Measurement of Micro-fluidic Channels by Modified Optical Coherence Tomography

Hon Luen Seck [1,2], Ying Zhang [1], and Yeng Chai Soh [2]

[1] *Singapore Institute of Manufacturing Technology, 71 Nanyang Drive, Singapore, 638075*
[2] *School of Electrical and Electronic Engineering, Nanyang Technological University, Nanyang Avenue, Singapore, 639798*
yzhang@SIMTech.a-star.edu.sg

Abstract

This paper proposes a modified optical coherence tomography for measurement of microfluidic channels. The technique is implemented on a Fourier domain optical coherence tomography based on a mix free space and fiber interferometer. It is shown that the proposed technique can improve the resolution and recover the channel dimension with less measurement data.

1 Introduction

Microfluidic devices have gain wide spread applications in several areas like life sciences, biotechnology and chemistry. This is driven by the needs in investigation of local physics properties and simultaneous large scale testing at an affordable cost. Since the properties investigated are sensitive to the physical dimensions of the microfluidic channels, accurate characterization and calibration of the channel dimensions are critical.

Traditional microscope has been used to measure the channel depth of microfluidic chip [1]. Such a method relies on an ability to focus sharply on the channel bed through the use of high numerical aperture objective lens. A limitation presents in the case of bonded chips when the channel is embedded deeply below the top plate. The short working distance of the objective lens does not permit the lens to be close enough to features concerned. This limitation can be circumvented through the use of absorption dyes [2] and a confocal microscope to achieve three dimensional profiling of bonded chips. But this requires the additional use of dyes. While, white light confocal microscope [3] has also been used for topography measurements in microfluidic devices, this may not be suitable for characterizing multi layer microfluidic chips as the sensitivity is not high enough.

In this paper, we proposed a modified optical coherence tomography (OCT) technique to measure the dimensions of channels embedded in microfluidic chip. Traditional OCT allows only the optical path distance to be measured within the coherence length which is about 10 micrometers. It requires the optical spectrum to be detected with sufficient resolution and span. This becomes challenging since the channel concern maybe more than several millimetres below the surface. Without sufficient detection resolution, the information would be lost due to aliasing. While it is possible to customize a spectrometer with sufficient resolution, the total amount of data used is unnecessarily overloaded. It is actually possible to recover the channel dimension with higher resolution and less amount of measurement.

2 Method

A typical Fourier domain based optical coherence tomography setup is shown in figure 1. Light reflected from the surface of the micfofluidic device is used to interfer with light reflected from beneath the surface. As a result, the locations of the channel interfaces are encoded in the fringe frequencies of the optical spectrum.

Let *a(z)* denotes the features in the device. Then the signal detected is $s(\kappa) = G(\kappa)\left|1 + \sum a(z)e^{-i2\kappa z}\right|^2$ where κ is the wavenumber, *G(κ)* is the optical spectrum of the light source, and *z* is the optical path length difference. The modified method attempts to recover the axial scan by minimising the *l1* norm of *a(z)* instead of inverse Fourier Transform in the traditional case. The features of the microfludic device should be manifested as pikes trains on the reconstructed axial scan. Since *l1* norm is known to recover spiky data, the norm is chosen to be the optimization criteria. First, the interference spectrum is written into an algebraic form as shown below

$$\begin{pmatrix} s(\kappa_1) \\ \vdots \\ s(\kappa_N) \end{pmatrix} = \begin{pmatrix} G(\kappa_1)e^{-i2\kappa_1 z_1} & \cdots & G(\kappa_1)e^{-i2\kappa_1 z_M} \\ \vdots & \ddots & \vdots \\ G(\kappa_N)e^{-i2\kappa_N z_1} & \cdots & G(\kappa_N)e^{-i2\kappa_N z_M} \end{pmatrix} \begin{pmatrix} x_1 \\ \vdots \\ x_M \end{pmatrix} \tag{1}$$

where $\kappa_n \subseteq \{0,N-1\}$ and $z_m \subseteq \{0,M-1\}$. Then, vector **x** is recovered by minimizing the *l1* norm of **x** subjected to (1) using linear programming. As **x** is sparse, the number of columns of **s** which also represents the number of data points required for reconstruction is small. This translates to less data requirement needed.

3 FDOCT Instrument

The light source is a Superluminescent diode with centre wavelength at 1550nm. The spectrum is has approximately 50nm FWHM linewidth. This gives a free space axial resolution of 20µm. The optical signal detection is carried out by an optical spectrum analyzer (OSA) with detection resolution set to 2nm over a span of 154nm. Then, the data is transferred to the computer for processing with homemade software developed under Labview.

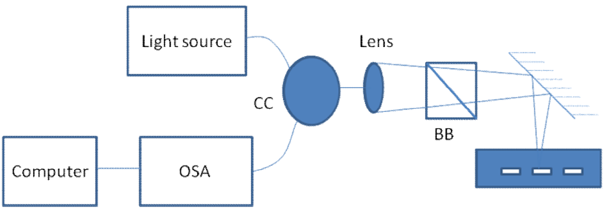

Figure 1: OCT setup (CC: Circulator, BB: Cube Beam Splitter)

4 Results

In the experiment, 200 data points out of a total of 1541 points from the optical spectrum analyzer were used to reconstruct the cross sectional image of the microfludic channel based on *l1* mininzation. For performance comparsion, experimental data collected from a single experiment is used to demonstrate the improvement of the modified optical coherence tomography.

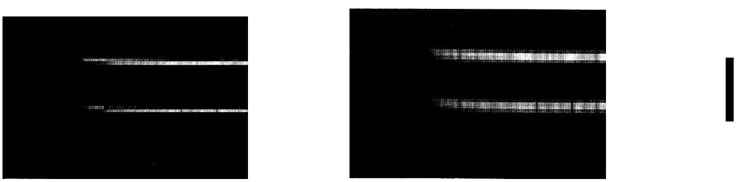

Figure 2: Image of modified (Left) and conventional (Right) optical coherence tomography. The vertical bar represents 100um.

It can be seem the the resolution of the image is enhanced and the channel features can be located more precisely.

5 Conclusion

The proposed OCT technique makes use of the sparsity of channel features in the OCT image. Linear programming optimization method instead of traditional inverse Fourier Transform method is used in reconstruction of the features. Since only sparse features are recovered, the proposed method requires significantly fewer measurement data than previously required. By appropriate modelling of the measurement data, the location of the channel bed and top can be identified. Compared to traditional OCT measurements [4], the new method has greatly improved the resolution. Thus, it is expected as a promising metrology tool for characterization of micro-fluidic devices.

References:

[1] J. Liu, C. Tian, Z. Wang and J. Lin, "Measurement of channel depth by using a general microscope based on depth of focus", Eurasian Journal of Analytical Chemistry, Vol. 2, No. 1, Pg.12-20, 2007.

[2] I. Broadwell, P. D. I. Fletcher, S. J. Haswell, T. McCreedy and X. Zhang, "Quantitative 3-dimensional profiling of channel networks within transparent 'lab-on-a-chip' microreactors using a digital imaging method," Lab on a Chip, Vol. 1, Pg. 66–71, 2001.

[3] S. Li, T. Thorsen, Z. Xu, Z. P. Fang, J. Zhao,and S. F. Yoon, "Microvalve thickness and topography measurements in microfluidic devices by white-light confocal microscopy," Applied Optics, Vol. 48, No. 27, Pg. 5088-5094, 2009.

[4] K. Wang, Z. Ding, T. Wu, C. Wang, J. Meng, M. Chen and L. Xu, "Development of a non-uniform discrete Fourier transform based high speed spectral domain optical coherence tomography system," Optics Express, Vol. 17, No. 14, Pg 12121-12131, 2009.