MINIATURIZING THE WHOLE DEVICE: MICRO-TOTAL-ANALYSIS SYSTEM FOR IN-SITU COLORIMETRIC WATER QUALITY MONITORING

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ABSTRACT

This work presents the design and characterization of the individual microfluidic instrument components to be used for an integrated micro-total-analysis device for in-situ, colorimetric, water quality monitoring. Components include a microfabricated filter, a passive micromixer, a 1-cm pathlength microfluidic absorbance flow cell, mini-motor driven peristaltic micropumps with normally-closed valving capacity, a miniature collapsible reagent storage bag, and compact water-proof packaging. Preliminary development of the integrated device employing a miniature spectrometer is also presented.

KEYWORDS: micropump, micromixer, water quality, environmental, in-situ

INTRODUCTION

Truly portable field analysis systems, the possibility of complex monitoring networks, and remote & autonomous devices can all be realized with the advantages that miniaturization offers. Several microfluidic devices for colorimetric water quality monitoring have been demonstrated in the literature and are best summarized by Marle & Greenway [1]. This work advances the field by miniaturizing all instrument components, addressing the environment-chip interface, and focusing on an in-situ microfluidic instrument. The design and characterization of the individual microfluidic instrument components are presented. The ultimate goal of a versatile, portable, and in-situ monitoring platform is highlighted for which different colorimetric reagent can be used to perform a variety of analyses.

EXPERIMENTAL

Microfabrication of components was performed by replica molding polydimethylsiloxane (PDMS) from SU-8 lithographic masters on silicon substrates. PDMS chips were then either plasma bonded to glass slides or to another PDMS microchip by preserving the plasma activation in methanol followed by manually aligning microfeatures [2]. Fluidic interconnections were formed by plasma bonding Upchurch Nanoports to PDMS using the supplied adhesive rings [3]. Interconnections in the portable device were formed by casting polyvinylchloride (PVC) tubing into PDMS chips using magnetic fixturing. Polyetheretherketone (PEEK) capillary tubing was then inserted into the PVC tubing.

The micromixer design is a simple Y-mixer with geometric focusing to a width of 50 μm based on the concepts presented by Hessel et al. [4]. Characterization of mixing efficiency was performed by monitoring the absorbance of the formation of iron thiocyanate (excess iron, [5]) with a microscope spectrometer with a 2D CCD.
array. The spectrometer slit was aligned perpendicular to the mixing channel to provide absorbance cross sections of the mixing channel.

The microfabricated flow cell has a 1-cm pathlength and a 200-μm width. Optical fibers with a total diameter of ~250 μm dictated the channel height and were inserted through ‘fiber guide channels’ to rest against a PDMS window. The guide channels were filled with PDMS to secure the fibers and to minimize optical interfaces. The flow cell was characterized by integration with the micromixer and comparing an iron thiocyanate calibration curve to that of premixed solutions measured in an Ocean Optics benchtop spectrometer.

The microfabricated filter consisted of an array 50 x 50 μm posts that are 100-μm tall and was originally developed for in-reservoir use and tested with biological samples [6]. Here the viability of in-situ filtering of ‘dirty’ environmental samples was demonstrated. Willamette River (OR, USA) water was used to test the filter by immersing into a beaker of stirred river water and aspirating sample into the chip. The flow rate was monitored, the filter was visually inspected using a microscope, and a control experiment (filter design without post array) was used for comparison.

The micropump was inspired by commercial bench-top peristaltic pumps. A circular microchannel of rectangular cross section was formed around a hole in the center of the chip. The center hole housed a miniaturized roller-type actuator, to compress the channel walls, thereby invoking peristalsis [7]. An analogous design which utilized commercial tubing in a polycarbonate housing was also developed. Compete compression of the channels/tubing provided normally-closed valving capacity. The actuator was driven with a miniature geared motor (Precision Microdives, London, UK) originally intended for video camera focusing. The two micropumps had similar dimensions with the fluid/actuator portions being ~2 x 2 x 1 cm and the mini-motor/gearbox having dimensions of 2.1 x 1.0 x 2 cm. The micropumps were characterized by monitoring flow rates with a micro-rotameter (Omega) as a function of RPM, channel dimensions/tubing ID, and PDMS microchip compression.

Reagent bags were formed using a FoodSaver heat sealing device from static shielding bags. Collapsible bags, formed to hold between 0.5 and 2 mL, were used to facilitate pressure equalization. Connections were made by sealing in capillary PEEK tubing using a heat-activated film adhesive.

Compact water proof packaging was fabricated from 2” PVC pipe and is shown in Figure 1. The interior of the packaging housed a compact footprint integrated mixer-flow cell which also served as a gasket to seal against the outside environment. Two micropumps and an adapted Zeiss miniature diode array spectrometer were also interior to the packaging. The interior PDMS microchip connected to an outer filter chip and reagent bag which was protected from environmental debris.

Figure 1. a) Mixer-flow cell microchip, micropumps, and miniature spectrometer. b) Filter chip and reagent bag. c) Packaging
with a stainless steel screen. Complete packaging dimensions were 6-cm diameter and a 13.5-cm length.

RESULTS AND DISCUSSION

The results of the mixing efficiency experiment were compared to a Comsol Multiphysics model (dilution model, 2D) in Figure 2. Complete mixing occurred in ~0.27 s; at a net flow of 10 µL/min, 5 mm was an adequate mixing length. The integrated mixer-flow cell performed comparably to the premixed solutions in a bench-top spectrometer, as shown in Figure 3.

![Figure 2. Dependence of mixing efficiency on mixing length (10 µL/min). Compared to a 2D dilution model.](image)

![Figure 3. FeSCN calibration curves of. Comparison of integrated mixer & flow cell and premixed solutions.](image)

The microfabricated filter filtered 40 mL of river water continuously for 13.5 hr without any clogging of the post-filter channel or flow rate degradation. A post-filtration filter bed is shown in Figure 4. Significant particle build-up occurred in the channel downstream of the control experiment ‘filter’ chip after 1 hr of filtering.

A sample of the micropump flow rate data is presented in Figure 5. Channel/tubing dimensions, actuation frequency (RPM), percent compression of the PDMS microchip, and roller diameter were varied to provide a wide range of flow rates. A linear flow rate range spanning 0.5-27 µL/min was obtained for the PDMS micropump by varying RPM and channel cross-section. The PDMS micropump valved up to 2 psi, while the tubing-based pump exhibited no leakage up to 50 psi.

The tubing-based pump with 250-µm ID tubing was tested for longevity over a period of 25 days without maintenance. After a break-in-period of ~5 days, the flow rate remained relatively constant (8% RSD). A shorter term stability test was performed by running the tubing-based performing any micropump, PDMS micropump, and a commercial peristaltic pump for 2 hr continuously, and the relative standard deviations in the flow rates were comparable and less than 5%.
Preliminary results for the components integrated into the compact water-proof packaging demonstrate adequate mixing with two tubing-based micropumps and the ability to pump from the collapsible reagent bag while the device is submerged.

CONCLUSIONS
The individual microfluidic components necessary to perform and in-situ colorimetric water quality analysis were designed, characterized, and integrated. The success of this endeavor indicates the feasibility of a robust, portable, in-situ microfluidic water quality monitoring system. Future work includes integrating electronics, control programming, and application of the device.

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REFERENCES

Figure 4. Photo of filter bed after filtering 40-mL of Willamette river water.
Figure 5. Pump flow response for different channel dimensions. ◆: small—50 x 250-μm. ■: Large—445 μm x 300-μm. ▲: Large with back wall.