Strain gauge based on nanocomposite CTPE for monitoring Bio-MEMS drug delivery systems.

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In recent years, one of the most exciting progresses in microelectromechanical system (MEMS) application is the rapid evolution of biological-MEMS (bio-MEMS). These systems have a wide range of applications in the field of biology, as for example fast diagnostics, smart therapy and tissue engineering [1, 2]. Moreover, the rapid prototyping through 3D printing has increased the ability to design custom devices. In advanced therapy, there is a growing interest in localized and controlled drug delivery. By operating at micro scale, bio-MEMS provide the possibility to improve drug delivery, e.g. by lowering drug doses and related side-effects and reducing patients' discomfort. In this context, basic electrolytic actuators, such as microchannels, microvalves and micropumps for flow management at microscopic volumes, can be used as active elements of smart pills. In particular, an easy way to deliver drug into specific body areas, such as intestine, is the use of smart pill constituted by two chambers, one to contain the drug and the other to house a micropump for the release. Generally, a polymeric membrane is employed to push out the drug (see fig.1).

Strain gauge sensor embedded in the membrane on micropumps can be a valuable method to evaluate the membrane deformation, in order to achieve a closed-loop control of drug delivery [3]. To monitor deformable surfaces strain sensors made by viscoelastic membranes loaded with conductive nanoparticles, such as PDMS, are often used but this kind of sensors show some properties that can be detrimental for applications where rapid variations may occur (e.g. large sensor drift) [4]. Alternatively, blend of graphite nanoparticles mixed with a thermoplastic elastomer (TPE) can be used [5].

In this work, we propose to adopt the abovementioned conductive thermoplastic strain gauge sensor (CTPE) as valuable solution to monitoring and measure the micropump membrane deformations. For the tests, we use electrolytic actuators such as micro displacement pumps [6], which exploit the expansion of a gas evolving from a fluid solution. The electrolytic pump consists of an electrolytic solution reservoir, sealed by an elastic PDMS membrane, with Pt electrodes. Inserting the pump in a drug delivery system (DDS), the displacement of the membrane, due to gases production, can allow the release of the drug contained in the separate chamber in contact with the abovementioned membrane. The body of the electrolytic pump has been designed and fabricated using a 3D printer (HD 3000 Project by 3D Systems) (Fig.2). The pump contains 120 μl of non-toxic saline solution (NaCl in water, 0.5 M). The bottom of the reservoir lodges two Pt electrodes (ϕ1mm) that protrude in the solution reservoir for 3 mm. Outside the reservoir, the electrodes are connected to a power supply system. The electrolytic solution reservoir is sealed by a PDMS membrane (thickness 100 μm), which acts as a supporting structure for the CTPE strain sensor. CTPE exhibits a good ability to follow low speeds deformation, such as those involved in electrolytic reactions (10÷20μm/s). Preliminary tests on CTPE have been carried out linearly stretching the sensor with a stepping motor (Newport sp300) and measure the resistance change with Agilent HP4140B (Fig.3). As expected, resistance increases with strain: this phenomenon can be attributed to the progressive spacing of the conductive nanoparticles inside the polymer matrix. Furthermore, we placed the same device on the membrane of the DDS (as the setup in Fig. 2) and collected the resistance change during the electrolytic reaction at 3V (Fig.4).

This voltage on the electrodes generates a displacement of the membranes with an average speed of 12μm /s. In conclusion, according to the preliminary test, we demonstrated that CTPE sensor can effectively monitor the deformations of the elastic membrane to provide a feedback for the released amount of drug in DDS. Therefore, this sensor can be further implemented on different bio-MEMS offering a valuable method to control and monitor crucial parameters in DDS.

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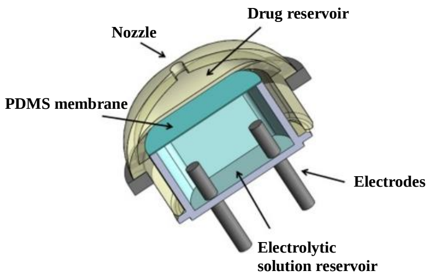

Figure 1. Section diagram of the smart pill constituted by two chambers.

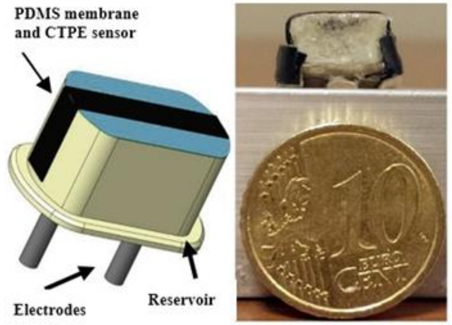

Figure 2. Electrolytic pump (Reservoir volume 120μl, PDMS membrane area $40mm^2$, CTPE sensor area $10mm^2$)

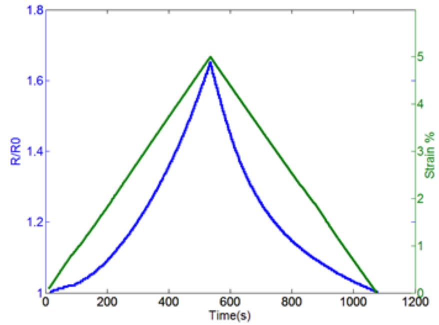

Figure 2. Behavior of the sensor (blue curve) for a one cycle traction (green curve).

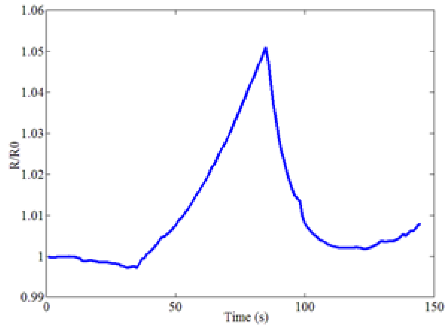

Figure 3. Resistance measured when the membrane is deformed by inflation/deflation.