Microfluidic Channels for Silicon Photonic Chemical- and Bio-Sensors

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Background – Optical Biosensors

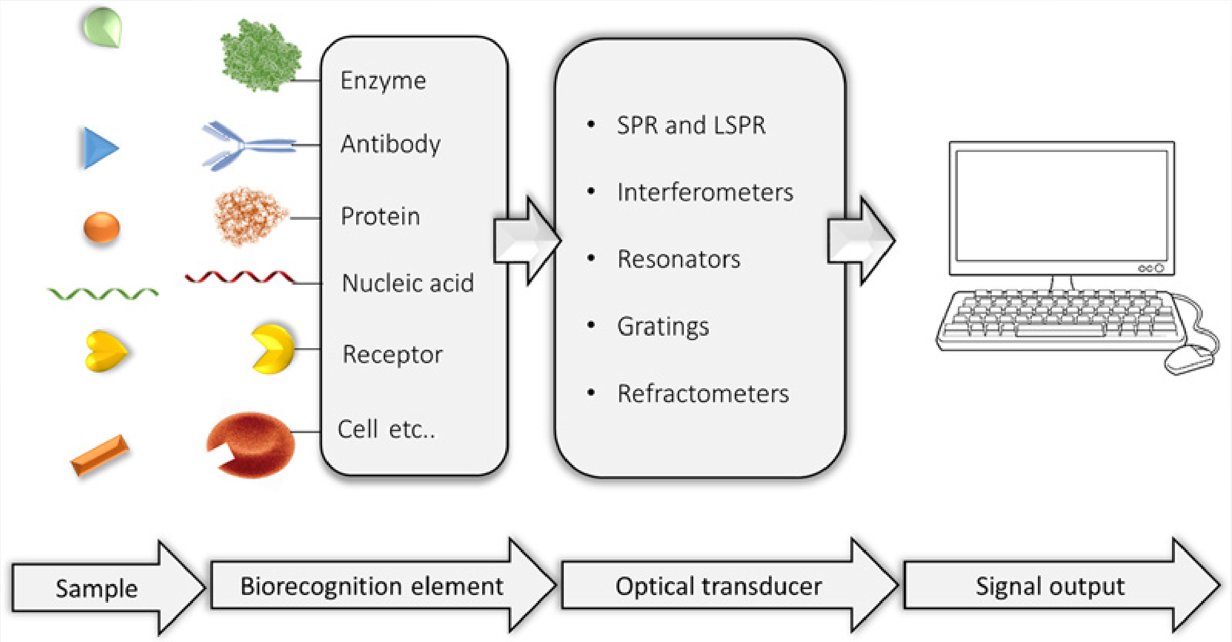


Figure 1: Overview of optical biosensors

- Most common type of biosensor
  - Enable direct, real-time, label-free detection
- Surface plasmon resonance (SPR), evanescent wave fluorescence, bioluminescent optical fibres, surface enhanced Raman scattering

[1] Borisov, Sergey M., and Otto S. Wolfbeis. "Optical biosensors." *Chemical reviews* 108.2 (2008): 423-461.

Background – Silicon Photonic Crystal Sensor

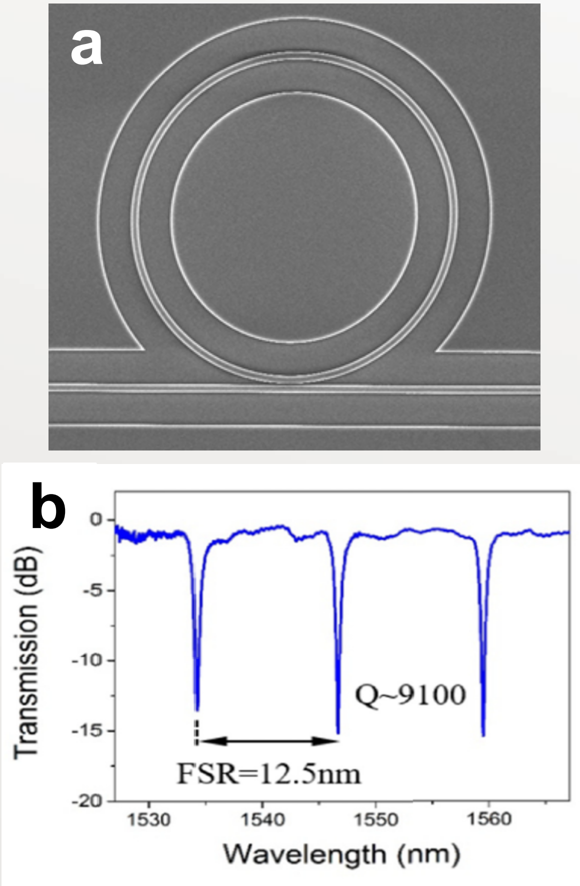


Figure 2: a) A Scanning Electron Microscope (SEM) image of a microring resonator and b) its corresponding transmission spectra.

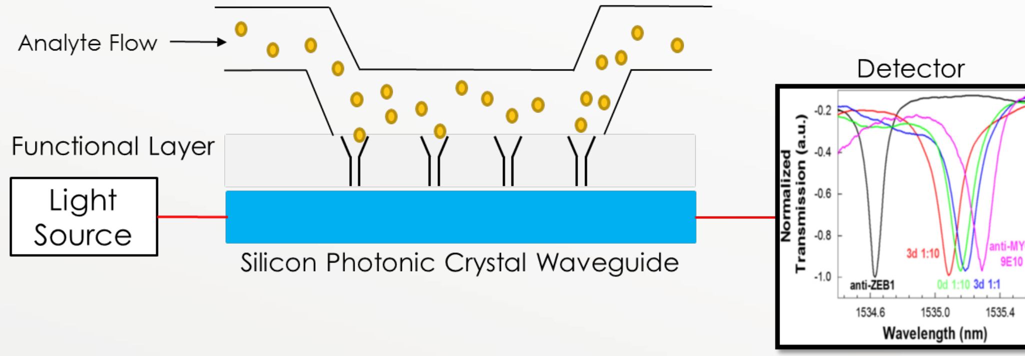


Figure 3: A sample is flowed on top of a silicon photonic crystal waveguide as light passes through it, resulting in a transmission spectra at the detector.

- Light travels through the periodic silicon structure from input to output
- A liquid sample is flowed on top of the silicon, filling the periodic holes
- A change in refractive index causes a change in the frequency of light trapped in the microcavity, which causes a shift in the resonance frequency observed in the transmission spectra

[2] Chakravarty, Swapnajit, et al. "Multiplexed specific label-free detection of NCI-H358 lung cancer cell line lysates with silicon based photonic crystal microcavity biosensors." *Biosensors and Bioelectronics* 43 (2013): 50-55.

PDMS Microfluidics Project

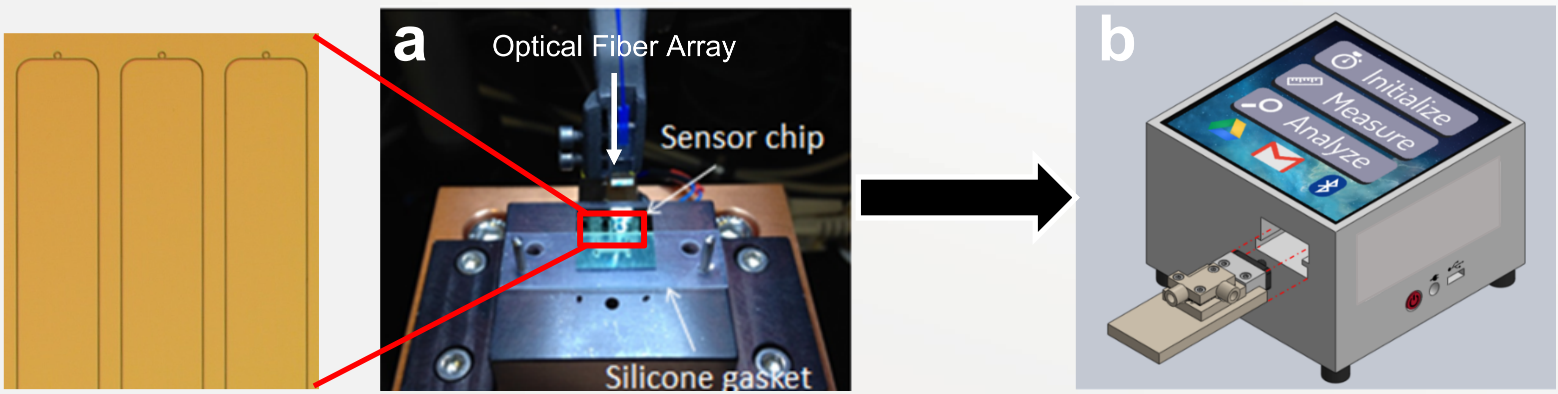


Figure 4: a) A benchtop system for testing silicon photonic chemical- and bio-sensors with waveguide enlarged and b) A portable sensing system.

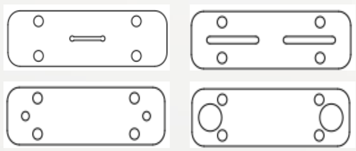
- Optical biosensors need to become more portable for an end user to easily take measurements
- This project aims to create microfluidic channels from polydimethylsiloxane (PDMS) layers for the purpose of contributing to making portable optical chemical- and bio-sensors
- PDMS-PDMS bonds were created using an oxygen plasma bonding method
- The PDMS-PDMS bonds were tested for leakage by flowing dyed red water through the channels
- A full waveguide test was completed to demonstrate compatibility with the testing procedures

Approach

KEY:
- Bonding Procedures (black arrow)
- Tests Performed (red arrow)

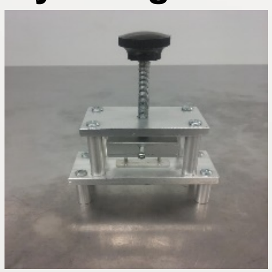
x3

① **PDMS Layers**

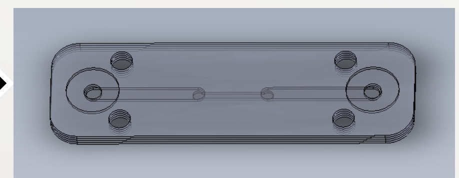


② **Oxygen Plasma Surface Activation**

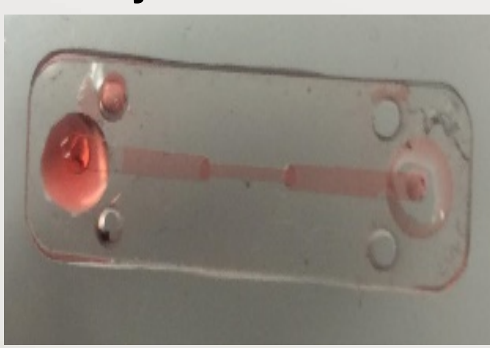
③ **Layer Alignment**



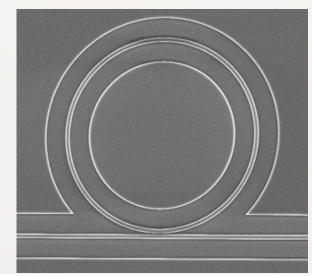
④ **PDMS Microfluidic Channels**

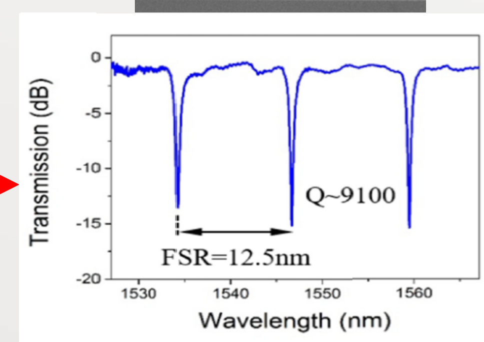


⑤ **Dyed Water Test**



⑥ **Full Waveguide Test**





Polydimethylsiloxane (PDMS) Layers

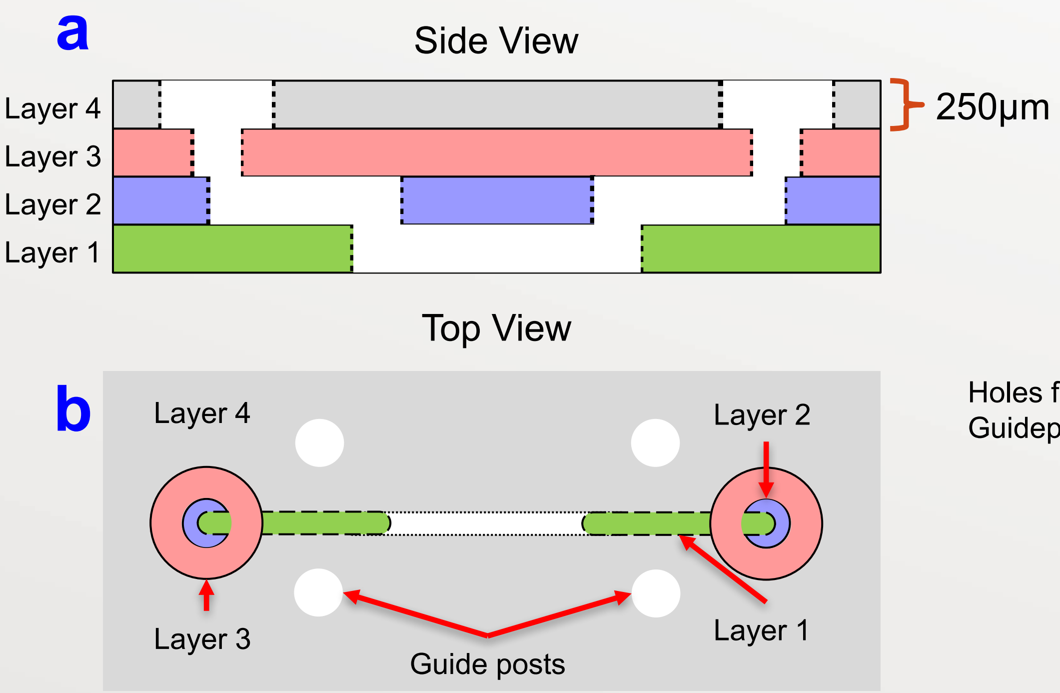


Figure 5: Schematics of a) Side and b) Top views of 250 μm PDMS layers forming microfluidic channels

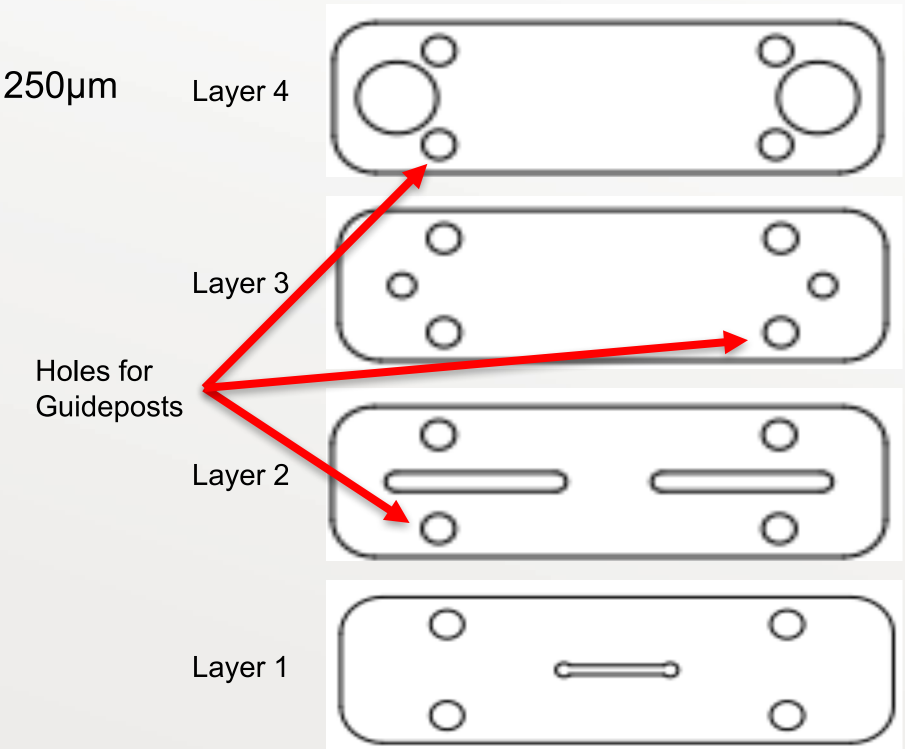


Figure 6: All four PDMS layers with laser-cut slots and holes.

The PDMS layers were bonded together to create microfluidic channels.

Oxygen Plasma Surface Activation

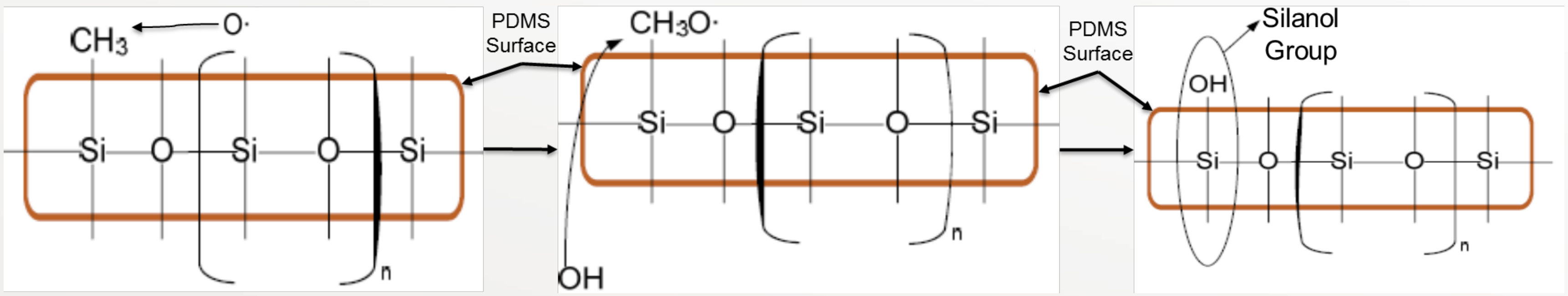


Figure 7: A methyl group in PDMS layers being replaced by a silanol group for the purpose of bonding to another PDMS layer.

- Reactive oxygen species attacks methyl group
- Unstable CH_3O^- is detached from surface
- OH^- hydroxyl group replaces CH_3O^- on surface creating silanol group
- Two layers in contact form Si-O-Si siloxane covalent bonds that are strong and irreversible
- Used Nordson March Asher to bond PDMS layers together
- Also tried with an etcher, but it did not make a permanent bond

This oxygen plasma chemical process was used to bond the PDMS layers to each other.

[3] Koh, Kai-Seng, et al. "Quantitative studies on PDMS-PDMS interface bonding with piranha solution and its swelling effect." *Micromachines* 3.2 (2012): 427-441.

Custom Alignment Apparatus

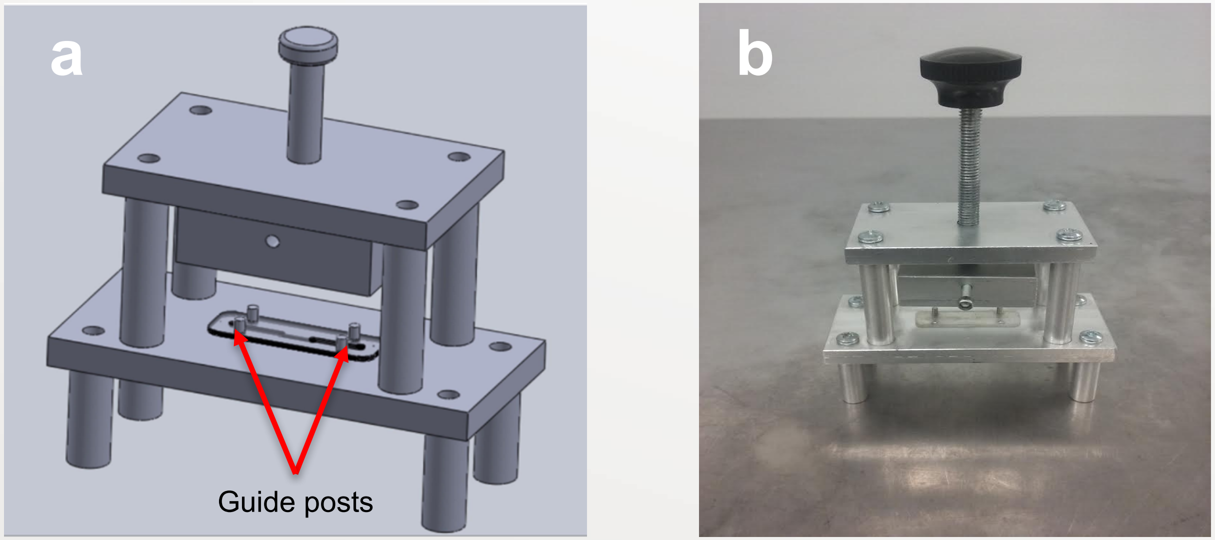


Figure 8: Two pictures of the custom alignment apparatus where a) is a SolidWorks CAD drawing of the apparatus and b) is an optical image of the apparatus. Both pictures have the PDMS layers in place.

- Four guideposts are present for help with aligning the PDMS layers
- One screw applies even pressure to PDMS layers through a metal slab for help in the bonding process
- Only the screw and the metal slab move

The custom alignment apparatus was helpful in aligning and bonding the PDMS layers.

Alignment Results

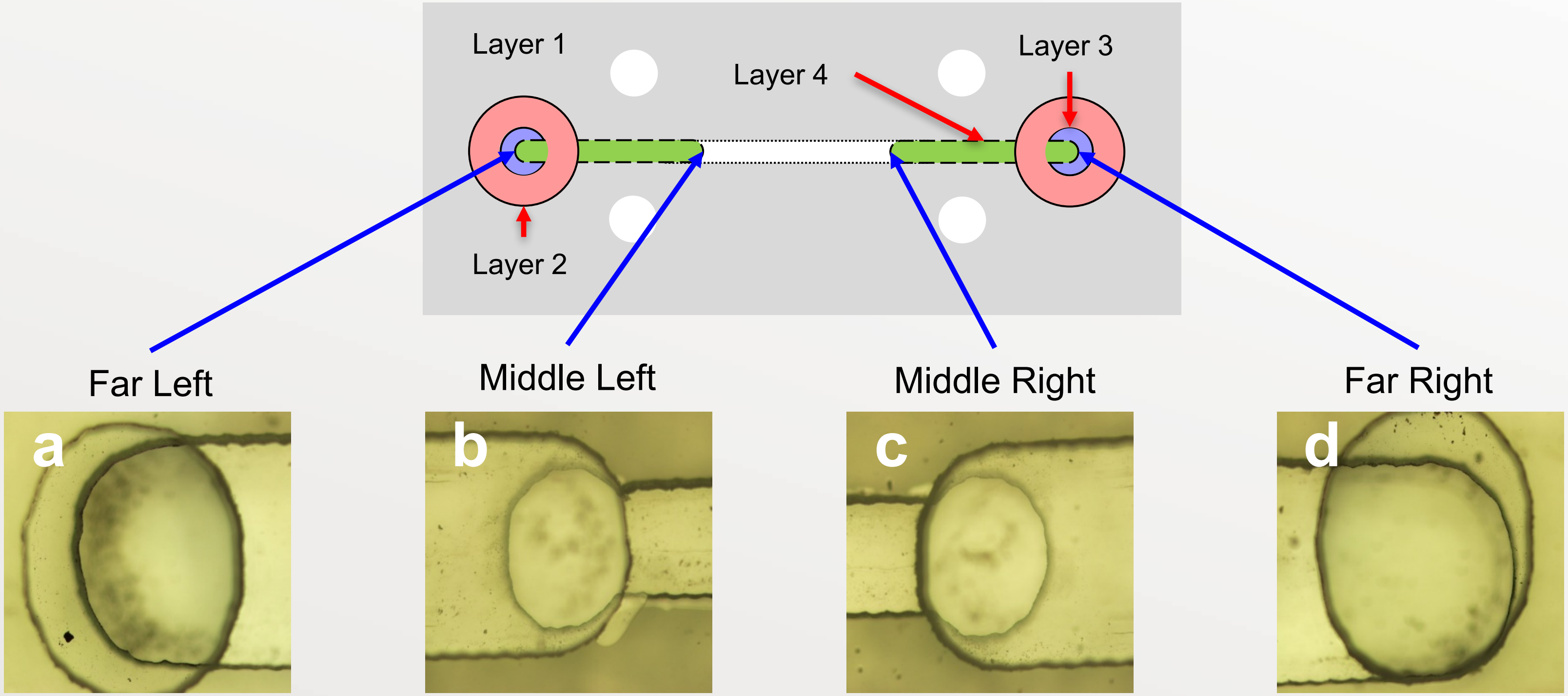


Figure 9: Optical microscope images of the PDMS layers at specific alignment points denoted as a) far left, b) middle left, c) middle right, and d) far right.

- All four layers were well aligned at all four points
- The aligned PDMS layers create permanent microfluidic channels

The PDMS layers were able to be aligned with one another to make microfluidic channels.

Dyed Water Test

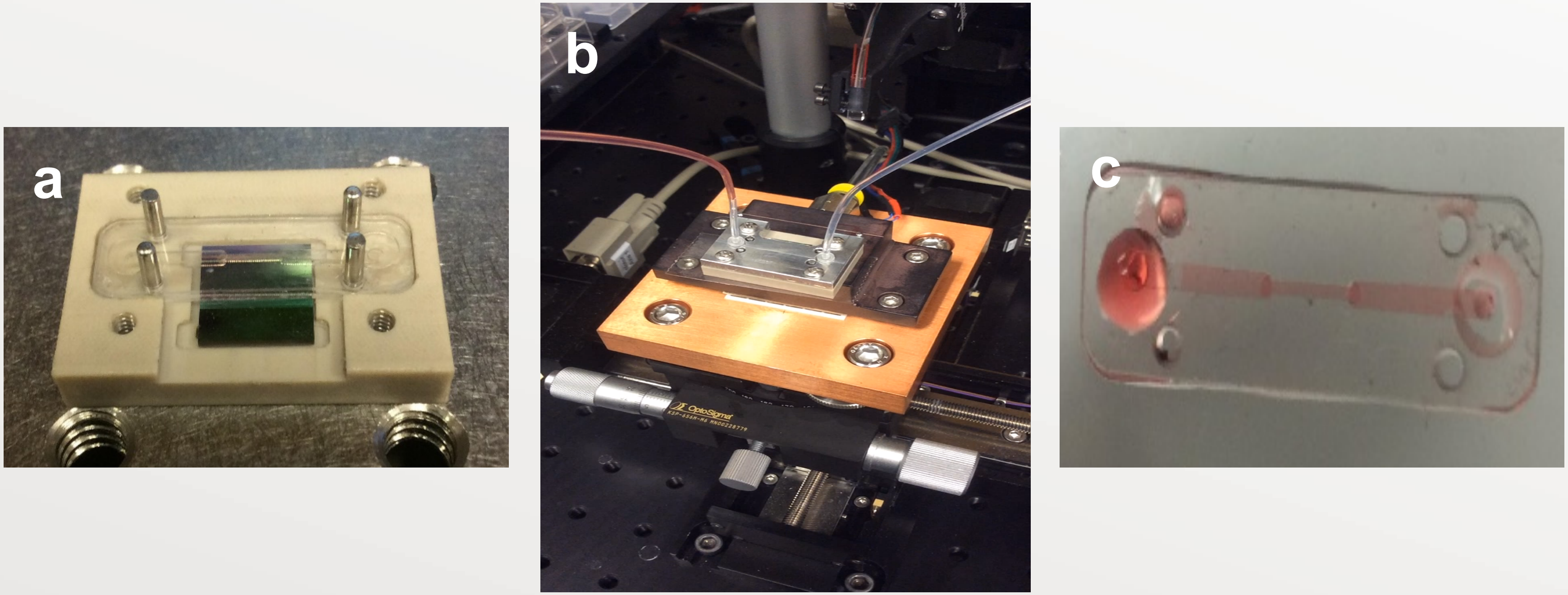


Figure 10: Demonstration of a dyed water test with a) microfluidic channels set up over a silicon substrate, b) water that was dyed red flowing through the PDMS channels, and c) no leakage in the channels.

The PDMS layers were successfully bonded as demonstrated by the water flowing through the layers, and no leaking present.

Full Waveguide Test

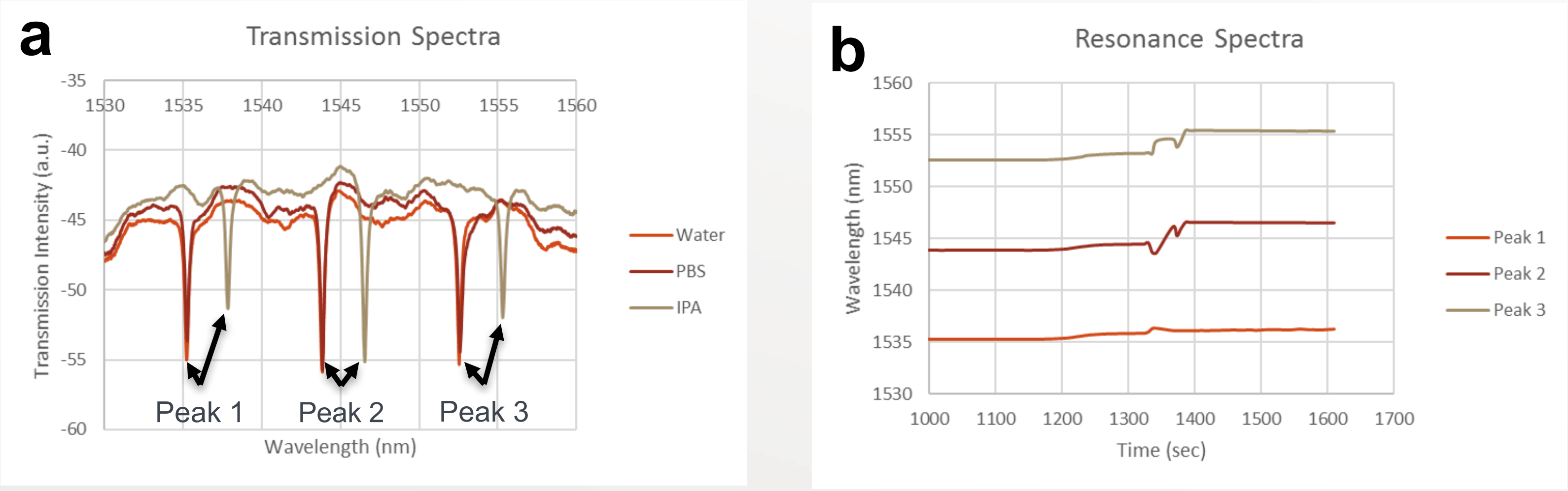


Figure 11: Graphs of a) transmission spectrum using a microring resonator and b) the resonance spectra showing a shift in the peaks from water as the analyte to Isopropyl Alcohol (IPA) as the analyte.

- The microfluidic channels were tested with a 10 micron diameter microring resonator and the benchtop system
- Water (refractive index of 1.33), Phosphate Buffered Saline (PBS) (refractive index of 1.335), and Isopropyl Alcohol (IPA) (refractive index of 1.38) were used as testing liquids
- A change in refractive index causes a change in the frequency of light trapped in the device, resulting in a shift of the transmission spectra

Successful waveguide tests demonstrated successful fabrication and usage of microfluidic channels with the system.

Summary and Future Work

- The goals of this project were to create microfluidic channels and test them using the benchtop system
- The microfluidic channels were created by bonding PDMS layers together
- Bonding PDMS layers was completed using an oxygen plasma bonding technique
- The microfluidic channels were tested for permanent bonds by flowing dyed red water through the channels
- The microfluidic channels were tested with the benchtop system and worked with silicon photonic waveguide
- Since the purpose of the microfluidic channels is to help in the development of a portable system, the new PDMS microfluidic channels will need to be tested with a portable system

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