Flow-Through Multi-Hole Capillaries for Optofluidic Bio-Chemical Sensing

Yunbo Guo, Maung Kyaw Khaing Oo, and Xudong (Sherman) Fan

Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI 48109

Motivation

- We develop novel flow-through multi-hole microstructured fibers/capillaries for sensitive bio-chemical detections with inherent micro-/nanofluidic channels. Compared to the widely-studied photonic crystal fibers (PCFs), the capillaries provides many unique characteristics, and will allow us to carry out versatile and critical applications.

Objectives

- Build a capillary pulling system and fabricate multi-hole capillaries
- Construct an optofluidic Fabry-Pérot cavity biosensor
- Develop an optofluidic 3-D surface-enhanced Raman scattering (SERS) platform for ultrasensitive analyte detection

Capillary Fabrication

Capillary Pulling System

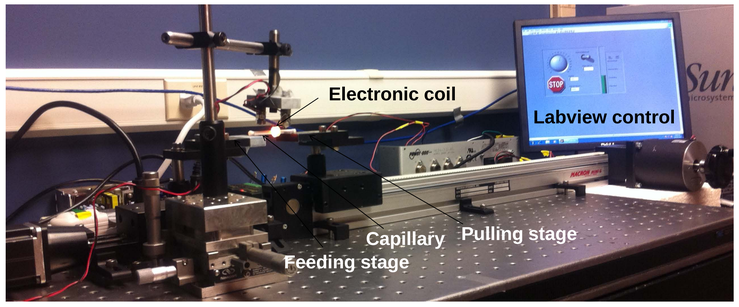


Fig. 1 Capillary pulling system built

Images of Pulled Capillaries

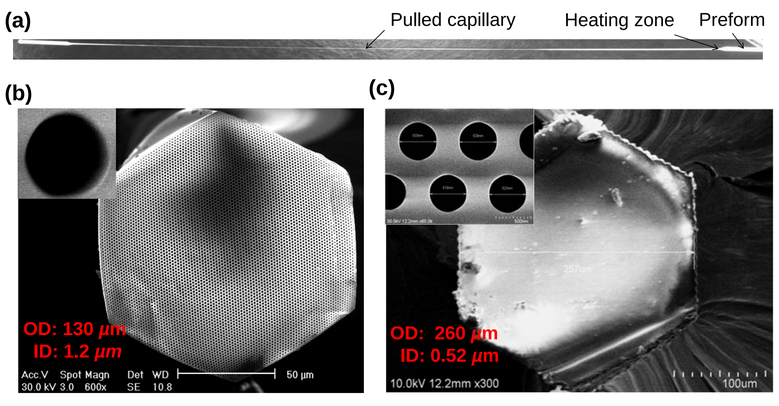


Fig. 2 (a) Pulled capillary (up to 50 cm); (b) 7,000 holes; (c) 100,000 holes

Optofluidic Fabry-Pérot Cavity Biosensor

Operating Principle

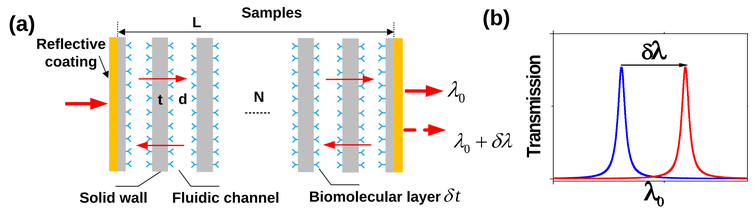


Fig. 3 (a) Schematic of the optofluidic Fabry-Pérot cavity biosensor
(b) Resonance wavelength shift due to biomolecular binding to inner surface

Resonance conditions of the Fabry-Pérot cavity:

$$\left.\begin{aligned} 2nL &= m\lambda_0 \\ 2(nL + 2N\cdot\Delta n\cdot\delta t) &= m(\lambda_0+\delta\lambda)\end{aligned}\right\} \quad \frac{\delta\lambda}{\delta t} = \boxed{2N}\cdot\frac{\Delta n}{nL}\cdot\lambda_0 \propto A/V$$

Sensitivity is greatly increased with thousands of micro-/nanosized holes

Optical Sensing System

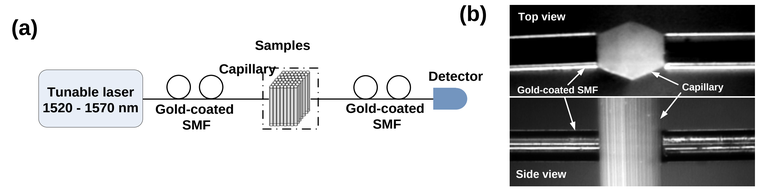
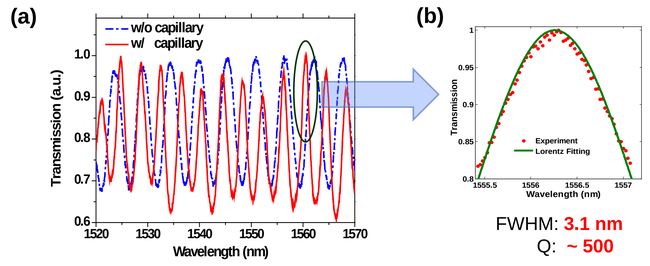


Fig. 4 (a) Schematic of optical sensing system; (b) Implementation

Fabry-Pérot Resonance Modes



FWHM: **3.1 nm**
Q: **~ 500**

Fig.5 (a) Resonance modes of the cavity with or without capillary
(b) The FP resonator's Q is higher than other flow-through sensors

Rapid Analyte Delivery & Sensitive Biomolecular Detection

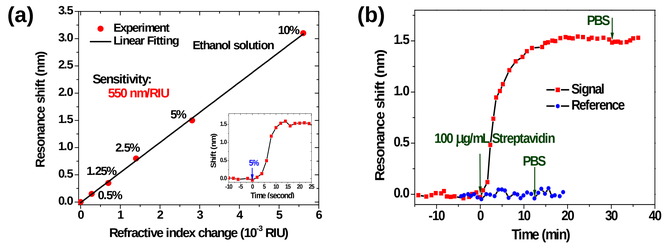
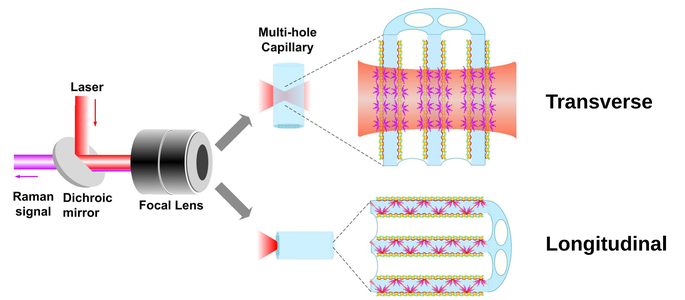


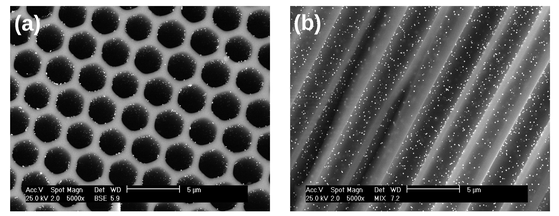
Fig.6 (a) Bulk solvent sensitivity. Inset shows rapid delivery (total volume: ~ nL)
(b) Sensorgram of streptavidin binding to biotinylated sensing surface

Optofluidic 3-D SERS Platform

Detection Configurations

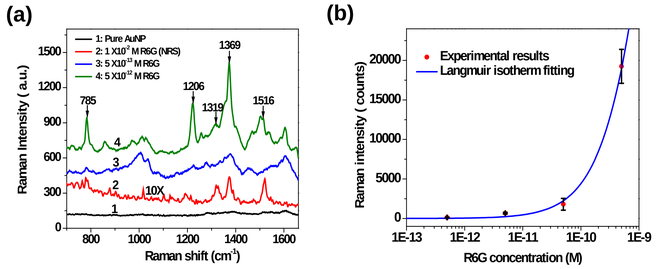


SEM Images of Capillary Immobilized with Gold Nanoparticles



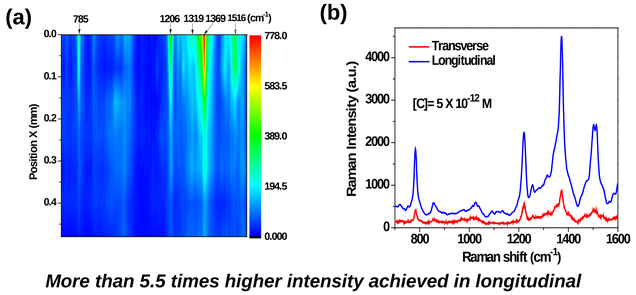
Density:
6 particles/μm²

Ultrasensitive Molecule Detection (Transverse)



Enhancement factor: > 3 X10⁹
Detection limit: < 100 fM
3 orders of magnitude sensitive than using PCF

Longitudinal vs. transverse



More than 5.5 times higher intensity achieved in longitudinal

Summary

We have successfully fabricated flow-through multi-hole capillaries and developed their applications in optofluidic Fabry-Pérot cavity biosensor and 3-D SERS platform for rapid and ultrasensitive bio-chemical detections.