Microfluidic device based on opto-acoustics for particle concentration detection

Rahul Kishor[12], Zhichao Ma[3], Sivaramapanicker Sreejith[4], Yen Peng Seah[5], Ye Ai[3], Zhenfeng Wang[5], Teik-Thye Lim[6] and Yuanjin Zheng*[2]

[1]*NEWRI, Interdisciplinary Graduate School (IGS), Nanyang Technological University, Singapore.*
[2]*School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore.*
[3]*Singapore University of Technology and Design, Singapore*
[4]*Division of CBC, SPMS, Nanyang Technological University, Singapore*
[5]*Singapore Institute of Manufacturing Technology, Singapore*
[6]*School of Civil and Environmental Engineering, Nanyang Technological University, Singapore*

* Email: YJZHENG@ntu.edu.sg; Tel.: +65-65927764

Rapid, sensitive and selective detection of bioparticles is of prime importance in point of care diagnostic devices and various micro- and nano-systems [1] relying on microfluidics are being developed. This paper reports a design of a new optoacoustic microfluidic device which can quantitatively detect the concentration of micron sized bioparticles in a solution. In our previous work [2], we have introduced a new sensing scheme utilizing surface acoustic wave (SAW) detection of the photoacoustic (PA) signal generated from optical absorption of bioanalytes present in the microfluidic channel. In the current work, we combine a SAW based particle concentration on a microfluidic reservoir with the SAW-PA sensor to enable rapid, quantitative and sensitive microparticle detection (polystyrene) on a single piezoelectric substrate. The detection of analytes from the bulk of the solution, along with the mechanical scanning, particle concentration and continuous fluid flow, highlights the device capability to handle clinically relevant sample volume (millilitres) in comparison to the low throughput (microlitre sample) of the existing devices.

A schematic view of the device is illustrated in Fig. 1. Orthogonal interdigital transducers (IDT) on the 128^0 YX lithium niobate (LiNbO3) piezoelectric substrate is used for actuating and sensing. An IDT excited at 15.8 MHz (labelled ‘A’) oriented in the Y direction is used for particle concentration inside the microfluidic reservoir. The IDT at centre frequency of 10 MHz oriented in the X direction is used for sensing. The numerical simulation results confirms that the SAW-PA frequency for a 10 μm (diameter) polystyrene particle is sensitive for frequencies less than 50 MHz. Table I shows the SAW device specifications. A pulsed laser at repetition rate of 10 Hz at a wavelength of 532 nm is used, with an optical spot size of 200 μm. A mechanical scanner focusses the laser spot across the particles located inside the microfluidic reservoir. Fig. 2 shows the schematic of the experimental setup used for sensing. Black polystyrene microparticles with an optical absorbance of ~ 0.7 at 532 nm is used as the sensing sample for the experiment.

Fig. 3 shows 10 μm particles aggregating after SAW exposure for 40-50 sec. The particles are concentrated at a vertical height close to the liquid-air free surface. The preconcentration before detection bounds the mechanical scanning to only half of the cavity, thereby reducing the detection time. Fig. 4 shows the experimental results for the detection of the 10 μm particles for a concentration varying from ~10-200 particles per 10 μL. The power spectral density of the SAW-PA signals for varying particle concentration demonstrates a quadratic response, with a detection of 7 particles in 10 μL of solution. The sensitivity can be improved further to a single particle by optimizing the SAW design to match the acoustic frequency generated due to microfluidic channel resonance. Furthermore, utilizing dual SAW IDTs aggregates the particles at a preferred location, thereby eliminating the mechanical scanner. Thus, a rapid (few sec) and sensitive (single) particle detection device could be envisaged, comparable to the 3D droplet detection device[3].

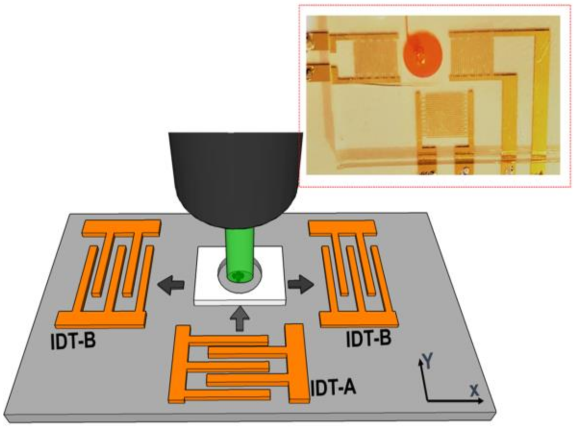

Fig.1 Schematic diagram of the microfluidic device with the concentrating (IDT-A) and sensing (IDT-B) interdigital transducers (IDT). A pulsed laser irradiates on the particle inside the reservoir to generate a SAW. Inset shows the photograph of the fabricated SAW device.

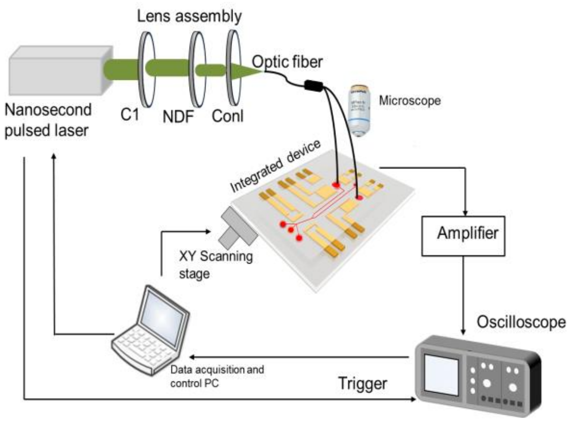

Fig.2 Schematic of the experimental setup used for SAW-PA detection of microparticles inside a microfluidic reservoir.

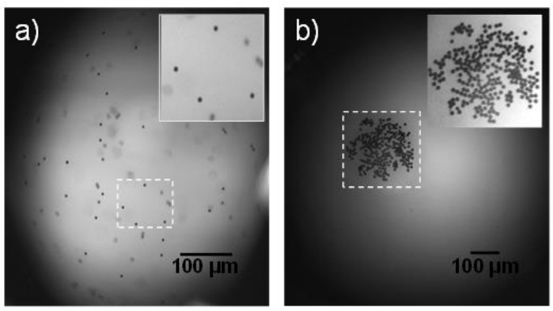

Fig. 3 Particle-laden cavity before (a) and after (b) SAW exposure for 50 sec.

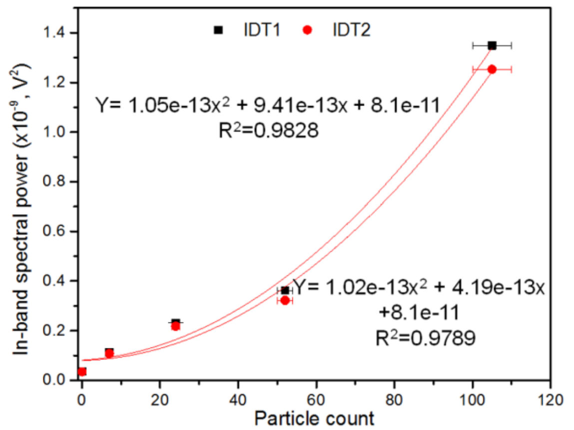

Fig.4 Experimental results for the SAW-PA sensing of the particles. Power spectral density (9-11 MHz) for various particle concentrations is calculated at the two sensing IDTs. The spectral power exhibits second order response with particle concentration.

Table 1. SAW IDT configuration

Parameter	*IDT-A*	*IDT-B*
IDT width (µm)	*99.5*	*49.75 (λ/8 design)*
Number of IDT pairs	*10*	*10*
Aperture (mm)	*4*	*4*
Thickness (nm)	*200*	*200*

REFERENCES:

[1] C. D. Chin, T. Laksanasopin, Y. K. Cheung, D. Steinmiller, V. Linder, H. Parsa, *et al.*, "Microfluidics-based diagnostics of infectious diseases in the developing world," *Nat Med*, vol. 17, pp. 1015-1019, 2011.

[2] R. Kishor, F. Gao, S. Sreejith, X. Feng, Y. P. Seah, Z. Wang, *et al.*, "Photoacoustic induced surface acoustic wave sensor for concurrent opto-mechanical microfluidic sensing of dyes and plasmonic nanoparticles," *RSC Adv.*, vol. 6, pp. 50238-50244, 2016.

[3] D.-K. Kang, M. M. Ali, K. Zhang, S. S. Huang, E. Peterson, M. A. Digman, *et al.*, "Rapid detection of single bacteria in unprocessed blood using Integrated Comprehensive Droplet Digital Detection," *Nat. Commun.*, vol. 5, p. 5427, 2014.