

A SMARTPHONE-INTEGRATED DIELECTROPHORECTIC PLATFORM FOR RAPID AND IN-SITU MONITORING OF ENVIRONMENTAL WATER QUALITY THROUGH LAMP ASSAYS

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ABSTRACT

A smartphone-integrated dielectrophoretic (SiDEP) platform is presented for on-site and real-time monitoring of fecal indicator bacteria (FIB) to examine the presence and concentration levels of fecal contamination in environmental water via loop-mediated isothermal amplification (LAMP) assays on a smartphone. Experimental demonstrations have verified the SiDEP's capabilities for (1) on-chip water sample processing, (2) portable LAMP assays, and (3) colorimetric analysis of fecal water quality. The SiDEP truly offers a low-cost, portable, and fully-integrated system enabling rapid on-site detection of the presence of FIB and their associated pathogens in environmental water without the need for sophisticated laboratory equipment or skilled personnel.

KEYWORDS: Dielectrophoresis (DEP), Optoelectronic tweezers, Smartphone detection, Water quality, *E. coli*

INTRODUCTION

Rapid and reliable technologies for in-situ monitoring of microbial water quality are important to prevent public health from the dangers of transmitting waterborne pathogens. However, conventional laboratory-based methods are laborious and timing-consuming, requiring bulky and expensive equipment [1]. Hence, there is a strong motivation to develop a low-cost, portable system that enables rapid on-site detection of microbial water quality.

OVERVIEW OF THE SiDEP PLATFORM

Figure 1 shows a schematic of the SiDEP system for on-site and real-time detection of fecal contamination in water. It consists of three components, floating electrode optoelectronic tweezer (FEOET) device, transparent heater, and smartphone, which are compactly assembled as an all-in-one platform for low-cost and portable water-quality detection through the LAMP assays. Figure 1(a) and (b) present the FEOET device structure and its droplet-based microfluidic functions for on-chip processing of water samples without any bulky and complex microfluidic components such as pumps, tubes, and microchannel structures, using a light-driven DEP principle [2]. To implement portable LAMP assays, a transparent heater adheres to the bottom surface of the FEOET device (Figure 1c). The integration with the heater enables on-chip isothermal nucleic acid amplification at 65°C for in-situ analysis of water quality via LAMP assays, which can be conveniently carried out on the SiDEP platform without bulky and expensive equipment (e.g., thermal cyclers). Lastly, an

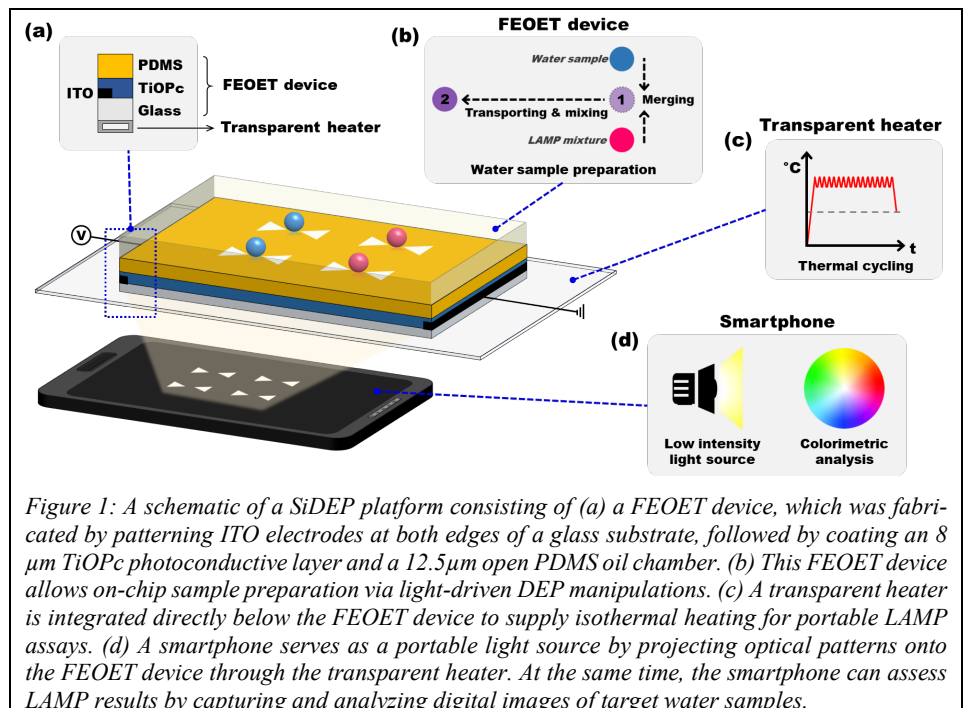


Figure 1: A schematic of a SiDEP platform consisting of (a) a FEOET device, which was fabricated by patterning ITO electrodes at both edges of a glass substrate, followed by coating an 8 μm TiOPc photoconductive layer and a 12.5 μm open PDMS oil chamber. (b) This FEOET device allows on-chip sample preparation via light-driven DEP manipulations. (c) A transparent heater is integrated directly below the FEOET device to supply isothermal heating for portable LAMP assays. (d) A smartphone serves as a portable light source by projecting optical patterns onto the FEOET device through the transparent heater. At the same time, the smartphone can assess LAMP results by capturing and analyzing digital images of target water samples.

integrated smartphone can also provide various features to replace auxiliary equipment and components (Figure 1d). For instance, a smartphone serves as a low-intensity, portable light source to provide dynamic light patterns onto the FEOET device through a transparent heater for on-chip dropwise processing of water samples. Furthermore, a smartphone's built-in camera captures digital images of target water samples as well as its image processing app can perform quantitative and accurate analysis for colorimetric study of the LAMP assay results by counting their red-green-blue (RGB) values.

EXPERIMENTAL DEMONSTRATIONS

For experimental demonstrations, *Escherichia coli* (*E. coli*) was used as a proxy to assess fecal contamination of environmental water samples. Figure 2(a) depicts video snapshots of on-chip sample processing. A 1.0 μL freshwater droplet (collected from freshwater reservoirs in Singapore) containing *E. coli* DNA and 1.5 μL LAMP mixture were placed on the SiDEP platform. By illuminating optical patterns from a smartphone onto the device, the DEP forces were induced to merge the two droplets. The combined droplet was then driven back and forth at an average speed of 1.28 mm/s. During this transportation process, an internal flow was induced for droplet mixing by a shear force from the bottom surface [2]. Next, the transparent heater was operated to provide isothermal heating at 65 $^{\circ}\text{C}$ (Figure 2b) for the successful LAMP assays of *E. coli* DNA, which allowed a cost-effective and field-portable LAMP testing without bulky and expensive equipment like thermal cyclers. Figure 3(a) shows digital images of the target droplet before and after the LAMP reaction taken by a smartphone's digital camera, where the droplet color changed from pink to pale yellow. A smartphone colorimetric analysis app then processed these images and their RGB values were plotted in Figure 3(b), thus representing a successful DNA amplification.

CONCLUSION

An all-in-one SiDEP platform was presented where three components are fully integrated into a low-cost, portable system that enables rapid in-situ water-quality detection. It can perform on-chip water sample processing with the smartphone projecting optical patterns onto the FEOET device. LAMP assays can then be conveniently conducted with the integrated heater. Finally, the smartphone performs quantitative analysis of the target samples with its built-in digital camera and image processing app. This study offers a field-portable solution for assessing water quality in resource-limited settings, without the need for sophisticated equipment or skilled personnel.

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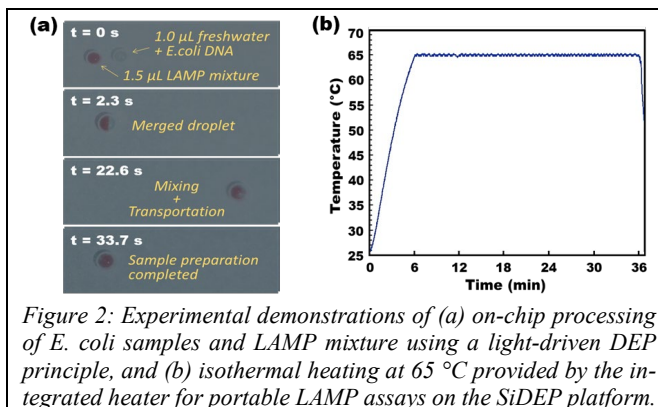


Figure 2: Experimental demonstrations of (a) on-chip processing of *E. coli* samples and LAMP mixture using a light-driven DEP principle, and (b) isothermal heating at 65 $^{\circ}\text{C}$ provided by the integrated heater for portable LAMP assays on the SiDEP platform.

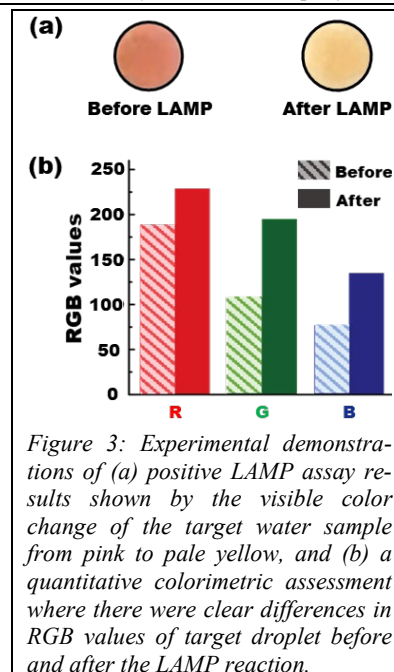


Figure 3: Experimental demonstrations of (a) positive LAMP assay results shown by the visible color change of the target water sample from pink to pale yellow, and (b) a quantitative colorimetric assessment where there were clear differences in RGB values of target droplet before and after the LAMP reaction.