Study on detection of contamination of pure water using silica microsphere and silica toroid microcavity

Jiro Nishimura and Takasumi Tanabe*

*{takasumi@elec.keio.ac.jp}

Department of Electronics and Electrical Engineering, Faculty of Science and Technology, Keio University, Japan
Outline

1. Introduction: Conventional optical sensors
   ✓ Tradeoffs device size vs. sensitivity
2. Objective
3. Sensor w/ silica toroid microcavity
   ✓ Detection limit
4. Sensor w/ silica microsphere
   ✓ Comparison of two types of cavities
5. Summary
Advantage of microcavity sensor

Conventional: IT spectroscopy

![Diagram showing laser, sample, power monitor, and light interacts only once]

New method: Microcavity

![Diagram showing output light, fluidic channel, input light, ring resonator, and interact many times]

Small size & sensitivity **CANNOT** coexist

Small size & sensitivity **CAN** coexist

<table>
<thead>
<tr>
<th></th>
<th>Silicon microring resonator</th>
<th>Photonic crystal</th>
<th>Silica toroid cavity</th>
<th>Silica microsphere</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>V</strong></td>
<td>2.5 μm³</td>
<td>1.7 μm³</td>
<td>110 μm³</td>
<td>5,000 μm³</td>
</tr>
<tr>
<td><strong>Q</strong></td>
<td>5,000</td>
<td>10⁶</td>
<td>10⁸</td>
<td>8 × 10⁹</td>
</tr>
<tr>
<td>Coupling w/ fiber</td>
<td>difficult</td>
<td>difficult</td>
<td>easy</td>
<td>easy</td>
</tr>
</tbody>
</table>

**References:**

F. Vollmer et al., APL 80, 4057 (2002).
Objective

1. Demonstrate high sensitivity and small size using a silica toroid microcavity

2. Show the comparison between toroid microcavity vs. microsphere
Detection is performed according to resonant shift

\[
\frac{\Delta \lambda}{\lambda_0} = \frac{\alpha_{ex} \sigma}{\varepsilon_0 (n_s^2 - n_0^2) R_0}
\approx \frac{\Delta R}{R_0} + \frac{\Delta n}{n_0}
\]

Experiment using silica toroid microcavity

**Experimental procedure**

1. Tapered fiber
2. Liquid
3. Soak (3 min)
4. Dry
5. Measure

**Measure**

**Soak (3 min)**

**Dry**

**Measure**

**Pure water**

**NaCl aq (25 mM)**

**Q = 1.0 \times 10^6**

**Transmittance (a.u.)**

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Transmittance (a.u.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1551.0</td>
<td>Before adsorption</td>
</tr>
<tr>
<td>1551.5</td>
<td>After adsorption</td>
</tr>
<tr>
<td>1552.0</td>
<td></td>
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<tr>
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<td></td>
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**Wavelength (nm)**

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<tbody>
<tr>
<td>1544.5</td>
<td>Before adsorption</td>
</tr>
<tr>
<td>1545.0</td>
<td>After adsorption</td>
</tr>
<tr>
<td>1545.5</td>
<td></td>
</tr>
<tr>
<td>1546.0</td>
<td></td>
</tr>
<tr>
<td>1546.5</td>
<td></td>
</tr>
</tbody>
</table>
NaCl detection w/ toroid microcavity

Experimental results agrees well w/ theory

\[ \frac{\Delta \lambda}{\lambda_0} = \frac{\alpha_{ex} \sigma}{\varepsilon_0 (n_s^2 - n_0^2) R_0^{-1}} \]

\[ \Delta \lambda \frac{\lambda}{\lambda_0} = \frac{\alpha_{ex}}{\varepsilon_0 (n_s^2 - n_0^2) R_0} \sigma \]
Our method | Commercial method
---|---
Detection limit | 1.2 mM | 1.7 mM
Sample volume | 0.1 nL | 0.3 mL
Experiment using silica microsphere

Experimental procedure

Tapered fiber
Silica microsphere

Measure → Soak → Dry → Measure

Liquid

32.2 μm
92.7 μm

$Q = 1.0 \times 10^6$

Pure water

Transmittance (a.u.)

Wavelength (nm)

37.15 pm
Azimuthal number vs. shift

Randomness $R^1 (\mu m^{-1})$

Comparison between silica microsphere and silica toroid cavity

Silica microsphere

- Δ\(\lambda_{FSR}\) = 5.91 nm
- Many azimuthal modes are excited
- Diameter: 92.7 µm
- Length: 32.2 µm

Toroid cavity

- Δ\(\lambda_{FSR}\) = 6.65 nm
- Easy!!
- Diameter: 38.7 µm

A number of modes

A few modes
Summary

1. Demonstrated NaCl detection in water with silica toroid microcavity
   - High detection sensitivity: ~10 mM (can reduce to 1.2 mM)
   - Small sample volume: 0.1 nL

2. Discussed the comparison between microtoroid vs. microsphere
   - Toroid microcavity is more appropriate than microsphere
Thank you very much