Chemical Controls Over Insect Cyborg Flight Using Implantable Microfluidics

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Abstract:

This work describes a fusing of a microfluidic drug delivery technique with a living organism, Manduca sexta, to control its flight metabolics; to take a step towards an alternative method of creating a small scale aircraft. We present the overall design, operating principle and construction of the device, and the modulations of the internal metabolic rates of the moths.

Introduction:

Modern microsystems technology has enabled the development of an array of biomedical devices, which allow us to monitor biological systems and biomolecular events with extreme accuracy. While such technology is proving extremely successful, rarely has the extension been made to exerting active control over a living system. Therefore, instead of simply monitoring biological systems with common nanotechnology techniques, this work is designed to establish active control over them.

This effort involves the fusion of microfluidics and a living organism though the implantation of a microscale payload into insects. Here we are specifically focusing on the development of microfluidic systems that enable chemically-induced responses rapidly ejected from multi-reservoirs including immobilization, retardation, stimulation and subsequent reanimation. In this study, we present our results on the development of implanted microfluidic devices which allow such control over flying insects, namely Manduca sexta moths.

One potential application of such a hybrid-insect system is in the development of Insect Micro-Air-Vehicles, which would exploit the highly evolved aerodynamics of insects and power efficiency with recent advances in microdevice engineering. An overview illustrating the system integration is presented in Figure 1.

Drug Delivery System:

The device structure is a modification of that presented by our previous work [1,2], which is based on the integration of previous implantable drug delivery technologies with our recently developed electrochemical reaction induced ejection technique [3]. The device consisted of three main parts; 1) a microwell defined in a silicon substrate, 2) a poly(methyl methacrylate) (PMMA) spacer to hold more volume, and 3) a polyimide bottom substrate, on which gold has been patterned. Each compartment is filled with approximately 15 microliters of different chemicals to have different responses from them.

As illustrated in Figure 2, when a dosage command is issued, two concurrent electrochemical reactions cause the ejection process. First, the electrochemical reaction between the chloride ions in the phosphate buffered saline (PBS)
and gold membrane forms water soluble gold complex results in a gradual loss of the membrane which eventually ruptures, making the outlet for the chemicals. Secondly, the two electrodes also serve as an anode and cathode for electrolysis of water. Formed gas on the bottom electrode during this reaction results in pressure builds up in the reservoir which rapidly propels the drugs out through the dissolved membrane.

**Moth Tests:**
A series of experiments for fully integrated hybrid system were tested. Briefly, to enhance the moth flight capability, two electrodes are inserted into moth’s head close to the antenna lobes. A moth is stimulated from rest into continuous flight through electrically driven pulses. Figure 3 illustrates that by on-command, one of the reservoirs from the microfluidic chip ejects 15 microliter of 5.0 M solution of L-Glutamic Acid (LGA) into the moth’s circulatory system, and approximately 1 minute later, the moth is fully paralyzed as shown in the Figure 3B, despite still being electrically stimulated. The moth regained full activity later based on the injected types/volume/concentration of chemicals.

**References:**

Figure 2: Illustration showing ejection of fluorescent polystyrene microsphere particles from a reservoir. (A) Before applying potential. (B and C) Ejection into the air; frame taken one minute after application of 12 V potential. (D) Ejection into the water [3].

Figure 3: Illustration showing moth paralysis by releasing LGA. (A) Before applying potential: active. (B) After chip actuation: full paralysis.