothermal relaxation oscillator. The use of this material permits the relay to be operated in air, without the need for inert packaging. It also provides a resistance of <2 Ω (including both the actuator and the contact), which makes it amenable to low drive voltages. Using an input of 5 V and a 56 mH transformer with a turns-ratio of 46, peak pulsed outputs of 1200 V are obtained. A DC output of 276.5 V is obtained for an output power of 76 mW.

Keywords: Power conversion, Relaxation oscillator, Electro-thermal actuator, Bulk metal

I. INTRODUCTION

A number of micromachined devices ranging from electrostatic actuators [1], to microfluidic electrokinetic pumps [2], to discharge based chemical sensors [3], to Geiger counters [4], all need high voltages for their operation. One alternative for supplying high voltages on-chip is to use miniaturized high voltage power sources. An example is a micro scale solar cell that operates from incident light and generates voltages up to 120 V [5]. Another alternative for obtaining high voltages is to step up power from a low voltage DC supply.

Existing methods for voltage conversion use charge pumps [6]. While suitable for powering energy-conserving and low-power actuators like electrostatic drives, charge pumps are less attractive for other applications that require >1 KV output and/or tens of milliwatts of power.

Another alternative is the use of induction coils [7], which have the ability to supply high power. The components required are an inductor, and a high-power switch that periodically changes its state from on to off and vice-versa (Fig. 1). The final output voltage can be further increased by the use of a transformer instead of a simple inductor. The challenges to this approach are primarily in the design and fabrication of a high power, self-reciprocating relay. The contacting surfaces of such a relay must present minimum parasitic resistance and must be resistant to corrosion despite the likelihood of elevated temperatures at the point of contact. In this effort, we explore the use of electrothermal relaxation oscillators fabricated from bulk foils of Pt-Rh for this purpose. Section II describes the design and fabrication of these devices, as well as the choice for the coils and inductors. Experimental results and closing remarks are in section III and IV.

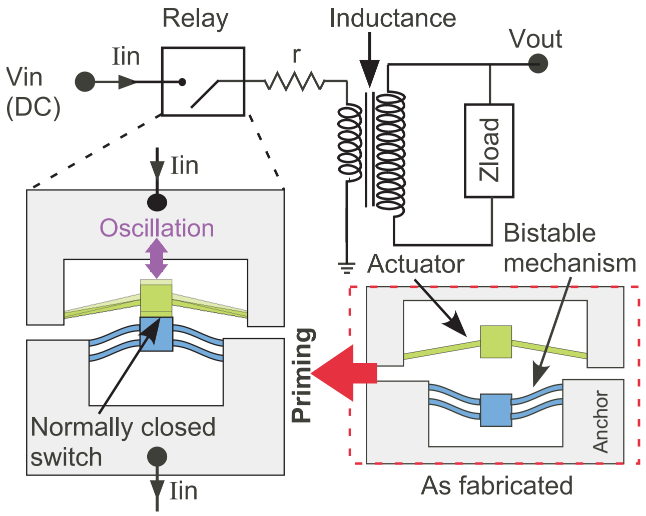

Fig. 1: Circuit of high voltage generator and schematic of oscillating relay. Relay operation: Before the relay can be operated it must be primed once forming a normally closed switch using the bi-stable mechanism. Once primed, current flow through the closed switch causes displacement of the electrothermal actuator, opening the switch. Subsequent cooling of the actuator closes the switch, permitting repetition.

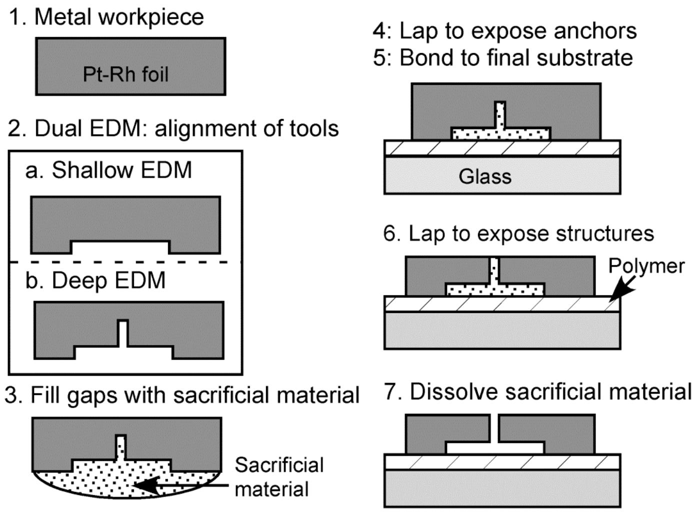

Fig. 2: Fabrication process flow.

II. DEVICE CONCEPT AND FABRICATION

On-chip batch fabricated inductors have been used in power electronic applications to carry out voltage conversions in the past [8]. Although these inductors have been proven to be useful for power electronics, they typically have modest inductance values in the range of a couple of micro-Henries [9]. An alternative approach is to assemble wound-wire inductors. These are attractive because they offer relatively high inductance values at similar volumes.

The oscillating relay is a new design based on the concept first described in [10]. An electrothermal actuator is powered through a switch that cuts off current as the actuator heats up and moves (Fig. 1). (The normally closed switch is created by manually setting a bi-stable element just once after fabrication.) Subsequent cooling of the actuator closes the switch, permitting repetition. The frequency and duty cycle of the oscillation are determined by a combination of the mechanical, thermal, and electrical characteristics of the structure. One attractive aspect of the actuation approach used in this structure is that forces that open and close the contact can easily exceed milliNewtons, yet require only a few volts (or less) to operate. These forces are sufficient to break through thin surface films that may prevent the switch from properly closing; they also permit the use of stiff restoring springs that can overcome any micro-welding at the contacts caused by high current flow.

The fabrication process uses a reverse

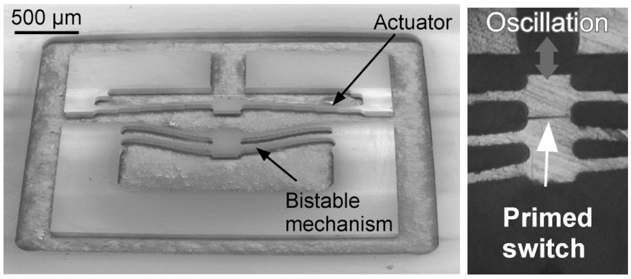

Fig. 3: (a-left) An SEM image of the bulk Pt/Rh metal oscillating switch. It has 120 μm tall structures with 50 μm features. (b-right) A close-up image of switch after priming.

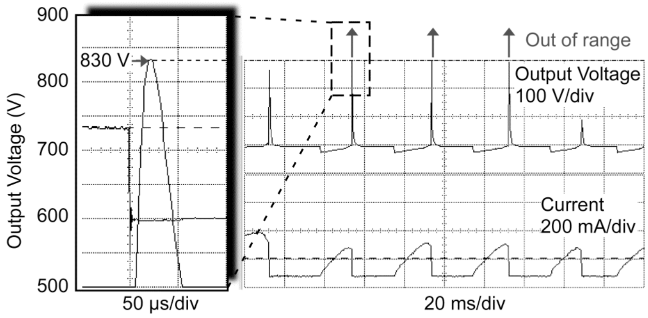

Fig 4: Output waveforms as obtained on an oscilloscope for the high voltage generator operating from a 5 V supply. Peak measured voltage using a 56 mH transformer with a turns-ratio of 46 is 1200 V.

damascene approach with micro electro-discharge machining (Fig. 2). The process is applicable to in-plane structures made from almost any conductive material. It yields Pt-Rh relays bonded to a glass substrate. The remaining elements – an inductor or transformer, and potentially other voltage regulation elements – are surface mounted on a common substrate with it.

A SEM image of a 120-μm thick Pt-Rh (80-20) relay with 50 μm features is shown in Fig. 3a. The footprint of the device is about 2.5x2.5 mm^2 and the released structures are separated from the substrate by a gap of about 15 μm. Figure 3b shows a primed relay switch in its normally closed state. As fabricated, a relay contact plate attached to the bi-stable mechanism is separated from the other contact plate that is part of the actuator. The bi-stable mechanism is displaced into its second stable position using a micromanipulator, where it remains permanently, forming a normally closed switch with the contact plates touching. The use of Pt permits this relay to be operated in air without inert packaging; the Rh content provides increased mechanical strength.

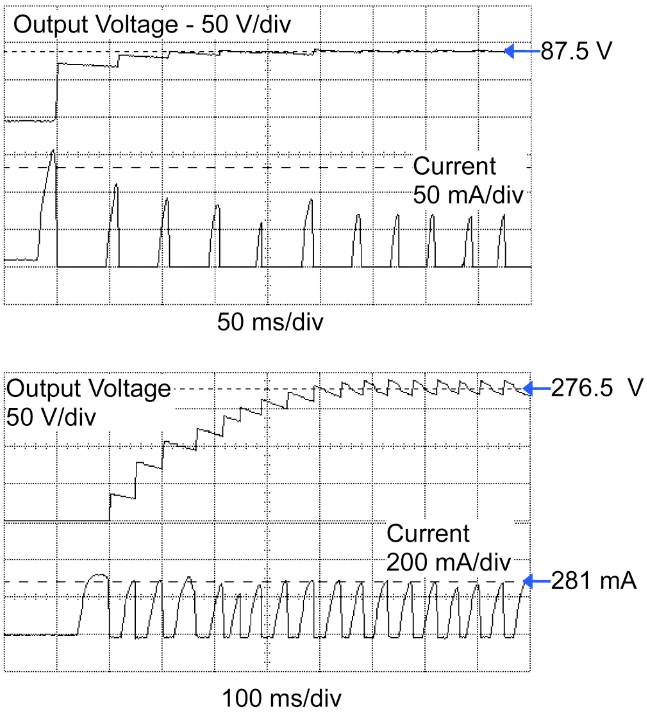

Fig. 5: A DC voltage is obtained by connecting a capacitor across the load along with a diode in the current path. The currents through the circuit and the output voltages obtained with a 1 MΩ // 0.01 μF load are shown.

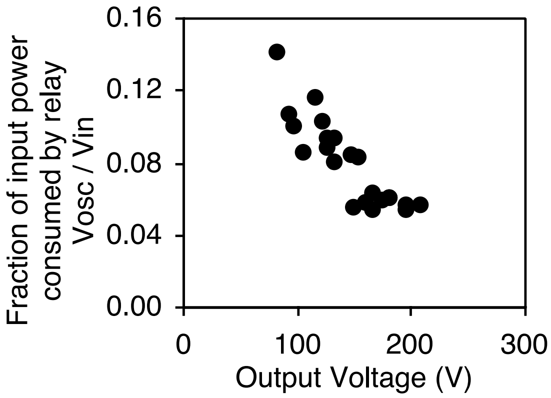

Fig 6: The relay consumes between 4-15 % of the total power system.

III. EXPERIMENTAL RESULTS

The measured contact resistance of the switch is about 1 Ω, while the actuator resistance is 0.95 Ω, permitting the use of a low voltage (< 3 V) DC supply. However, a higher voltage allows greater input current, and consequently higher output voltage. For example, high voltage pulses generated with a 56 mH output transformer and a 5 V input to the relay are shown in Fig. 4

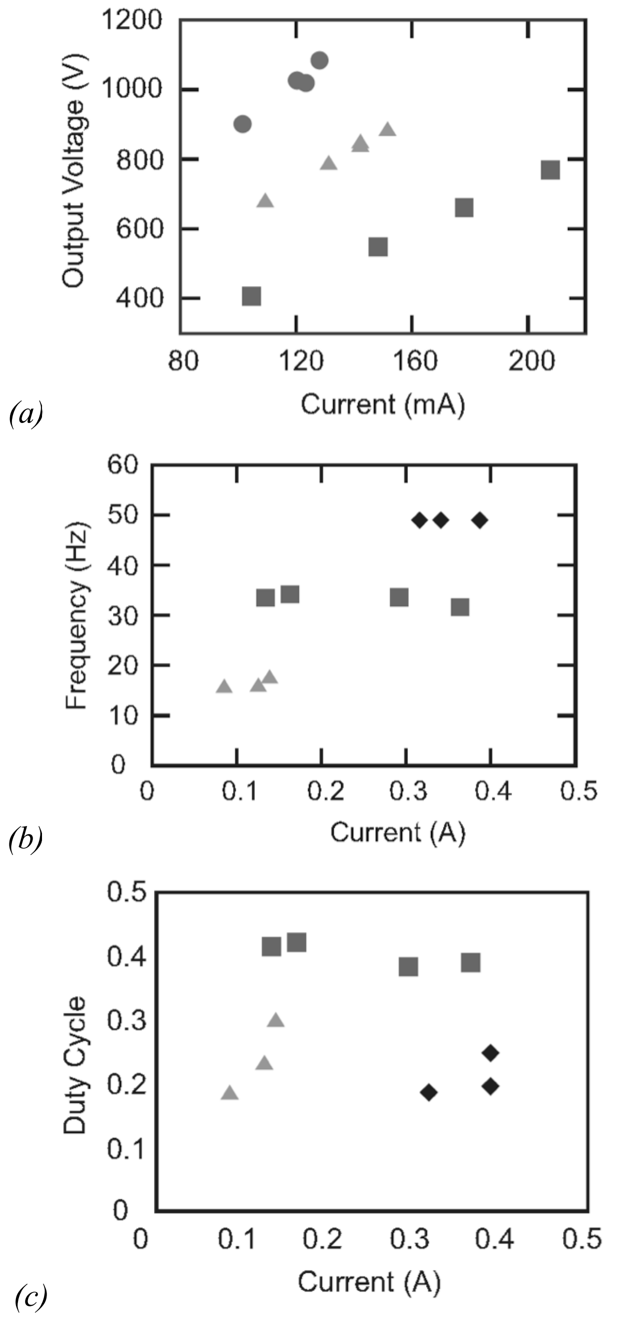

Fig. 7: In these figures, the circles, triangles, and squares represent measurement results obtained with transformers of 53 mH, 3.6 mH, and 1.1 mH, respectively, with turn-ratios of 45, 12, and 14. The diamonds represent oscillator performance without an attached transformer. (a) Output voltages in excess of 1100 V have been generated and depend on the value of inductance used. (b) The frequency of the oscillating switch is about 49 Hz and decreases with the addition of inductance. (c) The duty ratio of the system changes and depends on inductance as well current through the system.

(although the voltage peaks are off the scale). As the relay is closed, the current ramps up. As it re-opens, the current drops to zero and a high voltage output pulse is generated. Figure 5 shows the system charging a capacitor to generate a 276.5 V output. (For some applications this capacitor can provide large instantaneous output current.)

Figure 6 shows that the fraction of the power that is consumed by the relay varies from a maximum of about 15% for output voltages below 100 V to about 4 V for output voltages near 200 V and higher. Wire inductors operate with efficiency exceeding 95% [11]. These present a reasonable level for the intended applications: for commercial DC-to-DC converters, efficiency at full load is generally in the range of 70% [12].

Figure 7a shows the output voltage peaks obtained by various transformers; it is evident that higher current peaks and larger inductance values provide higher voltages. Figure 7b shows that the frequency of the oscillating relay is about 49 Hz in the absence of an inductive load. While it reduces as the inductive load is increased, it is not sensitive to the current level for any given transformer load. Figure 7c shows that the duty cycle of the oscillation ranges from 0.2 to 0.45 depending upon the current and the inductance.

IV. CONCLUSIONS

This effort has shown that electrothermal relaxation oscillators micromachined from Pt-Rh foils can be used as self-reciprocating relays, and that they can operate in an air ambient without the need for packaging. Further, these relays can switch large currents, and when combined with coils or transformers, they can generate voltages in excess of 1 KV. The present version of the relay oscillates at frequencies <50 Hz. Applications that require a DC output can benefit from designs that provide a higher reciprocation frequency, which suggests that research directed toward reducing the thermal capacitance of the heated elements could be helpful.

Acknowledgements

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