The 6th Advanced Lasers and Photon Sources (ALPS’17)

Growing Carbon Nanotubes on a Silica Toroid Microcavity to observe Saturable Absorption

Naoya Hirota¹, Wataru Yoshiki¹, Atsuhiro Hori¹, Koki Namiki¹, Katsuya Sato¹, Hideyuki Maki¹ and Takasumi Tanabe¹

¹Faculty of Science and Technology, Keio University
1. Introduction
   ● Background
   ● Motivation

2. Fabrication of CNT-grown silica toroid microcavity

3. Measurement of CNT-grown toroid characteristics
   ● Absorption loss induced growing CNT
   ● Observation of saturable absorption
**Background**

**Existing pulsed light source**

- Ti:Sapphire laser
- Fiber laser

https://www.uni-jena.de/uni_journal_1_2008_nachrichten.html

**New pulsed light source**

Silica toroid microcavity

- Ultrahigh $Q$ (~$10^8$)
- On chip
- Small size
- Low cost
- Easy fabrication


**Problem**

- Large
- Expensive

**Frequency comb**

- Unknown laser frequency
- $f_{\text{laser}} = nf_{\text{rep}} + f_0 + f_{\text{beat}}$
- $n = 2$
- $2n f_{\text{rep}} + f_0$
- Beat at $f_0$

**Problem**

- Difficulty of mode locking

**Kerr comb**

- $f_{\text{laser}} = m f_{\text{rep}} + f_0 + f_{\text{beat}}$
Background

CNT (Carbon nanotube)  ➔ SA (Saturable Absorption)
Absorb low intensity light
Transmit high intensity light

Passive mode locking

Previous research

CNT + Fiber ⇒ Fiber laser

Motivation

Silica toroid microcavity

FWM

\[ + \]

Increase robustness

Realize easy generation of mode locked Kerr comb

CNT
1. Introduction
   • Background
   • Motivation

2. Fabrication of CNT-grown silica toroid microcavity

3. Measurement of CNT-grown toroid characteristics
   • Absorption loss induced growing CNT
   • Observation of saturable absorption
Fabrication

Grow CNT over part of cavity

- Fabricate silica toroid
  - Side: Photolithography → Dry etching → Reflow → Complete
  - Top: Silicon dioxide (SiO₂), resist

- Grow CNT
  - Plasma ashing
  - Deposition
  - Remove
  - CVD
  - EB and development

Copyright © Keio University
Fabrication

Grow CNT over part of cavity

Result

<table>
<thead>
<tr>
<th>Ashing</th>
<th>SEM image</th>
<th>Raman mapping</th>
</tr>
</thead>
<tbody>
<tr>
<td>×</td>
<td><img src="image1.png" alt="SEM image" /></td>
<td><img src="image2.png" alt="Raman mapping" /></td>
</tr>
<tr>
<td>O</td>
<td><img src="image3.png" alt="SEM image" /></td>
<td><img src="image4.png" alt="Raman mapping" /></td>
</tr>
</tbody>
</table>

The rim of the toroid was not coated.
⇒ Grew CNT at stripe and at rim

The rim of the toroid was coated.
⇒ Grow CNT only at stripe
⇒ control the amount of CNT
1. Introduction
   - Background
   - Motivation

2. Fabrication of CNT-grown silica toroid microcavity

3. Measurement of CNT-grown toroid characteristics
   - Absorption loss induced growing CNT
   - Observation of saturable absorption
Measurement  Absorption of CNTs

Experimental setup

- CNT is grown over entire surface
- CNT is grown over part of surface

Result

<table>
<thead>
<tr>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="before" /></td>
<td><img src="image2.png" alt="after1" /></td>
</tr>
<tr>
<td><img src="image3.png" alt="before" /></td>
<td><img src="image4.png" alt="after2" /></td>
</tr>
</tbody>
</table>

- Q = 2.0 × 10^6
- Q = 1.9 × 10^6
- Q = 1.6 × 10^4
- Q = 3.6 × 10^5
Measurement  Saturable absorption

➢ Experimental setup

- TO effect
- Cavity absorbs heat
  ⇒ Change refractive index
  ⇒ Change resonance frequency
Measurement  Saturable absorption

- Measured transmission spectra

Entire surface

Partial coverage
Measurement Saturable absorption

- Measured wavelength shift power dependence

![Graph showing resonance shift vs. power for different conditions: Entire surface, Part of surface, No CNT.](image-url)
Summary

- Fabrication of CNT-grown toroid
  - Grow CNTs over part of surface (linearly)
- Measurement of CNT-grown toroid characteristics
  - Observe SA

Kerr comb generation
Acknowledgements

• Grant-in-aid from the Ministry of Education, Culture, Sports, Science and Technology (MEXT), (KAKEN 16K13702)

• Strategic Information and Communications R&D Promotion Programme (SCOPE), from the Ministry of Internal Affairs and Communications (MIC) (#152103015).
Thank you