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Waveform measurement of ultra-high repetition mode-locked pulses generated from a silica toroid microcavity

Zhelun Chen, Takuma Nagano, Yusuke Okabe, Tomoya Kobatake, and Takasumi Tanabe
Department of Electronics and Electrical Engineering, Faculty of Science and Technology, Keio University, Japan
takasumi@elec.keio.ac.jp

Abstract

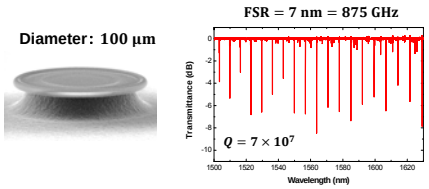
Optical Kerr comb from a microcavity exhibits a high-repetition rate pulses in time domain. We measured the output in time-domain and demonstrated a 9.1-THz repetition rate pulse train generation. The large free-spectral range of the generated Kerr comb is due to the high Q and small V of the toroid microcavity, which is a unique feature compare to other systems. We also show that an add-drop configuration will allow us to have a better temporal profile.

Motivation

- Want to reveal the temporal dynamics of an optical Kerr comb in toroid microcavity by measuring the output waveform
- Want to demonstrate the generation of high repetition rate pulses.
- Want to investigate a method to obtaining clean output (i.e. investigate the effect of an add-drop configuration).

Some background

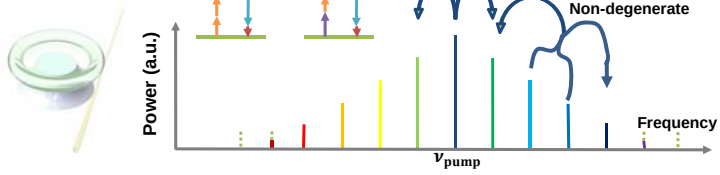
Silica toroid microcavity



The threshold power of Kerr comb generation is proportional to the mode volume inversely proportional to Q^2.

$$P_{th} \propto \frac{V}{Q^2}$$

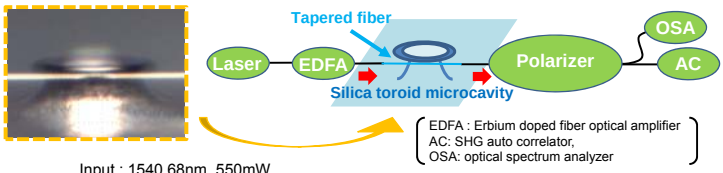
Kerr comb



Four wave mixing (FWM) occurs in the cavity and Kerr-comb is obtained

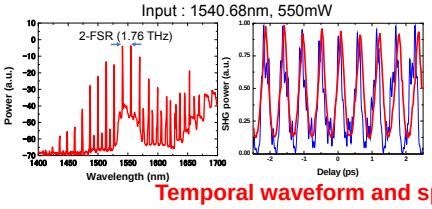
Experiment and Result

Time domain measurement



EDFA : Erbium doped fiber optical amplifier
AC: SHG auto correlator,
OSA: optical spectrum analyzer

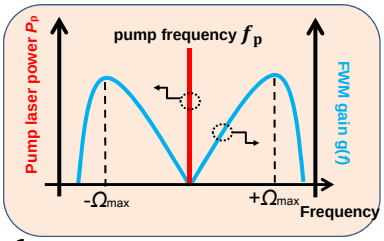
Input : 1540.68nm, 550mW



Left:
Generated Kerr comb spectrum
Right:
SHG auto correlation trace (red)
Fourier transform limit pulses of the spectrum (blue)

Temporal waveform and spectrum agrees well.
(repetition rate: 1.75 THz, SHG auto-correlation width: 0.4 ps)

Generation of high-repetition rate pulses (theory)



When a CW pump is applied, four-wave-mixing (FWM) gain is given as g(Ω).
Ω_{max} is the frequency of the peak of g(Ω).

$$\Omega_{\max} = \sqrt{\frac{4\gamma}{|\beta_2|}\frac{Q}{2\pi f_{\mathrm{p}}}P_{\mathrm{p}}} \propto \sqrt{\frac{Q}{A_{\mathrm{eff}}}}$$

$$g(\Omega_{\max}) = \gamma L \frac{Q}{2\pi f_{\mathrm{p}}}P_{\mathrm{p}} - a_{\mathrm{tot}} \propto \frac{Q}{A_{\mathrm{eff}}} \quad (\because \gamma \propto A_{\mathrm{eff}}^{-1})$$

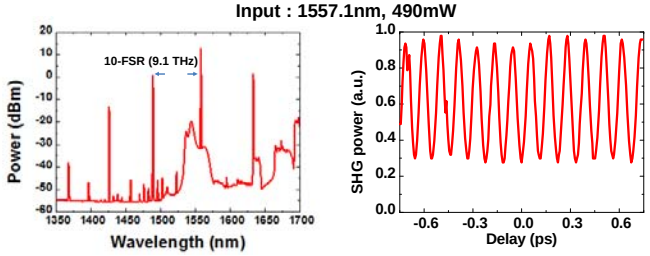
γ: nonlinear coefficient ($W^{-1}m^{-1}$), Q: Q-factor, f_{FSR}: free spectral range (s^{-1}),
f_p: pump frequency (s^{-1}), L: cavity length (m) , a_{tot}: total loss (-),
A_{eff}: effective mode area (m^2), P_p: pump power (W), β_2: group velocity dispersion (s^2m^{-1})

	Silica toroid cavity	Crystal cavity	Ring cavity
Size	~ 100 μm ○	1 mm ~ ✕	~ 100μm ○
Q	10^8 ○	10^9 ◎	10^6 △
	SiO_2	MgF_2	SiN

Silica toroid cavity allow us to have large Ω_{max}, due to the high Q and small size.
→ Ideal system to obtain high repetition rate pulses.

Generation of high-repetition rate pulses (exp.)

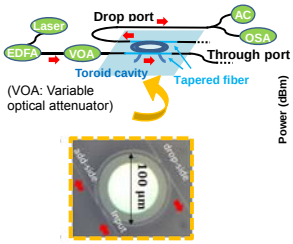
Input : 1557.1nm, 490mW



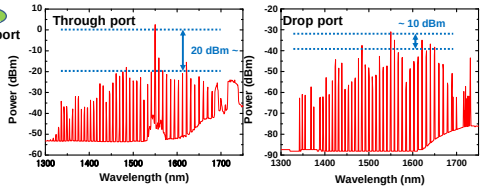
Successful generation of 9.1-THz repetition rate pulses

Add-drop system for better contrast pulses

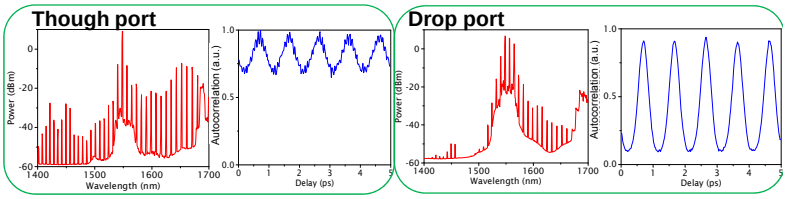
In order to having better SHG contrast, add-drop system is used (it will cut the pump)



(VOA: Variable optical attenuator)



Flat spectrum is obtained at drop port



Kerr spectrum and autocorrelation waveforms (Input: 1547.5 nm 500 mW) at the through-port (left) and at drop-port (right).

We can have higher SHG signal contrast by using drop-port output

Conclusion

- Time domain measurement is performed to observe the pulsed output of a Kerr comb from silica toroid microcavity.
- Silica toroid microcavity allows 9.1-THz pulse train generation due to the high Q and small mode volume.
- Add-drop configuration is ideal to have high contrast output pulses.

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