An Improved Electrolytic Pump for Potential Drug Delivery Applications

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Abstract: This work presents a novel prototype of an electrolytic pump that uses a platinum (Pt) coated-nickel mesh in the pumping chamber for increasing the recombination rate electrolysis products. The Pt coated-nickel mesh that acts as a catalytic reforming element is able to significantly reduce the pulsed pumping period of the pump, resulting in a more controllable system. Our presented electrolytic pump can provide the cyclical actuation required for a solid drug in reservoir delivery system and shows potential application in the field of drug delivery.

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1 INTRODUCTION

The combination of microelectromechanical systems (MEMS) with biochemical applications has attracted growing interests, especially in the field of drug delivery systems. MEMS fabrication technology applied in drug delivery systems can provide a high efficiency and accurately delivered dose and more friendly operation (Nisar *et al*., 2008). MEMS based drug delivery devices in general consisted of a micro-pump, micro-fluid channels, micro-sensor and another necessary units. As an essential component of drug delivery devices, the micro-pump performs the function of transferring the drug from the reservoir to body tissue or blood vessel safely and reliably. According to the different actuation mechanism, micro-pumps can be divided into two categories, namely mechanical micro-pumps and non-mechanical micro-pumps.

In a mechanical micro-pump, actuators are required to perform a pumping function. The working mechanisms of mechanical micro-pumps that show a potential application associated with drug delivery systems are namely electrostatic (Teymoori *et al*., 2005), piezoelectric (Junwu *et al*., 2005), thermo-pneumatic (Hwang *et al*., 2005) and shape memory alloy (SMA) (Guo *et al*., 2004). Though mechanical micro-pumps provide a large actuation, they require higher applied voltage and consume more power causing large heat dissipation. In contrast to mechanical pumps, non-mechanical pumps do not need any reciprocating mechanical component, the working principle of this kind micro-pump is generally based on the conversion of non-mechanical energy to kinetic momentum. Moreover, non-mechanical micro-pumps usually have neither moving parts nor complicated valves so that the corresponding geometry design and fabrication process are relatively simple. The popular actuators that can be applied in non-mechanical micro-pumps include osmotic-type (Su *et al*., 2004) and electrochemical (Li *et al.*, 2008 & 2010; Sheybani *et al*., 2012) categories. Osmotic-type pump does not require any external power, but its pumping force is extremely small and not controllable. Therefore, osmotic pump is a suitable option for those drug delivery applications of long-term use with extremely low dosing requirements.

In contrast to those micro-pumps with the traditional mechanisms, the electrolytic bubble actuator has attracted a growing interest, particularly in the field of drug delivery systems due to its easy setup, low power consumption, miniaturized size, simple operation, accurate delivery control and adequate actuation force. In previously reported electrolytic pumps for drug delivery (Li *et al.*, 2008 & 2010), a liquid drug reservoir (LDR) approach has been operated for high efficiencies, but requires control of extremely small fluid volumes and fabrication of complicated bellows. Recently, a solid

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drug in reservoir (SDR) approach was proposed using magnetic actuation (Pirmoradi *et al*., 2011) to pump fluid in and out of a reservoir that is filled with a low solubility drug in solid form. This allows for long term use because the reservoir can refill and dissolve the next dose. This kind of micro-pump shows a simplified structure but requires a strongly aligned orientation and operates within short range. Our proposed drug delivery system adopts the simple structure of an SDR system and the flexibility of an electrolytic pump system for releasing the consistent drug. Moreover, improving on our previous work (Yi *et al*., 2013), we further introduce a platinum (Pt) coated nickel mesh into the pumping chamber to achieve a higher recombination rate, thereby reducing the pumping cycle time.

The rest of this paper is organized as follows; Section 2 illustrates the prototype of the electrolytic pump. Experimental setup and measurements are evaluated in section 3. Conclusion is given in section 4.

2 PUMP PROTOTYPE

This section illustrates a prototype of a drug delivery system where the cyclical actuation is performed using an electrolytic pump. Figure 1 illustrates a cross sectional view of our initial prototype system.

For easy prototype testing, a cannula is replaced by an inlet and outlet tube which can be mechanically clamped. The major components of our proposed electrolytic pump include: a flat PDMS membrane, Pt electrode base and a Pt coated mesh. The Pt electrode array was fabricated by a sputtering technique and then patterned on a silicon wafer. The corresponding design is shown in Figure 2 (a). The dimensional parameters are 100 µm in width with 100µm spacing and a 400 nm height. Pt electrodes are immersed in a deionized (DI) water filled pumping chamber before assembling the other components. Platinum was sputtered onto the surface of a nickel mesh, forming a platinum coated nickel mesh. Because the direction of sputtering is vertical, the horizontal aspect of the nickel mesh was not covered by platinum. When the Pt mesh was immersed into the DI water, both platinum and nickel were exposed to the electrolyte. The corresponding micrograph of Pt mesh was shown in Figure 2 (b). Figure 2 (c) illustrates the prototype of pumping chamber. Nafion was coated onto the platinum electrode to get a faster electrolysis-based bubble generation rate (Sheybani et al., 2012). The pumping chamber is separated from the drug

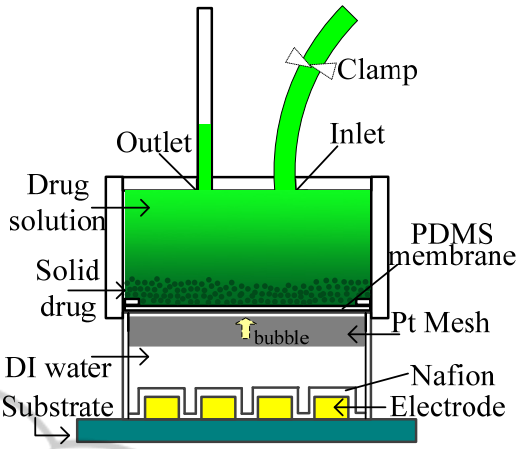

Figure 1: A cross-section view of the electrolytic pump with major system components.

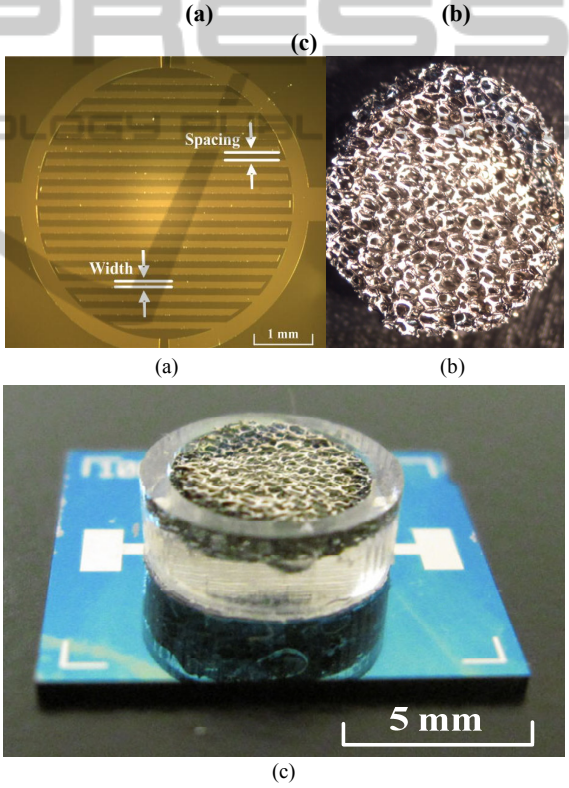

Figure 2: a) Micrograph of 400nm thick Pt electrode layout showing element width and spacing of both 100µm. b) Micro-scope of Pt-coated nickel mesh. c) Photograph of pumping chamber with Pt mesh and Nafion coated electrode.

reservoir by a PDMS membrane to avoid electrochemical interaction with drug fluids. When voltage is applied to the electrodes, electrolysis reactions occur resulting in hydrogen (H_2) and oxygen (O_2) bubble generation, the gas expansion

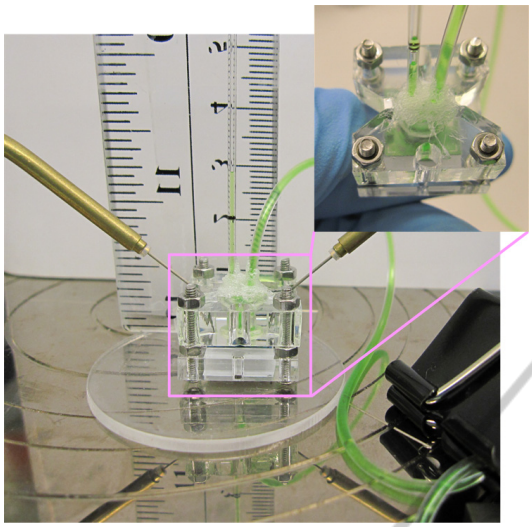

Figure 3: Photograph of the experimental setup and figure of electrolytic pump.

pushes the membrane upwards to in turn push dissolved drug solution out the cannula. Power is applied until the desired volume of fluid is delivered, after which the power is turned off and the pressure in the electrolytic reservoir begins decreasing due to the recombination of H_2 and O_2. They rate of the recombination is improved via the catalytic properties of Pt, so that the membrane moves downward drawing fresh fluids into the drug reservoir to dissolve more of the remaining solid drug. Power is turned on and off to the pump periodically, so that the dissolved drug can be delivered using this cyclical actuation.

3 EXPERIMENTAL RESULTS

Our proposed electrolytic pump was assembled and measured using the test fixture as shown in Figure 3. For easy prototype testing inlet tube is mechanically clamped in order to accurately calculate the bubble generation rate and recombination rate. The size of the holder is 2 cm : 2cm : 2 cm (length : width : height). In prospective drug delivery applications, the pump could be permanently bonded allowing the size of the structure to be significantly reduced. Two probes are used to apply DC voltage to the electrodes. A digital camera is placed in front of the setup to record the displacement rate of the pump. In the experiment, Nafion was uniformly spin-coated onto electrodes because it is capable of preventing bubble occlusion on the surface of the Pt electrode and improving diffusion of gases away from the catalyst surface (Maruyama *et al*., 1998).

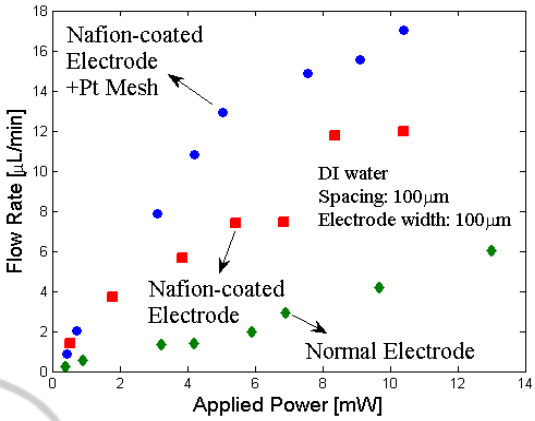

Figure 4: Electrolytic pump flow rate vs. applied power for with Pt-coated mesh and without Pt mesh.

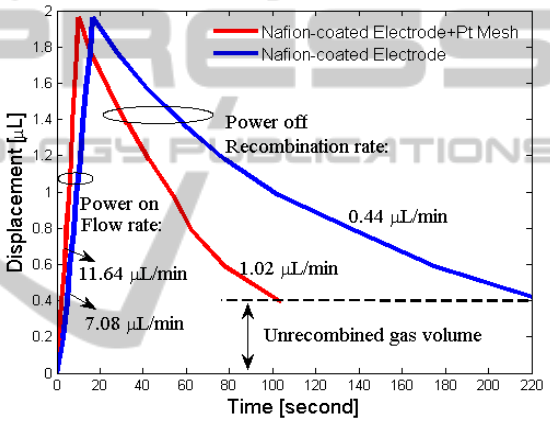

Figure 5: Gas recombination rate comparisons for electrolytic pumps with and without Pt mesh. Power of 4.6 mW was applied until the membrane achieved a maximum displacement and then turned off.

Optimum electrode dimensions (Li *et al*., 2010) and Nafion coating (Sheybani *et al*., 2012) had been previously analyzed for achieving a higher pumping efficiency, as shown in Figure 4. Based on the same experimental conditions and electrodes, we added a Pt mesh as shown in Figure 2 (b), and obtained a higher flow rate than previous works (see Figure 4) as well as a faster recombination rate (see Figure 5), because Pt mesh increases the contact area between the catalyst and electrolyte, improving catalytic reactions.

Because the concentration of drug dose can be kept stable during each delivery (Yi *et al*., 2013), a faster bubble generation rate and recombination rate that reduce each period of pumping allow delivering a consistent and high drug volume within a short pumping duration. Most importantly the Pt mesh used in the electrolytic pump requires less power

(several mW) to achieve the same flow rate level compared to the original electrolytic pump, which makes the integration of wireless power transfer techniques (Yi *et al*., 2013) and drug delivery systems feasible.

4 CONCLUSIONS

This work presents a prototype electrolytic pump that uses a Pt coated-nickel mesh in the pumping chamber to improve the cycling time of an electrolytic pump intended for a drug delivery system. Using our catalytic reforming element, the cyclical actuation of the drug delivery system improved both in terms of the time of the pump/recombination cycle, as well as the applied power requirement, resulting in a faster and more efficient drug delivery system.

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