AN OPTO-FLUIDIC SENSOR FOR MONITORING INTRACRANIAL PRESSURE

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ABSTRACT

Monitoring intracranial pressure is a critical aspect of post operative care of patients suffering from Traumatic Brain Injury. We present an implantable and powerless opto-fluidic device for monitoring intracranial pressure (ICP). The device converts ICP changes to wavelength changes through the use of a tunable, liquid-filled microlens that focuses light to a multi-layered quantum dot array.

KEYWORDS: Intracranial pressure, tunable microlens, quantum dot array.

INTRODUCTION

Traumatic Brain Injury (TBI) is a medical condition accounting for nearly 50,000 deaths and 235,000 hospitalizations every year in the US. Monitoring the intracranial pressure (ICP) has emerged as a critical diagnostic tool for the effective treatment of severe TBI requiring surgery [1].

\begin{figure}
\centering
\includegraphics[width=\textwidth]{fig1}
\caption{(a) Monitoring ICP using the proposed opto-fluidic sensor, (b) ICP changes (over the flexible membrane) result in changes in the microlens focal length, (c) The flexible membrane and the microlens (both 700 \textmu m in diameter) are connected via a straight microfluidic channel (layer 1). The pressurised chamber (layer 2) is located above the flexible membrane.}
\end{figure}
Current ICP monitoring approaches have three major drawbacks [2]: (a) they are associated with high risk of infection, (b) they do not allow long-term ICP monitoring and (c) they are not MRI (Magnetic Resonance Imaging) compatible. This work demonstrates the development of a novel opto-fluidic ICP sensor that incorporates powerless micro-optical components. The device is fully implantable, MRI compatible, it reduces the risk of infection, and it enables the long-term ICP monitoring.

**DEVICE CONCEPT**

The device (figure 1(b)) converts ICP changes to wavelength changes in the near infra-red (NIR) spectrum where the brain tissue is transparent. It integrates a tunable liquid-filled microlens that is microfluidically connected to a flexible membrane (~15-20 \( \mu \)m thick), with a quantum dot (QD) array (figure 1(c)). The QD array consists of multiple liquid solutions separated by glass slides, each one containing quantum dots of a single colour. The flexible membrane when pressurized (due to a change in the ICP), it deflects downwards, displacing the liquid contained beneath it. As a result, the microlens membrane (~15-20 \( \mu \)m thick) deflects upward, forming a Plano-convex microlens of tunable focal length. ICP changes result in focal length changes and therefore fluorescence excitation/emission of a particular QD layer. As NIR wavelengths undergo low attenuation in biological tissues, signals can be acquired through the brain tissue and analyzed using a non-implantable spectrometer. The initial focal length of the device can also be preset by controlling the amount (and thus the pressure) of the fluid contained within the bottom layer. That is a great advantage as moderate numerical apertures (0.08-0.16) can be achieved at low pressures.

**EXPERIMENTAL**

The two PDMS layers that consist of the opto-fluidic sensor were fabricated from two SU-8 moulds using soft lithography. The microfluidic channel (layer 1) is filled with water and hermetically sealed using plugs. A custom-made imaging setup was build on top of the xy-stage of an inverted microscope to measure the focal length.

**RESULTS AND DISCUSSION**

As expected, the deflection of the flexible membrane resulted in reduction
in the microlens focal length (figure 3). Additionally, the response of the microlens to pressure changes was controlled by pre-pressurizing the fluid contained within the microlens. Microlenses pre-pressurised at high pressures resulted in lower initial focal lengths (and therefore increased numerical apertures). The trade-off of pre-pressurizing the microlens is that the dynamic range of the device is decreased.

![Figure 4: Distinct spectra obtained when different layers of the Q-dot array get excited.](image)

The characterized microlens was then used to excite a two-layer QD array (the microscope objective in the imaging setup was replaced by the QD array). The array consisted of two QD solutions with emission maxima at 620 nm and 705 nm respectively, separated by thin microscope cover slips (~170 \( \mu \)m thick). A green laser (\( \lambda = 532 \) nm) was used as an excitation source. Figure 4 shows the spectral signals obtained when the external pressure applied on the flexible membrane was varied. At lower pressures, the microlens has a longer focal length resulting in the excitation of the lower QD solution (figure 4(b)). Increased pressure resulted in decrease in the focal length resulting in the spectrum obtained in figure 4(c).

**CONCLUSIONS**

We fabricated a novel opto-fluidic intracranial pressure sensor that can be used for long term and infection-free ICP monitoring. The device is capable of converting pressure changes to spectral signatures through the use of a tunable, liquid-filled microlens that focuses light to a quantum dot array. We believe that the proposed technology will provide a new generation of implantable pressure sensors opening up a new way in monitoring ICP.

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**REFERENCES**