Designing remotely-activated microvalves for biomedical applications

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RF-controlled battery-less microvalves, designed for drug delivery, are based on a surface-acoustic-wave device and are fabricated on a biocompatible substrate that allows for communication and remote actuation.

A number of microscopic valve structures have been developed that are based on silicon and use an energy source that is directly connected to the device. These are appropriate for many uses, but not for biomedical applications. On the other hand, some researchers have addressed the possibility of using biomedical implants for biotelemetry applications. If these devices are to be implanted in an animal or a human body, we need to find a way to make them both biocompatible and remotely actuated. Size, weight, complexity, and security must all be addressed.

The shorter the microwave signal frequency, the shorter the penetration depth through water-containing tissues. Therefore, we’d like to find the optimal tradeoff between the interrogation signal frequency and microvalve size. Microvalve applications usually require small size and low weight, which creates an upper limit on the antenna size.

Also, we would like to have a microvalve that doesn’t incorporate a battery, both because this would decrease the size and weight of the valve and because it would eliminate battery-replacement requirements. An additional disadvantage of powering the devices by a battery or a capacitor—charged using inductive coupling— for short-term burst operation is that these schemes require active microelectronics to be integrated with the microvalve. In contrast, we propose using a piezoelectric polymer material with no active microelectronic components. This allows the integration of the antenna, interdigital transducer (IDT), surface acoustic wave (SAW) device, and actuator to control the microvalve without batteries on a biocompatible substrate (see Figure 1).

We have developed four microvalve structures. Two of them use a bimorph actuation mechanism (see Figure 2), while the others use unimorph actuation. These structures were modelled using simulation tools from ANSYS, Inc. We also conducted modelling of a water-based microfluidic structures to demonstrate a high flow rate. Our modelling shows that the bimorph actuation has a higher flow rate than the unimorph structure.

Because of the wireless nature of the device we investigated improving the security of the microvalve by developing coding techniques to ensure activation only when a coded RF signal matches an embedded code in the microvalve. We have demonstrated that secure actuation of a microvalve is possible using SAW-device-based IDT structure with variable code length. Our modelling shows it is possible to achieve such actuation by using SAW correlator in conjunction with the developed microvalve structure. We have demonstrated the use of Barker, maximum length sequence (MLS), and Golay codes for unique activation of the microvalve with a high signal-to-noise ratio. The binary

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Figure 2. A bimorph microvalve structure in which the valve is normally closed. (1) Side view of the structure shows the path of the fluid flow when the valve is open. (2) Top view of the structure. When the valve is interrogated by a coded RF signal, the bimorph cantilever—made of a piezoelectric material—bends downward, allowing liquid to flow from the inlet to the outlet.

weighted Barker code was found to provide the highest processing gain needed for a unique activation.7

We propose using microvalve structures in a number of medical applications: for cancer chemotherapy, the device could provide a higher concentration of the drug dose in certain areas; for hormonal treatments, the device can apply well-controlled doses; and for flow cytometry, a microvalve could be used to sort microscopic particles suspended in a stream of fluid.3

The mechanical coupling efficiency in the SAW correlator is low, which reduces its output voltage, which results in less voltage available to actuate the microvalve. We are now looking into the use of floating-electrode type unidirectional transducer to improve the mechanical coupling efficiency. Also we are currently investigating a number of techniques to miniaturize the antenna size including dielectric loading, slow-wave structural patterns on the radiating element, and either capacitive or inductive loading. Also, we are looking into fabricating the proposed microvalves to evaluate their performance. A further extension of the project is to develop a micropump using a piezoelectric diaphragm that is synchronized with the actuator for independent operation.

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References

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